Proceedings of the 5th International Conference on Rain Water Cistern Systems

Show-Chyuan Chu
Editor

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FOREWORD

Lack of adequate water supply and sanitary facilities continues to pose serious problems in many countries worldwide. Most rural communities rely solely on natural water sources such as rivers, streams, open wells, and springs. These water sources are, however, often contaminated or even polluted. In some countries women and children are sent to far away places to fetch for safe drinking water. For the past decade, ferrocement tanks and jars used to store rainwater are regaining popularity as demands for water continue to rise at ever faster paces. Rain Water Cistern Systems (RWCS) have been proven to be an effective alternative for urban, as well as rural, water supplies both in developed and less developed countries. In developed countries, rainwater may supplement public water supply; whereas it may be the only alternative in rural areas where groundwater is unfit for human consumption.

The 1991 International Conference on Rain Water Cistern Systems is the fifth in an official series which began in Hawaii, June 1982, originated by Dr. Yu-Si Fok (the "Father" of RWCS). Coincidentally, it also marked the beginning of the United Nations' International Drinking Water Supply and Sanitation Decade (1981-1990). Subsequent conferences were held in Virgin Islands (June 1984), Thailand (January 1987), and Philippines (August 1989). Each conference has attracted over one hundred interested scientists, policy makers, planners, implementers and students. The results are well-documented, application-oriented and the published international proceedings have been widely acclaimed by the scientific community. The International Organizing Committee, during the 4th Conference in Philippines decided to hold the 5th Conference in Taiwan. It was not only an honor but also an opportunity for the scientists in Taiwan. Partly due to negligence in the past, we in Taiwan have not been very active in conserving our water resources. This conference will provide the necessary impetus to reevaluate our present stance and strategies.

The Fifth Conference has the theme "Rain Water Catchment for Future Generations". The purpose of this conference is to bring together scientists and end users together and to present recent advances in rain water cistern and catchment systems, to exchange information on strategies for improving rain water cistern and catchment systems operation, and to provide a forum for discussions and contacts for all people concerned. It was also designed to focus on future research needs and applications of rain water cistern and catchment systems, as well as to assess the achievement of rain water cistern and catchment systems in meeting the United Nations' Water Decade's goal.

Responses to our call for papers for the Fifth Conference was overwhelming. The organizing committee finally decided to print 70 submitted papers in one volume. These papers report original work conducted in 32 countries. Consequently, the papers prepared for this Conference represent an excellent review of the state-of-the-art of rain water cistern systems research throughout the world.

I would like to take this opportunity to express my gratitude to all sponsors and co-sponsors of this conference. Without whose support, this event would not have been accomplished. We are appreciative of many authors who followed the detailed guidelines provid-

ed for manuscript preparation exactly, were timely in submitting their manuscripts, without their cooperation our preparation works would be unendurable.

Show-Chyuan CHU, Editor

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PROGRESS OF INTERNATIONAL CONFERENCE ON RAIN WATER CISTERN SYSTEMS

Yu-Si Fok, Professor*

ABSTRACT

As the subject conference series has been progressed to the 5th conference, it is very appropriate to document the back-ground, the birth and highlights of each conference for the benefit of the future development of this conference series,This paper is based on an invited keynote paper presented at the 2nd conference which has not been published. The development and highlights of subsequent conferences have been included in this paper. In addition, the initiation and establishment of the International Rainwater Catchment Systems Association (IRCSA) are also included. This paper is intended to put important events of each conference in the record. The request of past conference participants to contribute their own experience in this conference series has also been made.

INTRODUCTION

The use of rain water cistern systems (RWCS) as one of the means to provide domestic water supply has been recorded in history in many parts of the world for thousands years. The advances in technology in recent centuries helped the development of the centralized public water supply systems in cities and metropolises with dependable and adequate water for users. As a result,privately owned rain water cistern systems and other water supply systems become less popular among city dwellers. Although, some of the rain water cistern systems are still a viable water supply system in many urban and rural areas because of special applica-bilities. Recently, many public water supply systems in the world have shown signs of an inability to adequately supply water to the ever increasing demand. As a result, water shortages have occurred frequently, and moratoriums on new building permits have also been

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imposed due to the water shortage. Rain water cistern systems are regaining their popularity in water shortage areas as water users seeking alternative and supplementary water supply under the concept of self-sufficiency and conservation.

BACKGROUND

During the 1977-1978 drought period in Honolulu, Hawaii, U.S.A. A news item reported residents in the Tantalus-Round Top area had to perform Indian dance to pray for rainfalls to refill their empty rain water cisterns. This news item inspired the author to conduce a research project of rain water cistern systems. When one of his paper abstracts appeared in the American Geophysical Union's EOS special issue for the 1979 Fall Meeting, it attracted the attention of Dr. S. J. Perrens, Dean, Faculty of Resources Management, The University of New England, Armidale, N. S. W. Australia. On the 22 January 1980, he wrote a letter to the author stating that the roof catchment rainwater system design is an area in which he has had some interest for many years and would very much like a copy of the author's paper and any others that the author has published. Dr. Perrens enclosed two rainwater catchment related papers in his letter for information exchange.

INCEPTION OF THE CONFERENCE

Seeing that a need exists for better cooperation for researchers and planners, the author stated in his reply letter to Dr. Perrens of 31 January, 1980 that an International Conference on Rain Water Cistern Systems should be conducted in near future, in order that the general public and water supply management agencies can benefit from our effort in promoting the rain water cistern systems. The favorable responses from Dr. Perrens and Dr. L. Stephen Lau, Director, Water Resources Center, University of Hawaii at Manoa, inaugurated the International Conference on Rain Water Cistern Systems(ICORWCS)

THE FIRST INTERNATIONAL CONFERENCE

Dr. L. Stephen Lau provided his whole hearted support of this conference. He helped to write letters to Office of Water Research and Technology (OWRT), U.S. Department of Interior, United Nations

Educational, Scientific and Cultural Organization (UNESCO) Division of Water Science and several water related organizations for possible funding support of this conference. As a result, a grant of $3,000 was provided to this conference from the Technology Transfer Program, OWRT through the program chairman at the University of North Carolina. Also the cost for printing the conference announcement and call-for-papers of $264.16 was paid by Dr. Lau's office. A total of 2,400 copies of this conference announcement brochure were distributed to potential participants by mail with existing mailing lists of the Water Resources Research Center, list of a conference participants provided by Dr. Perrens, lists of participants of conferences conducted by the International Water Resources Association (IWRA) and by conference organizing committee members most of them are the national representatives of IWRA. The distribution of the conference announcements was during July, 1980 giving potential authors 7-month to submit their paper abstracts.

Dr. Ven Te Chow, an internationally well-known authority in water resources, hydraulics and hydrology and the founding President of the International Water Resources Association, had been informed the development of the conference as early as 24 March 1980 by the author to seek his guidance and advice. Dr.Chow's response was full of encouragement and directions of potentials funding supports. Later, he also gladly accepted the author's invitation as the keynote speaker of the conference.

Initial funding support of the conference has been recognized and directed during this conference early development stage, the author has to secure needed funds to support the conference development activities, and the pending support of $3,000 from OWRT was pending on the availability of funding. Therefore, the author resorted to ask writers of the paper abstract to contribute $50 nonrefundable fee to cover the expenditures of publishing their papers in the conference proceedings and promised a $50 deduction of their registration fee when they attend the conference. This unusual request enable the conference an early operational fund of $1,650.

The logistic for conference program arrangement, such as conference site rental, Printing of the conference program and registration form plus travel and hotel arrangement for participants,registration, coffee breaks and lunches was contracted to the University College of Continuing Education and Community at a fee of 18-percent of the conference registration revenue. The conference program and registration form was distributed during September 1981 to allow participants 8-month working time to plan for their travel arrangement.

The conference proceedings was printed by the Center of

Engineering Research, College of Engineering, University of Hawaii at Manoa fee of charge. Binding of the conference proceedings was done by a printing company at a cost. All the 50 papers of the conference proceedings had been edited for their grammatical and spelling mistakes and retyped, figure redrawn if it was not acceptable for publication. All this services had been made by the Editor of the Water Resources Research Center (WRRC), University of Hawaii at Manoa, Ms. Faith N. Fujimura and her fellow workers at their off-office hours for a fee of less than $1,000. This editorial work is well-worth its value at $35 per copy which has sold of more than 150 copies after the conference. This income helped the balance of the conference expenses, In addition, these proceedings helped to promote the application of the rain water cistern systems all over the world.

Finance Break-Even Point of the Conference

The author wishes to share his experience on the subject of conference finance in this paper because it is important for anyone who contemplates to conduce a conference. The author was following the principle of balancing the expenditures with assured income. Expenses of the conference should be itemized first and entered in a tabulation. For example many conference expenses have a fix-cost such as printing a fixed number pages proceedings for a fixed number of copies, rental of the conference place, printing the conference announcement and call-for-papers, printing of the conference program and registration form of a fixed number of copies, printing the conference envelopes and letter-heads, postage and other communication costs, secretarial and helpers hourly pay etc.

Once the total expenditure is at hand, the conference planner should select a tentative registration fee for the duration of the conference. This can be made by taking the average of existing fee charged by the recent conferences. Once the registration fee is selected, the number of needed participants can be estimated by dividing the estimated total expenditure with the selected registration fee. Therefore, the conference planner can keep a record of those confirmed participants including committed authors. When the number of committed participants reaches the needed number of participants, the conference planner can be sure that the breakeven point of income and expenses has been reached.Clearly, the earlier the date of reaching the break even point is better for the conference planner. The first international conference finance break-even point had been reached quite early because the great contribution of $50 from each writer of those paper abstracts.

The Lost of the Conference Keynote Speaker

When all the indications are pointing to a well attended conference, a very bad news had struck, Dr. Ven Te Chow, the conference keynote speaker, past away on 30 September 1981. This was a great set back of the conference, because participants were expected to hear Dr. Chow's presentation and to meet him personally. The executive committee decided to dedicate the conference proceedings to Dr./Professor Ven Te Chow and will not fill the vacancy of keynote speaker for the conference in honor of Dr. Ven Te Chow.

Proposal of the Second International Conference

Although the conference was still in its development stage, interest in conducting the second conference had been started. Dr/Professor Donald H. Waller of the Department of Civil Engineering, Technical University of Nova Scotia Nova Scotia, Canada was the first person who made the proposal to the author. Followed by Mr. Alton A. Adams, Jr. P.E. of the U.S. Virgin Islands in St. Thomas, and some others. The author could only tell those proposal makers to present their plans at the conference to give participants a chance to make a selection. Dr. Waller had made a great effort to have his proposal accepted even by coming to Hawaii before the conference. However, just two days before the conference, Dr. and Mrs. Waller were called back to Canada from Hawaii, because his mother past away. During the conference closing session, the determination of the second conference assignment had received several proposals; the delegation from the U.S. Virgin Islands led by Mr. Alton A. Adams, Jr. had gathered enough supporting votes to get the assignment to conduct the second conference in St. Thomas, U.S. Virgin Islands during June, 1984.

Highlights of the First Conference

Highlights of the first conference included the opening address by Dr. Fujio Matsuda, President, University of Hawaii; opening remarks and welcome speech by Dr.L. Stephen Lau, Director, Water Research Center, University of Hawaii; Lunch speeches given by Mr. Christiaan E. Gischler, UNESCO; Mr. Noel J. Brown, UNEP and Mr. John M. Kalbernmatten, World Bank. A light refreshments reception for all participants and guests was held right after the closing session of the conference.

A special field trip was offered and conducted by Mr. John A.

DeHaan, Sheltertech Company, Inc., Honolulu, Hawaii to bring interested participants to view the rain water cistern systems in the Tantalus-round Top area, Honolulu. An informal farewell dinner party was held at the residence of the author.

during the duration of the conference and workshop period, many ideas had been exchanged concerning the future of the rain water cistern systems (RWCS) among participants. Among these ideas, the idea of having an international rain water catchment systems association was frequently brought into discussion.

This conference attracted the attention of United States Senator Spark Matsunaga, he sent a letter to congratulate the author for the work accomplished of the conference. He also made a pledge of assistance from his office when the needs arise by stating in the last paragraph of his letter:

"You can be assured of my continued support of WRRC activities and your research to maintain a stable source of freshwater for Hawaii. Please let me know if you feel that I can be of help to you in the future to allow you to continue your excellent work."

THE SECOND INTERNATIONAL CONFERENCE

According to the foreword stated in the proceedings of the 2nd conference(1984), papers were reproduced directly from camera-ready copies submitted by the authors adhering to Specific guidelines. No attempt was made to extensively edit, reformat or alter individual papers except for printing production requirements or where obvious errors or discrepancies have been detected. This method of conference proceedings publication was followed by subsequent conferences. The format of the proceedings was closely resemble of the 1st conference, which give readers a sense of continuity between the 1st and 2nd conference.

With a reference to personal correspondence between Mr. Alton A. Adams,Jr. and the author, the development of the 2nd conference was initially not on schedule. This had been corrected after the appointment of Dr. Henry H. Smith as the co-chairman of the Technical Committee and editor of the 2nd conference proceedings. Dr. Smith was a former acting director of the Water Resources Research Center, Caribbean Research Institute, College of the Virgin Islands before he left for his Ph.D. degree study in the Colorado State University. Under the leadership of Dr. Smith, the 2nd conference's development was on schedule again, and the publication of the 2nd conference proceedings was on time and before the opening date of the 2nd conference. A total of 18 technical papers were published in the 2nd conference proceedings. There were several late papers had been presented at the conference. The conference was held in the Yacht Haven Hotel and was well conducted. The hotel is well known for its beautiful setting with a white sand beach which is located within walking distance to the business district of St. Thomas. The author was informed that Mr. Alton A. Adams, Jr. was the main fund raiser of the conference.

Activities and Highlights of the Second International Conference

The following 2nd conference's activities and highlights had been taken from Dr. Henry H. Smith's Summary of the Second International Conference on Rain Water Cistern Systems:

This conference was jointly sponsored by the Caribbean Research Institute, College of the Virgin Islands and the Virgin Islands Branch of the American Society of Civil Engineers. Dr. Norwell Harrigan of the Caribbean Research Institute, College of Virgin Islands and Mr. Alton A. Adams of the American Society of Civil Engineers were Co-Chairman of the conference. Dr. Yu-Si Fok of the University of Hawaii and General Chairman of the First International Conference on Rain Water Cistern Systems, served as Honorary Chairman.

The conference opened with a reception and registration at the Yacht Haven Hotel on June 24, 1984. Registration continued on June 25, 1984 when the formal sessions began. Opening remarks were made by Mr. Alton Adams, Co-Chairman of the conference and by Mr. Angel LeBron, Commissioner of the Virgin Islands Department of Conservation and Cultural Affairs.

On June 25-26, papers on a wide range of topics pertaining to the use of rain water harvesting and subsequent storage in cisterns were presented. The final technical session of the conference consisted of a general summary of the conference as well as the making of preliminary plans for the next conference. A committee was formed to establish in a more organized fashion communication among researchers with interest in rain water cistern systems. The Coördinating committee memberships are: Alton Adams (Virgin Islands), Adhityan Appan (Singapore), Yu-Si Fok (Hawaii, Chairman), Peter Hadwen (United Nations), Craig R. Hafner (Washington D.C.) and Donald Waller (Canada).Functions of the committee are promoting future potentials of rain water cisterns, to collect and disseminating information to public and private sectors. This action sets the initial stage for the development of the International Rainwater Catchment Systems Association (IRCSA). The final session also set tentative plans to hold the 3rd conference in Thailand during early months in 1986. This is because of professor Chayatit Vadhanavikkit of the Khon Kaen University, Thailand was the only participant from Thailand, and he was not sure that source of funding can be obtained for conducting an international conference.

The final day of the conference was devoted to field trips to site of rain water catchment and related public water supply systems. A brief tour was made to observe the newly installed desalination plants in operation. Next to the hillside catchment operated by the Federal Aviation Administration, Lastly a tour was made to the Mahogany Run Golf Course to observe a conjunctive use of rain harvesting, groundwater development and the use of reclaimed water. The day concluded with lunch at the Magens Bay Beach. Participants and their family members had a wonderful afternoon relaxing, swimming and socializing with each other which made a well-remembered conference to all of them.

THE THIRD INTERNATIONAL CONFERENCE

Under the great leadership of professor Chayatit Vadhanavikkit, and the very efficient conference committee's organizing and editorial staff, the 3rd conference was a well planned, finned, financed and conducted conference. The financial support from the International Development Research Center (IDRC) was an important factor which contributed to the great success of the 3rd conference. In addition, there were many agencies supported this conference as co-sponsors.

Providing a long lead-time for potential participants to react on a conference announcement is an important practice of a conference planner. On April 3, 1985, a form letter signed by Dr. Sacha Sethaputra, Conference Chairman of Technical Committee had enclosed the colorful brochure of the 3rd conference announcement and call-for-papers which gave about 8-month for authors to send their paper abstracts to the conference technical committee. To preserve the continuity, the logo of the 1st conference was again used on the 3rd conference announcement brochure. This early announcement of the third conference had accomplished its objective to attract early commitments to the conference from authors and potential participants. In a letter to Dr. Craig R. Hafner, and with copies to members of the international coordinate committee. Professor Chayatit Vadhanavikkit reported that 43 paper abstracts and 16 potential participants had been received and registered as early as March 18, 1986. He also projected a total of 70 participants would come from areas outside of the Khon Kaen

Province. Thailand, Again the scheduling of Conference proceedings production was very good, the camera-ready manuscripts arrived 7-month before the opening date of the conference. All of these efforts indicated that the 3rd conference would be a well managed conference.

Highlights of the Third International Conference

The conference site was located in the Rama of Khon Kaen Kosa Hotel in downtown Khon Kaen. The facilities of the hotel were very modern and comfortable. The buffet lunch provided Thai food and other countries' dishes, which helped everyone feel-at-home for their choice of food.

The welcoming party was a splendid dinner party with Thai dancers to perform Thai dances in a half-hour entertaining program which also provided a chance for those guests who wishes to try the Thai dance. This was a really ice breaking preaking party.

A field trip was conducted for participants to visit a model village of rain water cistern systems and experiments of rain water related project sites in the Khon Kaen University campus. Many participants were deeply impressed the demonstration construction of the famous 2-cubic meter Thai jai and the community constructed rain water storage tanks for their public school. Participants were very happy to be able to talk to the builders/users of these rain water cistern systems about their new water supply systems.

The good news of Thailand will be the first nation to attend the objective to provide safe drinking water supply t the whole nation during the United Nations' Drinking Water Supply and Sanitation Decade 1981-1990 had been well received. Because rain water cistern system were a major system in this effort.

Mr. Cornelio L. Villareal, Mr., Governor of the Capiz Province, Philippines attended the 3rd conference with two of his co-workers. They were actively participated at the 3rd conference. He even brought along with a poster presenting the integated farming method developed by Mr. Mamergo Fantilanan, Capiz, Philippines to dispaly at the conference. As a result, during the business session of the conference series, which was president by the author, the 4th International Conference was selected to be conducted in Manila. Philippines under the leadership of Governor Villareal in 1989.

THE FOURTH INTERNATIONAL CONFERENCE

The fourth conference had a slow start, as a consequence, the announcement and call-for-papers of the 4th conference was distributed in Fall, 1987. In addition, the deadline for paper abstract was set on January 31, 1989 which left only 6-month to gather camera-ready paper-manuscripts for technical review and publication of the conference proceedings. The reason for the delated technical papers submission and short time for the conference proceedings publication was not known. However, we have observed thata a great effort had been made to produce the conference proceedings on time. As a result, some copies of the conference proceedings had been distributed to some participants on the last day of the conference.

The conference had gathered more than 70 participants and had more than 30 papers presented during the three-day conference. The conference site was located in one of the big hotels of the new business-hotel district of Manila.

Highlights of the Fourth International Conference

The conference program was well designed and printed for the 4th conference, and the conference was very well conducted with a friendly welcome dinner held in the evening of August 1, 1989 to start the conference's informal gathering. A grand opening ceremony including the introduction of the conference theme word "HALARAN" had been made. Halaran means an offering in a community development approach. Which fits the theme of the conference: The Community and Rain Water Cistern Systems very well. The 4th conference was the first one has arranged an opening and closing ceremonies.

Highlights of the 4th International Conference

Dr./Professor Adhityan Appan, a faithful author and participant of the past three conferences was unable to attend the 4th conference due to sickness. However, he managed to send a petition to the conference's Philippines Organizing committee chairman, Govn, Villareal asking the organization of the International Rainwater Catchment Systems Association (IRCSA); came along with his petition was a drafted Association's organizaing structure, registration and headquarters, funds, and Association's bulletin/journal. All of these writings had been made just before his by-pass surgery. His devotion to the well-being of the rain water cistern systems deeply moved every participant. As a result, Members of the organizing committee in a lunch meeting decided to establish the Association and the author was elected to serve as the president, with the duty to establish the Association to join the family of international associations as a full member; and to seek financial sources to support missions of the Association and the rain water cistern systems conference series. Two vice presidents were appointed from the current and the in-coming general chairman of the International Rain Water Cistern Systems (ICORWCS). Regional directors were also norminated and appointed by the president; in turn, national directors of the Association were norminated by the regional director and appointed by the president, and the regional director, Mr. John Gould from United Kingdom was appointed as the Secretary General of the Association.

In the Plenary Session and Business Meeting, the host country of the 5th International Conference on Rain Water Cistern Systems selection was one of the important business. After proposals have been presented, voting was conducted. The Republic of China was selected the host country to conduct the conference in Keelung, Taiwan, Professor Show-Chyuan Chu and Dr. Andrew Lo were charged with the assignment to organize the 5th conference to be held in 1991.

The closing ceremony was full of the Halaran spirit, including a turn-over ceremony to the host courtry of the 5th conference, acceptance remarks, introduction of the Keynote speaker, Hon, Fiorello R. Estuar, Secretary, Department of Public Works and Highways presented the keynote speech, presentation of plaques of appreciation, and closing remarks.

All the participants felt it was very hard to say good-bye. Some of them who signed up to join the post conference trip to Capiz Province during August 5-7, 1989 felt very happy to have three more days to get together to learn more about each other, the integrated farming system, and seeing HALARAN in practices.

The fourth international conference was well conducted; logistic supports were very efficient. The conference room was beautifully decorated. Seating arrangement had two locations of audio addressing systems to serve participants discussion-question efficiently. The refreshment services were very smoothly operated. All of these were well remembered and appreciated.

THE FIFTH INTERNATIONAL CONFERENCE

The preparation of the fifth international conference started right in the Hotel Nikko Manila Garden Makati, Metro Manila after

Professor Show-Chyuan Chu and Dr. Andrew K. F. Lo gotten the assignment. They called a meeting with Mr. John Gould and the author to chart the plan for the development of the fifth conference. Important tasks and schedule were identified and dated, these included sources of funds, target dates for sending conference announcement and call-for-papers, paper abstract deadline, proceedings paper due date, paper review deadline, proceedings editorial work completion date, conference program organizing completion date, target date for conference program distribution, logistic arrangement including transportation to and from the conference hall, hotelarrangement for participants, post conference workshop tours, international transportation and visa plans. Practically all items related to the international conference had been considered. The drafted 5th confeence plan was presented and discussed with Governor Villareal during their trip to Capiz Province to gain his experience of conference management. Later, an international organizing committee of the 5th conference was appointed by letter of invitation in order that matters of conference promotion can be effectively conducted. In addition, several task committees were also organized.

A business session of the International Rainwater Catchment Systems Association had been scheduled in the final day of the conference. The main agenda is to rectify the constitution and by-laws of the Association. The draft of the Association's constitution and by-laws has been assigned to Dr. Adhityan Appan. All the participants of the 5th conference are members of the Association for one year, this arrangement had been established at the 4th conference. When the Association's constitution and by-laws were rectified, the Association can be registered as a non-profit international organization, having the bank account established to deposit of membership fee gathered from the membership drive, and to pay expenses in support of the chartered activities of the Association.

As of February, 1991, the 5th conference has gathered 75 paper abstracts which was published in a 130-page booklet, entitled "5th International Conference on Rain Water Cistern Systems Abstracts". In all the indications, the 5th conference will be another success of this conference series to serve the humanity.

REMARKS AND CONCLUSIONS

This paper reports the progresses of the International Conference on Rain Water Cistern Systems as observed by the author.

Clearly it is not a complete documentation. Past participants of this conference series are encouraged to contribute their own experience. TO SERVE THE HUMANITY is an acquired phase in our mind after we committed long hours of works to promote the use of rain-water catchment systems to users in different parts of the world. The tasks are numerous and problems related to rainwater catchment systems occur every days. Team works through the International Rainwater Catchment systems Association is the efficient approach to have the tasks completed and the problems solved.

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PROGRESSES OF THE U.N. WATER DECADE AND RAINWATER CATCHMENT SYSTEMS

Yu-Si Fok*, Show-Chyuan Chu**

ABSTRACT

According to a report by UNDP in December, 1989 (The progresses of the United Nations' International Drinking Water Supply and Sanitation Decade 1981-1990,) on the water decade, there are about 55% targeted population in developing countries has received safe drinking water supply while only 17% of those received sanitation disposal of their waste. This paper has made an assessment of factors that affects this imbalanced of development drinking water supply and sanitation during the U.N. water decade. In addition, possible approaches that may be used to fulfill the U.N. Water Decade's objectives are also presented. In the process of the assessment, progresses of rainwater catchment systems have examined. The Thailand Jar Rain Water Catchment Program is cited as an outstanding drinking water supply program which should be recommended to the U.N. Water Decade decision makers and planners for promotion.

INTRODUCTION

On 10 November 1980, the United Nations General Assembly approved and proclaimed 1981-1990 as the International Drinking Water Supply and Sanitation Decade, whose goal is to provide by 1990 all people with water of safe quality and adequate quantity, and with the basic sanitary facilities. Target population for drinking water supply was 1.26 billion, for sanitation facilities was 1.73 billion; at a total cost- US$180 billions. This U.N. Water Decade did not fulfill its goal. According to a report in World Development

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published by UNDP December, 1989, there were 0.7 billion people received safe drinking water supply and 0.3 billion had new sanitation facility in 1989. The reasons for not been able to reach the U.N. Water decade's goal are short in financial support, only one-third of the needed capital for the decade has been spent on the projects. In addition governmental budget did not give a better share to support the U. N. Water Decade's projects. According to World Development May, 1990 issue, there are twenty-five developing countries spend more on the military than on education and health, which discloses that annual military costs reprsented nearly 160 million man-years of income, three times the equivalent military burden of industrialized countries. This paper has made an assessment of the imbalance development among drinking water supply and sanitation during the U.N. Decade in order to alert decision makers and planners of the YEAR 2000, to make an effort to correct this problem. Meanwhile to point out that rain water catchment systems have gained the attention of individual country's decision makers because the success of the Thailand Jar Rainwater Catchment Program.

IMPORTANCE OF PARRALLEL DEVELOPMENT OF DRINKING WATER SUPPLY AND SANITARY TOILETS

The U. N. Water Decade 1981-1990 was developed based on the World Health Organization's report that water transmitted disceases can only be stopped by providing safe drinking water supply and sanitary toilet users. These two water related developments should be developed simultaneously to insure the health of individual as well as the community. It is evident that the U.N. Decade had an imbalanced development between drink-ing water supply and sanitation at a ratio of three to one. Reasons of this imbalance of development may be many, however, the following four items are presented for further discussion.

1. Governmental Policy
   Under budgetary constraint, if funds are limited, decision makers may select drinking water supply project first because this is human nature. Everyone knows that without water one will die in just a few days. Besides, drinking water development has better visibility and pleasant to show than sanitary facility.

2. Standardized System

Drinking water supply systems are mostly standardized. They do not required overall modifications in design and operation. In other words, there is no communication gap between decision makers and designers and planners on these systems. On the other hands, the selections of sanitary toilets are often difficult. Dry toilets are much easier to be built and operated with less chance of contamination of drinking water sources, and will not require water to flush the toilet. However, dry toilets are not the standardized systems in developed countries. Perhaps this is the reason that they are not widely used during the U. N. Water Decade. In fact, no one country promoted one type of toilets for the whole nation to fulfill their national goal for the U. N. Water Decade in sanitation. In fact there of wet toilets had been offered for selection which were outnumbered of the dry toilets. It seemed that wet toilets are the better selection because wet toilets have often appeared in movies and T.V. screens. Definitely, a wrong impression have been imprinted in the minds of decision makers that wet toilets should be their choice. In order to correct this wrong impression, waste water treatment systems' operational and collectional processes should also be shown to those decision makers so that they can see what a system of toilets that they are committed for the future.

3. Toilet is a Taboo

Most of us try not to use certain words in our language. Toilet is one of them. We have many other words to call a toilet room such as wash room, rest room, powder room, ladies, gentlemen, women, men, etc. Perhaps, this is the major reason for the U. N. Water Decade had only one-fourth project coverage to the sanitation development. In fact, by a coincidence the U.N. Water Decade used three words: DRINKING WATER SUPPLY against only one word: SANITATION to describe the name of the decade. The avoidance of naming toilet as the main objective of sanitary facilities in the U. N. Water Decade had undermined the development of sanitary toilet facilities in many needed developing countries for some extent.

4. Public Education

During the U.N. Water Decade, the importance of the safe drinking water supply had been promoted with public educational materials such as brochures, posters and community activities. However, the importance of sanitary toilets to public health had not been promoted equally or simultaneously. Again, this lack of public educational materials to expose how the sanitary toilet system can stop the spread of disceases may be a cause of less development of the toilet systems. In the record, public demand of drinking water supply was much stronger than sanitation.

The four reasons presented help to explain why an imbalance development between drinking water supply and sanitation during the U. N. Water Decade. Methods for the mitigation of this imbalance are presented for further discussion in follows:

BALANCE DEVELOPMENT OF DRINKING WATER SUPPLY AND SANITATION

1. Development Policy

   If a country has imbalance development of drinking water supply and sanitary toilet facility, a new development policy for their post U. N. Water Decade programs should be made to stress simultaneous development of sanitary toilet facilities and drinking water supply as project funding criteria. Perhaps special consideration may be given to those areas had drinking water supply but without sanitary toilet facilities in order to help them to complete their sanitation phase of development.

   The policy to grant participating villages with a revolving fund to help them with financial assistance to buy construction materials for their sanitary toilet and drinking water projects may be carefully developed so that borrowed revolving fund can be paid back on time.

2. Standardized Sanitary Dry Toilet

   As pointed out before that dry toilets are much easier to build, less chance to contaminate the drinking water sources and will not require water to flush the toilets. Decision makers have to select one type of the dry toilet as the standard toilet for their sanitation project so that mass production of this toilets can be made, operation and maintenance training of users can be simple and construction cost can be reduced. Fok (1983) suggested the low cost dry toilet - the Double-Vault Composting Latrine should be improved as the Fok Vault Wheeled-Boxes Composting Latrine. This improved latrine has two cement-lined vaults each fitted with a wheeled-box to make the roll-in and roll-out with easy. This latrine is constructed above ground level. A groove in the floor channels urine into a separated and covered vessel, while two holes in the floor(with lid) are used to collect the excreta. Kitchen ashes are used to cover the excreta to absorb moisture and deodorize. The vault with a filled boxed is to be sealed to create anaerobic or oxygen-free conditions in which harmful bacteria are neutralized and intestinal worm ova are destroyed. When the waste had completed decomposition process, it becomes harmless manuere which can be used as fertilizer. The construction cost of the latrine is minimal (about US$150), almost entirely for cement to line the vaults and for the floor. The double-vault latrine originated in Vietnam in the 1950s where human waste had been used as manuere for generations. It was also used in China and had been promoted by UNICEF in Bangladesh, Burma and Egypt during the U.N. Water Decade. Perhaps, this latrine should be promoted as the standardized sanitary dry toilet.

3. Sanitary Toilet Facility
   To break the taboo of avoidance of the word:TOILET, perhaps the most effective way is to put the word in the title of the project. For example, the U. N. Water Decade should have the title as the U.N. Drinking Water Supply and Sanitary Toilet Facility Decade 1981-1990. Better yet, it may be re-named as the U. N. Sanitary Toilet Facility and Drinking Water Supply Decade, 1981-1990. A change of the word order can give the emphasis of the sanitary toilet facility with more weight in the U. N. Water Decade.

4. Public Health Education
   The importance of the sanitary toilet facility in public health can be promoted by means of public education. Community organized public health meeting or program is the proper means to promote the sanitary toilet facility, and the importance to have safe drinking water supply should also be promoted as one package. Women participantion in community public health program are very effective. During the U. N. Water Decade, reports of women participation had frequently presented.

According to the discussions presented, the reason of the U. N. Water Decade failing to reach its goal was due to lack of financial support. In other words, construction costs for drink-ing water supply and sanitation were too high, and financial methods for construction had not been arranged to an affordable level for users. Talking about users affordability and the donor countries willingness to pay. Perhaps, this is a subject that has not been explored during the U. N. Water Decade. The concept of grant-in-aid is still propular in many developing countries. However, the concept of the using outside assistance to induce self-help had also been programmed in the U. N. Water Decade.

In an assessment of the progress of rainwater catchment systems during the U. N. Water Decade, the Thailand Jar Rainwater Catchment Program was cited as an outstanding program for low construction cost with revolving fund financial arrangement to assist users to develop their drinking water supply. A brief presentation of the important feature in the Thailand Jar Rainwater Catchment Program is given in follows.

RAINWATER CATCHMENT SYSTEMS

THE THAILAND JAR PROGRAM

1. The Objective is to have three jars per family for every rural household by the end of 1990. This translates to a total of 9 millions jars. Computation was based on the following data: (Sethaputra 1986)

   1. Each person needs 5 liters of water per day for drinking
   2. Average family size is 6 persons/family
   3. In a year,there are 200 days when water from jars is needed
   4. Three are three millions families to be served.
   5. Each jar can hold 2,000 liters of water.

2. National Plan

   A national plan for drinking and domestic water was prepared. This five-year plan is to be completed by the end of 1990.

3. Unit Cost of Jar

   Material cost for one jar of 2 cubic meters volume is between US$15 to 19 depending on location of construction. Each jar needs 2-man days to construct. Labor contributed by users.

4. Jar Construction and Specification Manual

   The publication of the Thailand Jar Construction and Specification Manual was supported by the Thai Government, Provincial University and Sponsor Foreign Countries such as Australia, Canada and New Zealand etc.

5. Training of Jar Construction Technicians

   Training of village jar construction technician was funded by Thai Government and conducted by provincial universities. Each village will send two trainees to learn jar construction method, operation and maintenance techniques so that they can teach others after they completed the short course training. The idea behind this program is to have users involved in their drinking water supply development so that they can acquire the skill and confidence to operate and maintain their water supply systems.

6. Construction Material Costs
   Construction labor is contributed by the users themselves, they can help each other to form team work to complete their project. However, the government will provide a revolving fund to help participating villagers to buy jar construction materials and have them to pay back a pre-determined amount on monthly basic in four to five months.

The Thailand Jar Rainwater Catchment Program was a great success. Thailand was the only country attended the U. N. Water Decade Drinking Water Supply for everyone's objective. According to their record, Thai Government spent US$7.4 million to train village Jar technicians, printing the construction manual, and provided the forms of the standard 2 cubic meters Thai Jar. In addition, provided US$13 millions revolving fund for villagers to borrow. This Thai Jar Program induced the users to invested US$180 millions to build 9 million Thai Jar to benefit 18 million users, and reached their objective in 1990 with an average per capita cost of only US$10.

If the U. N. Water Decade uses the Thailand Jar Program to provide drinking water supply to its target population of 1.26 billion, the total cost would be only US$ 12.6 billions which would be much less than the estimated cost at US$ 90 billion dollars. If the revolving fund finance method developed by Thailand were used. The UN could ask donor courtries to contribute US$518 millions for the training costs and US$910 millions as the revolving fund to reach their objective to provide drinking water supply in 1990.

As a lesson from the U. N. Water Decade, great efforts have to be committed to research what must be done to fulfill the unfinished works of the U. N. Water Decade cheaply and effectively. The Thailand Jar Program is one of the examples that should be examined for its applicability to other countries. Studies of the Thailand Jar Program should include its operation and maintenance especially its water quality and the users reactions. Ideally, at the same time the selection of a standardized sanitary toilet system must be made using the same ideas of low construction cost, user participation in construction and pay back the construction material cost and community team work in operation and maintenance of their sanitary toilet systems. Perhaps, in the near future, a Thailand toilet program will make another success story to complete their national goal of providing drinking water supply and sanitary toilet to the whole country.

INTERNATIONAL RAINWATER CATCHMENT SYSTEMS ASSOCIATION

As the natural outcome of the international Conference on Rain Water Cistern Systems series, the International Rainwater Catchment Systems Association was organized during the 4th International Conference on Rain Water Cistern Systems, Manila, Philippines, August 2-4, 1989, after a petition submitted by Dr. Adhityan Appan. The idea was to provide a communication center for interested members of rainwater catchment systems to work together, and to exchange information of new development on rainwater catchment systems more efficiently without waiting for the next International Conference on Rain Water Cistern Systems.

The development of the International Rainwater Catchment Systems Association (IRCSA) needs teamworks, and supporting financial funding. Especially at the initial stage of the Association's development. Fortunately, potential membership can be built on the past conferences' participants and the membership of the International Organizing Committee are well distributed. In the near future, the growth of the rainwater catchment systems in the world can be reflected the joint efforts of the membership of the Association and supporting funding agencies.

Although the initiation of the rain water cistern systems conferences series was not from the U. N. Water Decade, however, the noble course of the Water Decade has been accepted by all the participants of the conference. Therefore, it is very natural that an equal effort committed to the sanitary toilet systems is expected. Perhaps a sister International Sanitary Toilet Systems Association would be developed under the same spirit TO SERVE THE HUMANITY.

CONCLUSIONS

The U. N. Water Decade had an imbalanced development between drinking water supply and sanitary toilets at a raio of 3 to 1. Reasons of this imbalance have been evaluated as governmental policy, lack of standardized sanitary toilet for promotion, avoidence to use "toilet" (a taboo word) and inadeguate pubic educational promotion of public health. Methods to alleviate the imbalance development have also been presented in this paper for further discussion. A standard dry toilet system called the Fok Vault Wheeled-Boxes Composting Latrine was presented, its applicability and affordability have been discussed.

The Thailand Jar Rainwater Catchment Program was presented in a brief manner, its low construction cost at US$10 per capita was very attractive. The revolving fund financial assistance method for the Thai government to induce user-to-pay for their drinking water supply was an outstanding example to promote the U. N. Water Decade's objectives without involved heavy financial commitment from the public sector. This paper had pointed out that the U. N. Water Decade's objectives can be reached if policies like Thailand Jar Program were used by all participating countries.

The International Rainwater Catchment Systems Association was a natural outcome of the International Conference on Rain Water Cistern Systems because participants of this conference series recognized their needs should be more effectively served by the Association. According to the noble course of the U. N. Water Decade, a sister International Sanitary Toilet Systems Association is expected to be developed in the near future.

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The Contribution of Rainwater Catchment Systems to the International Drinking Water Supply and Sanitation Decade : Lessons from Thailand.

John E. Gould*

ABSTRACT

Compared to the lofty goals set for the IDWSS Decade in the late 1970's, the achievements in many developing countries seem disappointing. The Decade did, nevertheless, coincide with a period of renewed interest in Rainwater Catchment Systems (RWCS) technology and the implementation of many millions of tanks world-wide made a significant contribution to improving both access and quality of domestic water supplies for tens of millions of people. Although, during the last decade, thousands of individual community projects around the globe have recognized the potential for RWCS operating in tandem with other water supply technologies for meeting their water supply needs; only one national government, that of Thailand, has wholeheartedly taken the technology on board. Since the mid-1980's, Thailand has actively promoted and supported RWCS through the Thai Jar Programme and has incorporated it into its water supply provision plans at local, regional and national levels. The result of this was the construction of around 10 million 1-2m^3 jars and hundreds of thousands of 6-12m^3 rainwater tanks by the end of the Decade and Thailand becoming one of the few countries to even approach the IDWSS Decade targets for rural water supply provision.

Despite its unprecedented scale and success, the rapid implementation of the Thai jar programme encountered a variety of problems. These provide useful lessons for others and are examined in this paper. They include:-

i. The importance of conducting health and hygiene education campaigns associated with the operation and maintenance of the RWCS before and during their implementation, not afterwards.

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ii. The need for awareness about the adverse affects caused by the rapid commercialization of tank/jar construction and implementation on their effective operation and maintenance.

iii. The importance of research and of communicating the findings of such research widely and rapidly, particularly aspects relating to potential design problems or health hazards related to rainwater supplies.

INTRODUCTION

The International Drinking Water Supply and Sanitation Decade coincided with a renewed worldwide interest in the ancient art of rainwater catchment. Although rainwater is known to have been harvested since at least 2000 B.C. (Evenari 1961) and in all likelihood long before that, up until the 1970's the use of the technology was on the decline. In most industrialized countries (Australia being a notable exception) the practice had almost died out apart from isolated examples and limited collection of rainwater on a small scale for secondary uses such as gardening. In the developing world, however, renewed interest in rainwater catchment technologies has spread rapidly both in areas where they have been used traditionally and those where the technology was previously unknown. The number of rainwater tanks with volumes in excess of $1m^3$ is now of the order of tens of millions worldwide which is probably at least a degree of magnitude greater than a decade ago.

In Thailand alone the number of tanks ($>1m^3$) has increased from just a few thousand to around 10 million in less than a decade, (Gould 1990). The spectacular development of RWCS technology is the primary reason why Thailand is one of the only developing countries to come close to achieving the Decade targets for provision of potable water supplies in rural areas. The success of RWCS in Thailand provides a precedent which several other Asian countries, particularly neighboring states in Indo-China could quite feasibly follow. To a lesser extent, successful RWCS programs in Kenya provide a similar example of what may be feasible elsewhere in Africa (Lee and Visscher 1990, Nissen-Petersen 1982).

Apart from the immediate direct benefits of the growing number of successful RWCS programs, a significant long-term positive spin-off is their effect on the way water engineers and planners perceive RWCS technology. Until very recently, rainwater collection was generally considered as a water supply option of last resort, only to be considered where conventional surface and groundwater supplies were not readily available. Increasingly, however, engineers and planners involved with the implementation of rural water supplies in developing countries are now considering RWCS technology as simply another option to be considered alongside reticulated systems, handpumps, shallow wells, protected springs, boreholes, etc...

Despite the significant contribution of RWCS technology in improving rural water supply provision in a number of countries in Asia, Africa and Latin America, policy makers, major donors and many national governments have been slow in switching resources to RWCS and other low-cost, appropriate, small scale water supply technologies. This may be partly due to a failure to effectively disseminate information about the potential of these technologies. The main reason, however, remains the inertia of economic and political self-interest amongst decision-makers which favor continued investment in larger scale projects, often using imported technology and expertise. Nevertheless, some recent signs of more official recognition and support are hopeful, with the governments of Botswana and Kenya recently following the example of Thailand through allocating substantial resources towards the further development rainwater harvesting for domestic, as well as, agricultural purposes during the 1990's.

THE ROLE OF RAINWATER CATCHMENT SYSTEMS WITHIN THE IDWSS DECADE

The rapid expansion in the use of RWCS technology worldwide has coincided with a period of growing interest in the community based, grassroots, self-help, development paradigm. Indeed, the success of privately owned roof catchment systems, more than any other technology in the water supply field has demonstrated that individual ownership and small scale communal effort can bring impressive results. The rapid replication of the technology in several countries supports this proposition and these developments have been documented in Kenya, Indonesia, Thailand and the Philippines by Lee and Visscher (1990), Latham (1984), Wirojanagud and Vanvarothorn (1990) and Appan et. al (1989), respectively.

Despite the growth in both the numbers of rainwater catchment systems worldwide and interest in the technology, substantial opportunities were missed in the 1980's by governments and major donors through their lack of support for this trend. In most countries where significant development of the technology has taken place, numerous NGO's, bi-lateral and government agencies have each adopted their own approach; each developing different tank designs and implementation strategies. This has led to considerable duplication of effort and although it has provided a range of different systems and ideas from which the most appropriate can now be selected, a more co-ordinated approach would have been preferable. Kenya is a good example of a country where as many as 50 different agencies have been actively involved in RWCS implementation with only very limited overall planning and co-ordination.

THE THAI RAINWATER JAR IMPLEMENTATION PROGRAM

Thailand is a rare example of a country where grassroots initiatives in roof tank implementation stimulated by NGO's such as the Population and Community Development Association (P.D.A.) were supported and encouraged by the government both at local, provincial and national levels. The result of this unusual bottom-up meeting top-down approach was a nationwide program through which between 8-10 million rainwater jars were constructed in just over 5 years.

The program officially began in November 1985 when a national administration committee was established and charged with administering the program throughout the country. The planned implementation strategy aimed to:-

i. Involve villagers in the financial management and construction of the project.
ii. Establish revolving funds based on government loans which groups of villagers could contribute to and thus fund the tank construction.
iii. Provide government support in the form of training, tools and any research and administrative costs.
iv. Mobilize huge resources from the millions of project recipients in the form of free labor and contributions to the revolving funds.

It was estimated by researchers at Khon Kaen University that the cost of constructing the 6 million jars initially planned could be cut from around $132 million to just $25 million by mobilizing these village level resources. Wirojanagud and Vanvarothorn (1990). The government provided start up loans for village revolving funds ($250 per village), administrative costs and funds for training courses and research.

In practice, the actual implementation of the program proceeded in a quite different way. Because the program expanded so rapidly and demand for tanks was so great, the time and administration required for revolving funds presented a problem and generally these were not used. In most cases each district provided the materials, tools, training and the technical supervision required, while the villages contributed the labor and built their own tanks. Finance came from central and provincial governments, NGO's and even the private sector, with 2500 tons of cement being donated by one company, enough for the construction of 20,000 rainwater jars.

In some cases, groups of villagers were paid to construct jars at a central location and distribute them to households by lorry. Funding for these enterprises generally came from the Rural Job Creation Program. With so many people acquiring the skills of tank construction small tank building business enterprises quickly sprang up. These catered for private demand and were also sub-contracted by many districts.

LESSONS FOR THE 1990's BASED ON THE THAI EXPERIENCE

The advantage of the implementation strategy, which was actually followed over that originally planned, was that it enabled a far more rapid rate of construction and overall implementation than had been initially envisaged. There were, however, a large number of drawbacks to this strategy. Because many of the tanks were centrally produced and simply delivered to villagers at a subsidized cost, the benefits of active villager participation were diminished. In the initial phase of the program many basic, but vital, design elements were overlooked in the rush to build tanks as rapidly as possible. For example, many of the tanks built at the start of the program had neither taps nor covers. Even after these had been universally adopted in the standard tank design, a preoccupation with the 'hard-ware' construction and design aspects of the program' resulted in the 'software' aspects, such as operation of the systems and user hygiene education being left as after-thoughts. Only towards the end of the main construction phase of the program, was considerable effort directed to hygiene education campaigns to encourage users to avoid serious contamination of the water being consumed from the rainwater jars. Another problem has been that rationing the use of stored rainwater has not always been adopted, resulting in families returning to contaminated traditional sources for drinking water when the jars are empty (Tunyavanich and Hewison 1989).

One user education campaign which is succeeding well amongst 75,000 primary school children in Kelasin Province, involves teaching materials based around a rainwater jar cartoon character. The children are also invited to enter a competition to produce a poster for promoting the campaigns message. In another initiative, the Population and Community Development Association (PDA) are disseminating information on ways of preventing the spread of AIDS by using the rainwater jars themselves as appropriate objects on which to paint and display their message.

Although the Thai case study provides a good example of what is possible, it would be unrealistic to expect other countries to implement successful nationwide rainwater tank programs either as quickly or as cheaply. A number of factors greatly favoured the rapid development of the rainwater jar program in Thailand; these include;

i. A real , felt need for water and a preference for taste of rainwater.
ii. A period of national economic growth and increasing private affluence.
iii. The availability of cheap cement, skilled artisans with experience in a similar traditional technology (the Thai Household Storage Jar).
iv. a pool of indigenous engineers, technicians and administrators committed to rural development programs.
v. The full support of the government at local, provincial and national levels for the program.

Nevertheless, the implementation of the program was more successful in some parts of the country than others. In the south of Thailand, the wider availability of alternative sources and a lower preference for the taste of rainwater has resulted in far less rainwater jar construction.

THE IMPORTANCE OF RESEARCH

In a huge, nationwide rainwater jar implementation program, as exists in Thailand, the importance of research and of communicating the findings of such research widely, rapidly and unambiguously is vital. This is particularly true for elements of the program relating to potentially hazardous design problems or health hazards related to the rainwater supplies.

In the early 1980's technical problems relating to the venerability of bamboo reinforced tanks to fungal, termite and bacterial attack of the bamboo reinforcement were only fully realized after failures began to occur following the construction of over 50,000 tanks in Thailand alone, Vadhanavikkit and Pannachet (1987). This was particularly unfortunate since the design had been widely publicized. More caution and greater laboratory and field testing was consequently applied to a subsequent interlocking brick design, Vadhanavikkit and Viwathanathepa (1986). This design was eventually shelved since it was felt the level of workmanship required to produce a leak proof tank was unrealistic.

Concern over the effect of the huge increase in the number of rainwater jars and, hence, possible mosquito breeding sites led to serious fears relating to the possible effects on the incidence of dengie fever and malaria in Thailand. Research findings seemed to differ quite significantly on the extent of the problem. In a survey of 1017 rainwater jars, of which only 30% were covered, conducted by the Thai-Australian Project in Khon Kaen Province, mosquito larvae were only found in 2 (0.2%) of the jars. In another survey of 150 households in Khon Kaen Province (Chareonsook et. al. 1985), Aedes mosquito larvae were found in 34% of rainwater jars and 4% of large rainwater tanks. Since the larvae were found in 95% of small indoor water storage containers, however, it was not only rainwater jars which were creating the problem. Nevertheless, the covering of jars with nylon or wire mesh was recommended. This has the added benefit of protecting the stored water from contamination from lizards and other animals which seek refuge in the jars.

Despite concerns over rainwater quality, it was not until 1989, four years after the start of the program, that a major study on this was published, (Wirojanagud et. al. 1989). Although, this found that only 40% of 189 rainwater jars sampled met with WHO drinking water standards it was still concluded that potentially rainwater is the safest and most economical source of drinking water. Improvements in the hygienic collection and handling of the rainwater, sanitary practices and the use of disinfection techniques, where necessary, were recommended.

Pinfold et. al. (in press) have argued, however, that any systematic attempt to ensure water from rainwater jars met WHO quality guidelines would be both problematic and expensive, with negligible health benefits. It is suggested that a more realistic approach should involve incremental improvements maximizing the cost-effectiveness of available resources. Disinfection of stored rainwater through chlorination is also discouraged, due to its impracticality when dealing with so many discrete supplies and the dangers of health risks from over chlorination. Finally, it is suggested that rather than becoming preoccupied with efforts to achieve the unrealistic ideal of meeting WHO drinking water guidelines, it would be far more beneficial to concentrate resources on improving sanitary and water handling practices to reduce secondary contamination. There is considerable evidence to suggest that the increased availability and convenience of rainwater jar supplies has helped to improve health and hygiene and recent modifications to the jar design such as the mandatory taps, covers and netting have assisted in this.

Although most of Thailand is still free from the problems of serious industrial air pollution, in the rural areas around Bangkok where large numbers of people consume rainwater there is growing concern about the potential health threat. It is clear that more research in this area is urgently needed.

CONCLUSION

There is no doubt that RWCS technologies did make a significant contribution towards the goals of the IDWSS Decade through improving water supply provision in a number of countries, particularly in rural areas. When considered in a global context, however, the impact of RWCS still remains small in comparison with its potential. An enormous quantity of rainwater continues to run to waste, much of it in areas with severe water shortages simply because the political will, economic resources and community spirit have yet to be mobilized to tap this readily accessible water supply.

The Thai experience acts as a useful example of the potential benefits of RWCS technology and the substantial contribution it can make to water supply provision at a national scale particularly in rural areas. It should be born in mind, however, that the success of RWCS in Thailand was based on a large number of pre-conditions unlikely to be found elsewhere and similar rates of replication should not be expected. The high costs of materials, (especially cement), poverty, skills shortages and low levels of government commitment to rural development programs, are among the main obstacles hindering the development of similar programs in other countries, where a real felt need for improved domestic water supplies and a high potential for RWCS exists.

In the case of the Thai program, it was the 'hardware' aspects such as design and construction which dominated the initial phases of the project. This resulted in 'software' aspects such as operation and maintenance and user education only receiving priority in the later phases of the program. Many problems may have been overcome quicker and dealt with more effectively had the 'software' dimensions of the program been given the same initial consideration as the 'hardware' aspects. The extremely rapid expansion of the program also caused problems, particularly in relation to effectively implementing the original plan involving active villager participation and financing, through revolving funds.

Vast potential exists for the further development of RWCS in many regions of the world particularly in those parts of Africa and Asia where the technology is still uncommon. Future large scale projects might avoid considerable problems by noting and learning some of the lessons from Thailand. In the final analysis every project is location specific and has its own unique set of circumstances and problems to overcome, nevertheless, substantial benefits may accrue from considering the experiences of other projects.

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THE BACTERIAL CONTENT OF CISTERN WATERS IN HAWAII

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ABSTRACT

The drinking water quality of 15 cistern systems in Honolulu and 3 cistern systems on another island (Hawaii) in the State of Hawaii was evaluated. These cistern waters can be expected to meet turbidity, chloride, nitrate and pH levels established by USEPA for drinking water. However, the bacterial (total heterotrophic fecal coliform, *E. coli*, fecal streptococci) concentrations in these cistern waters usually exceeded drinking water standards. Low levels of *C. perfringens* and salmonella bacteria were also recovered from some cistern reservoir tanks. Higher concentrations of bacteria were recovered from cistern reservoir tanks than from household faucet sources. The cisterns in Hawaii are susceptible to contamination by indicator bacteria via multiple sources and cannot be expected to meet bacterial drinking water standards. We recommend that the portion of water to be used for drinking be disinfected and standards specifically for cistern waters based on fecal coliform or *E. coli* be established.

INTRODUCTION

Rainwater cistern continues to supply the household and drinking water needs for many communities in developing countries (Latham and Schiller, 1987). Even in developed countries, many communities and homes are located too far away from piped drinking water supplies or are too sparsely populated to warrant the piping of waters to these areas. In most countries, the quality of water delivered by public and private water suppliers are regulated by Federal, State and County laws and therefore routinely monitored.

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However, each cistern water system is considered a private source and therefore not regulated by public laws. As a result, the quality of cistern waters is usually not monitored and therefore not known. One each community is the affluent, Round Top-Tantalus community located in Honolulu, Hawaii. In 1985 we (Fujioka and Chinn, 1987) initiated the first systematic analyses of cistern waters in this community for bacteria, conductivity, turbidity and total solids. Of these parameters, only bacteria (total bacteria, total coliform, fecal coliform, fecal streptococci) consistently exceeded the current United States Environmental Protection Agency drinking water standard (EPA 1985) of 0 fecal coliform/100 ml. These cistern waters were also characterized by concentrations of total heterotrophic bacteria far in excess of the 500/ml drinking water guideline and interfered with the total coliform assay. As a result, we (Fujioka and Chinn, 1987) recommended that cistern waters be directly assayed for fecal coliforms and that a fecal coliform standard specifically for cistern water use be developed.

Although the cistern waters in the Round Top-Tantalus community contained high concentrations of fecal indicator bacteria and total heterotrophic bacteria, the true public health significance of these bacteria in these cistern waters was difficult to assess because there was no evidence that human feces were contaminating these sources. These results were further complicated by our other studies (Fujioka and Shizumura, 1985; Fujioka, Tenno, and Kansako, 1988; Hardina and Fujioka, 1991) which indicated that the traditional fecal indicator bacteria (total coliform, fecal coliform, fecal streptococci) are naturally present in the environment (fresh water streams, soil) of Hawaii. The objectives of the present study were to assess the quality of the cistern waters from the Round Top-Tantalus community based on: a) the presence of more specific fecal indicator bacteria such as *Escherichia coli* and *Clostridium perfringens*, b) the presence of an enteric pathogenic bacteria such as salmonella, and c) other water quality parameters (pH, turbidty, conductivity, nitrate). Finally, to compare the quality of a few cistern waters obtained from a different community located on another island (Hawaii) in the State of Hawaii.

MATERIALS AND METHODS

Study Sites and Sampling Sites

The primary site was the Round Top-Tantalus community located within the city of Honolulu on the island of Oahu, the most populated island in the State of Hawaii. This community is within the forest reserve area of Honolulu covering approximately 39 hectares at elevations ranging from 300 to 495 meters above sea level. It is a densely vegetated, semi-tropical forest area with an average of 300 cm of rain per year and most of the 110 homes are well scattered among groves of koa, kukui, eucalyptus and bamboo trees. A total of 15 cisterns from this community were selected for this study. Each of the 15 participating households were surveyed and interviewed to determine the history, use and characteristics of the cisterns under study. It should be noted that only 1 of the 15 households recognized the term of "first foul-flush diverter" which has been recommended (Michaelides, 1987) as an ideal mechanism to maintain high water quality in cistern systems. Table 1 summarizes the characteristics of each of the 15 cistern systems. Table 2 summarizes the consumptive use of the cistern water among these 15 households.

The secondary site was the Kailua-Kona community located on western coastline of the island of Hawaii, the largest and the most eastern island in the State of Hawaii. Cistern water samples from only three households from this community were obtained during a single sampling day.

Table 1

Composition and Maintenance of Fifteen Cistern Systems in the Round Top-Tantalus Area Honolulu, Hawaii

------Cistern------				------Reservoir Tank-----	
No.	Age	Users	Roof Composition	Inner Lining Material	Year Last Cleaned
1	40	6	Galvanized Steel	Wood & Vinyl	?
2	25	3	Galvanized Steel	Concrete	?
3	16	2	Pitch & Gravel	Concrete	1
4	40	3	Pitch & Gravel	Vinyl	?
5	18	3	Tile	Concrete	?
6	50	1	Aluminum	Redwood	1
7	5	7	Galvanized Steel	Vinyl	5
8	18	3	Aluminum	Steel	?
9	10	3	Galvanized Steel	Vinyl	Never
10	5	1	Aluminum	Vinyl	?
11	10	3	Metal	Steel & Wood	?
12	31	2	Aluminum	Concrete	?
13	20	1	Galvanized Steel	Vinyl	1
14	30	3	Steel & Aluminum	Vinyl	1
15	16	3	Aluminum	Redwood	1

Cistern water samples were collected into clean, sterile, polyethylene bottles from two sites. The first site (R) was from the reservoir tank, approximately six inches below the surface of the water or from a piped system located at least six inches above the bottom of the tank. The second site (H) was from the household tap water faucet from the kitchen. Aerators and other attachments to the kitchen faucet were removed before sampling and water was run for 1 minute before a representative sample was collected. All samples from the Round Top-Tantalus community were analyzed within 4 hours of collection while the samples from the island of Hawaii were analyzed approximately 6 hours after collection.

Table 2

Cistern System Water Consumption Information for the Round Top-Tantalus Area, Honolulu, Hawaii

	Adults	Teenagers	Children
Number of water consumers	23	7	4
Average daily water consumption	37 oz.	28 oz.	30 oz.
Shower-bathing times:			
<15 minutes	19	2	1
15-30 minutes	5	0	3
>30 minutes	0	0	0

Methods for Analysis

Turbidity was measured in nephelometic turbidity units (NTU) using the Hach Turbidimeter 1(Model 2100A) while conductivity was measured in µmhos/cm using the YSI Electrical Conductivity Bridge (Model 31A). pH was measured using the Orion Ross Electrode 1(Model 81-02) and Orion Research Microprocessor pH/millivolt meter (Model 811). The Hach Model DR/3000 spectrophotometer and Hach method for nitrogen-nitrate (cadmium reduction) was measured in mg/l.

The membrane filtration methods as described in Standard Methods (APHA 1989) were used to assay water for total heterotrophic bacteria (mHPC medium), fecal coliform (mFC medium), fecal streptococci (KF medium) and *Escherichia coli* (mTEC medium). *Clostridium perfringens* was assayed for using the membrane filtration method as described by Bisson and Cabelli (1979). Water samples were analyzed for salmonella using the direct membrane filtration method (Salmonella-Shigella Agar, Bismuth Sulfite Agar) and by a pre-enrichment method in Tetrathionate Broth. Presence of salmonella was confirmed after isolated colonies gave 4+ agglutination reaction using polyvalent (Fisher Co.) and individual somatic antisera for salmonella (Difco Co.).

RESULTS AND DISCUSSION

Initial Survey of Cisterns

To ensure that the quality of the cistern waters had not changed substantially from our earlier study, water samples from the reservoir (R) tank and from the household (H) kitchen cold water faucet from 15 cistern system in the Round Top-Tantalus community were initially analyzed for bacteria, pH, turbidity, conductivity and nitrate. All 30 water samples, 15 from reservoir tanks and 15 from household faucets, were determined to exceed 125,000 CFU/ml of total heterotrophic bacteria, far in excess of the recommended 500/ml for drinking water. The fecal coliform concentrations in the 15 reservoir water samples ranged from 0 to 520 CFU/100 ml (mean:103 CFU/100 ml) as compared to the 15 household water faucet samples which ranged from 0 to 420 CFU/100 ml of fecal coliform (mean: 58CFU/100 ml). Higher concentrations of fecal coliform were recovered from reservoir samples as compared to the household faucet samples. Only 1 of 15 reservoir samples met the USEPA MCL of 0 fecal coliform/100 ml whereas 3 of 15 household samples met the 0 fecal coliform/100 ml drinking water standard.

Some of these same cistern water samples were also surveyed for other water quality parameters. A total of 28 water samples representing 14 reservoir and 14 household sampling sites were analyzed for turbidity, pH, and conductivity. Turbidity measurements ranged from 0.1 to 2.7 NTU. Only 6/28 samples exceeded the recommended MCL of 1.0 NTU for community supples and none exceeded the MCL of 5.0 NTU established for non-community sources of drinking water. Measurements of pH for these same water samples ranged from 5.2 to 9.2. Although, 6/28 water samples exceeded the USEPA drinking water standard of 6.0 to 8.0 pH, the four acidic water samples had pH values 5.2 to 5.9 which are close to 6.0. Two fresh rainwater samples collected in and near the Round Top-Tantalus area were determined to measured pH 7.5. Based on these results and the recognition that pH changes as water is stored, we conclude that cistern waters from the Round Top-Tantalus area are not characteristically acidic. Measurements of conductivity in these same 28 water samples ranged from 23 to 128 μohms/cm. All samples were well below 490 μmhos/cm which correlates to 250 mg/l of chloride, the MCL established for drinking water. A total of 13 water samples, 5 from reservoir tanks and 8 from household faucets, were determined to contain <1.0 mg/l of nitrate, well below the USEPA drinking water standard of 10 mg/l of nitrate.

The results of this initial survey of cistern water samples showed that the bacterial content of cistern waters from the Round Top-Tantalus community can be expected to exceed USEPA drinking water standards for bacteria in the water whereas the other water quality parameters (nitrate, pH, turbidity, conductivity) appear to meet existing drinking water standards. These results are consistent with the conclusions we (Fujioka and Chinn, 1987) reached in our earlier study and indicate that the quality of water from these cisterns has not changed over the past five years.

Assay for E. coli in Cistern Waters

Since E. coli in drinking water has been reported to be the most reliable indicator of fecal contamination, 9 of the 15 cistern systems were re-sampled and analyzed specifically for E. coli as well as other parameters such as total heterotrophic bacteria, fecal coliform, fecal streptococci, pH, and conductivity. The results summarized in Table 3 show that fecal coliform was recovered from 8/9 reservoir (R) samples at concentrations ranging from 0 to 4,800 CFU/100 ml (mean:923 CFU/100 ml). In comparison, fecal coliform was recovered from only 4/9 household (H) samples at concentrations ranging from 0 to 48 CFU/100 ml (mean:6 CFU/100 ml). From these same cistern samples, E. coli was recovered from 7/9 reservoir (R) samples at concentrations ranging from 0 to 4,700 CFU/100 ml (mean:880 CFU/100 ml) and from 3/9 household 1(H) faucet samples at concentrations ranging from 0 to 7 CFU/100 ml (mean:1 CFU/100 ml). These results show that a significant fraction of the fecal coliform recovered from these cistern water samples is E. coli.

All nine cistern samples were also analyzed for total heterotrophic bacteria as well as for fecal streptococci bacteria. As previously determined, the total heterotrophic bacteria concentrations of all reservoir and household samples exceeded 125,000 CFU/ml. Fecal streptococci was recovered from 8/9 reservoir samples (Table 3) at concentrations ranging from 0 to 1,400 CFU/100 ml (mean:392 CFU/100 ml) and from 8/9 household samples at concentrations ranging from 0 to 260 CFU/100 ml (mean: 53 CFU/100 ml).

Table 3

Concentration of Bacteria, pH and Conductivity in Nine Cistern Water Samples Obtained from Reservoir Tanks (R) and Househole Faucets (H)

Cistern Number		CFU/100 ml Fecal Coliform	*E. coli*	Fecal Streptococci	pH	Conductivity µohms/cm
1	R	22	7	39	6.3	32.7
	H	0	0	4	6.5	32.1
5	R	4,800	4,700	1,400	7.8	119.8
	H	0	0	0	7.5	123.1
6	R	2,120	2,000	170	6.5	31.0
	H	48	7	9	6.6	35.3
8	R	1	0	9	6.0	27.8
	H	4	1	27	5.9	34.2
9	R	0	0	0	6.0	30.0
	H	0	0	2	6.0	30.0
10	R	22	9	620	6.2	36.9
	H	4	2	260	5.1	39.6
11	R	1,030	870	120	6.6	39.6
	H	1	0	4	6.7	38.5
14	R	30	20	250	6.4	35.3
	H	0	0	7	6.5	31.0
15	R	280	310	920	6.4	28.7
	H	0	0	160	6.6	30.0

Table 3 also summarizes the measurements of these water samples for pH and conductivity. The pH in these 9 cistern systems ranged from 5.1 to 7.8 indicating that pH of water from the cisterns in this community generally met drinking water standards. The conductivity of all these samples ranged from 27 to 123 µmhos/cm indicating that these waters were well below the MCL of 250mg/l of chloride (490 µmhos/cm) for drinking water.

Roof as Source of Indicator Bacteria

The fecal droppings of birds and rodents on the roof and gutters of homes are the obvious sources for the high concentrations of indicator bacteria recovered in the cistern reservoir tanks. To determine whether indicator bacteria can be recovered from the roof, one square yard of a roof with pitch and gravel composition (cistern number 3) was flooded with 2 gallons of coliform free water and the roof wash collected into a plastic bag as the water flowed off the roof. The roof appeared dry and dusty as it had not rained for some time. Fecal droppings were not observed within the one square yard of the roof. Only 2 liters of the roof wash were collected in the bag and the roof wash water was colored and turbid. Analysis of this water revealed >125,000 CFU/ml of total heterotrophic bacteria, 30 CFU/100 ml of fecal coliform, 40 CFU/100 ml of E. coli and 120 CFU/100 ml of fecal streptococci. The wash water also contained <1 mg/l of nitrate.

The results of this experiment show that indicator bacteria are present on the roofs of homes and can be expected to be washed off the roof by rain and carried to cistern water tanks by rainwater. The one square yard area of the roof was observed to contain dirt but no fecal droppings. Although this experiment does not prove the source of indicator bacteria on the roof, it is consistent with our earlier findings that fecal indicator bacteria (fecal coliform, E. coli, fecal streptococci) are naturally present in the soils of Hawaii and that indicator bacteria may be carried by soil blown onto the roofs of houses.

Analysis of Cistern Waters on the Island of Hawaii

To compare the quality of cistern waters in the Round Top-Tantalus area with other cistern waters in the State of Hawaii, three different cistern systems located in the Kailua-Kona district on the island of Hawaii were sampled on August 17, 1988. This area is very different from that of the Round Top-Tantalus area in that it is drier, located at a much lower altitude, and the people living in this area are not characterized as in the upper income area as those in the Round Top-Tantalus area. Moreover, the eruptive activity of an active volcano on this island had been occurring of and on for the past six years resulting in acid rain (Higa, 1987).

The sampling of water from the reservoir tank and household faucet from the three homes and the analysis of the water were similar to that done previously. However, since it began to rain during our sampling day, we also collected one rain water sample as it ran off the roof of cistern system 1. The characterization of the three cistern systems and the results of these water analysis are summarized in Table 4. The results show that the rainwater running off the metal roof of cistern 1 had a pH of 4.5, conductivity of 74.9 µohms/cm, 3 CFU/100 of fecal coliform, 0 CFU/100 ml of E. coli, and 35 CFU/100 ml of fecal streptococci. In comparison, water in the vinyl-lined reservoir tank of cistern system 1 had a pH of 7.6, conductivity of 64.2 µohms/cm, and 0 CFU/100 ml of fecal coliform, E. coli and fecal streptococci. Water from the household faucet from this same cistern system had a pH of 7.5, conductivity of 59.2 µohms/cm, 2 CFU/100 of fecal coliform, and 0 CFU/100 of E. coli and fecal streptococci.

Table 4

Concentrations of Bacteria, pH and Conductivity of Three Cistern Water Samples Obtained from the Reservoir (R) and Household (H) Faucets from Kailua-Kona Community

Cistern System	Material of Roof/ Lining of Reservoir Tanks	Water Source	pH	Conductivity µohms/cm	----CFU/100 ml---- FC	E. coli	FS
1	Metal/	Rain	4.5	74.9	3	0	35
	Vinyl	R	7.6	64.2	0	0	0
		H	7.5	59.2	2	0	0
2	Metal/	R	4.5	47.1	12	2	10
	Wood	H	5.7	38.5	6	10	1
3	Asphalt/ Concrete	R	9.3	66.7	0	0	0

FC = fecal coliform; FS = fecal streptococci.

Analysis of cistern system number 2 (metal roof, wood lined tank) showed that the water in the reservoir tank had a pH of 4.5, conductivity of 47.1 µohms/cm, 12 CFU/100 ml of fecal coliform, 10 CFU/100 ml of E. coli, and 2 CFU/100 ml of fecal streptococci (Table 4). In comparison, the water from the household faucet had a pH of 5.7, conductivity of 38.5 µohms/cm, 6 CFU/100 ml of fecal coliform, 1 CFU/100 of E. coli, and 10 CFU/100 ml of fecal streptococci. For cistern system number 3 (asphalt tile roof, unlined, concrete cistern) only the reservoir tank sample was collected. Water from this reservoir tank had a pH of 19.3, conductivity of 66.3 µohms/cm, and 0 CFU/100 ml of fecal coliform, E. coli, and fecal streptococci.

All cistern water samples collected from this Kailua-Kona community including the rainwater running off the roof contained heterotrophic bacteria exceeding 125,000 CFU/ml, <1.0 mg/l of nitrate and <0.5 NTU turbidity. The acidity of the rainwater running off the roof confirms report of acid rain in this community resulting from volcanic eruptions (Higa, 1987). The community had been forewarned of the high acidity of rainwater and had been advised to add lime to reservoir tanks to neutralize this acidity. Owner of cistern system 1 added lime to his reservor tank and this probably accounted for the neutral pH of that water. We could not verify whether chemicals were added to the reservoir tanks of cistern systems 2 and 3. The low pH in the water from cistern system 2 suggests that it was not sufficiently neutralized. The high pH in the reservoir tank from cistern system 3 suggests that the concrete was basic enough to increase the pH or too much chemicals were added which increased the pH to 9.3.

Assay for Salmonella and *C. perfringens*

To further characterize the bacteriology of cistern water samples, a total of 11 cistern reservoir samples (8 from the Round Top-Tantalus community, 3 from the Kailua-Kona community) were assayed for *C. perfringens*, a spore-forming enteric bacteria and for salmonella bacteria, the most common pathogenic enteric bacteria. The results (Table 5) show that *C. perfringens* was recovered in 8/11 reservoir cistern samples ranging from 0 to 5 CFU/100 ml (mean: 2 CFU/100 ml).

Table 5

Analysis of Cistern Reservoir Tanks from Round Top-Tantalus (T) and Kailua-Kona (K) for Clostridium Perfringens and Salmonella Bacteria

		Salmonella Bacteria		
Cistern Reservoir	*C. perfringens* CFU/100 ml	Direct Assay CFU/100 ml	Pre-enrichment Assay	Identified Serotype
K-1	0	<1	Negative	
K-2	0	<1	Negative	
K-3	1	<1	Negative	
T-1	1	<1	Negative	
T-5	2	<1	Negative	
T-6	4	<1	Negative	
T-8	5	<1	Negative	
T-9	0	<1	Positive	(Gp E)
T-11	2	<1	Negative	
T-14	2	<1	Positive	(Gp B)
T-15	4	<1	Negative	

The same 11 cistern reservoir samples were also assayed for salmonella bacteria using the direct method and an enrichment method. In the direct method, 100 ml of cistern water samples were filtered and the membrane placed onto two selective agar (BSS, SS) media for salmonella. Using this direct assessment, none of presumptive colonies were confirmed as salmonella bacteria. It can thus be concluded that these methods are unsuitable for the recovery of salmonella bacteria from cistern waters or that salmonella bacteria are present at very low concentrations. In the enrichment method, 250 to 500 ml of cistern water samples were samples were cultured in tetrathionate broths for 3-4 days at 41-43°C, to enable low concentrations of salmonella bacteria in the sample to multiply. The enrichment broth was then streaked on BS (bismuth sulfite) agar and the presumptive salmonella colonies isolated and confirmed as salmonella bacteria using agglutination reaction by specific salmonella antisera. Using this more sensitive technique, salmonella was not recovered in any of the 3 Kailua-Kona cistern samples but was recovered from 2/8 samples from the Round Top-Tantalus cistern systems. Based on the agglutination reactions, the salmonella recovered from Tantalus sample 9 was group E and from Tantalus sample 14 was group B. These results show that salmonella, a pathogen is present in some cistern samples but at low concentrations.

CONCLUSIONS

Although the rainwater cistern systems in Hawaii are well built and the users well educated and affluent, the design of cistern waters to collect rainwater from the roofs of houses will result in high concentrations of total heterotophic bacteria as well as continuous contamination with some fecal indicator bacteria. Thus, the quality of these water cannot be expected to meet public drinking water standards. Part of this problem is due to the fecal droppings of birds and lizards on the roof of homes and the fact that first foul flush diverters, filters and disinfectants are not extensively used. However, another factor in Hawaii and probably many other tropical countries appear to be the presence of these indicator bacteria in environmental soil and the transport of these bacteria to the roofs of houses by wind blown soil and dust. Contamination of these cistern water by feces of man or sewage, the most serious sources of indicator bacteria, can be ruled out. These factors should be considered in interpreting the public health significance of indicator bacteria in cistern waters.

It is clear that bacterial standards for cistern water used for drinking purposes should be established but that these standards should not be those set for public drinking water supplies and should be set recognizing the factors affecting the bacterial quality of cistern waters. Thus, the indicator bacteria to be used to establish cistern water quality standards should not be total coliform because the method to assay for this group of bacteria will be interfered with by the high concentrations of total bacteria in the water supply. Fecal coliform or E. coli are more appropriate indicators because these bacteria more specifically address fecal contamination and because the methods to assay for these indicator bacteria will not be interfered with by the presence of other bacteria. We propose that the drinking water standards for cistern waters be set at 10 fecal coliform/100 ml. This standard is reasonable and will encourage the treatment of cistern waters to meet these standards rather than to abandon the use of cisterns because of unachievable drinking water standards.

Finally, cistern waters are used for many purposes and only a small fraction is used specifically for drinking. In the implementation of drinking water standards for cistern waters, users should be informed that to ensure drinking water quality of 10 fecal coliform/100 ml, some form of filtration and/or disinfection may be required. The most practical approach for cistern systems in Hawaii and in many other communities will be establish one faucet (e.g., kitchen) for drinking purposes and to install a small filtration and Ultraviolet light disinfecting systems to treat the cistern water from the reservoir and to store this treated water in a smaller reservoir container. This is a practical approach and one we intend to evaluate.

ACKNOWLEDGEMENTS

This research was conducted in partial fulfullment of the requirements for the degree of Master of Public Health fro the University of Hawaii by Steven Inserra. The authors acknowledge their appreciation to all the residents of the Round Top-Tantalus area who participated in this study. Our special thanks to Mr. John DeHaan, a cistern owner and cistern systems expert for the Tantalus area, for his advise and cooperation. Also to the Department of Health, Hawaii county, for arrangements to obtain cistern waters on the island of Hawaii.

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IMPROVING CISTERN WATER QUALITY

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ABSTRACT

As cistern water systems become increasingly popular around the world, it is important that adequate attention be given to maintaining and improving cistern water quality. Periodic water testing, to at least determine the presence of coliforms, should be initiated in those areas where cistern water is used for drinking purposes. A number of relatively simple techniques are discussed in this paper, which will assist in improving cistern water quality. These include roof maintenance and removal of overhanging vegetation, installation of screens and first-flush devices, ultra-violet radiation, exposure to sunlight and the use of silver compounds in small quantities. The specific choice of a disinfection method depends upon the personnel and other resources available in any given area or region.

INTRODUCTION

Rain water cisterns have been in use in many regions of the world, e.g., rural parts of ohio and Kentucky in the United States, U.S. Virgin Islands and other Caribbean Islands, Hawaii, Parts of Nova Scotia and Saskatchewan in Canada, Bermuda, Mexico, Southern Australia, Thailand, Philippines, Malaysia, Indonesia, and Several countries in Africa. Although cisterns are not new, they range in a variety of sizes and shapes in different parts of the world. A considerable effort has been made to encourage rain water collection in the past decade and good progress has been made in that direction. However, it appears that in many cases, the quality of the water that is collected and used is not entirely safe for human consumption. The objective of this paper is to review water quality problems that have been encountered in rain water cistern systems in the past, and possible steps to overcome such problems and ensure a safe level of water quality for domestic consumption.

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WATER QUALITY PROBLEMS

Scott and Waller (1987) reported that sludge collected in Canadian cisterns contained debris from trees, fragmented animal forms and numerous algae. Fujioka and Chinn (1987) discussed the drinking water quality of 18 cistern systems in Hawaii, Wherein high concentrations of fecal indicator bacteria were often noticed, indicating that most of those cistern waters did not meet U. S. microbiological drinking water standards. Ruskin and Callender (1988) showed that in a study of 20 private residential cisterns in the U.S. Virgin Islands, if only overall averages were considered, not one of them would have met the Safe Drinking Water Standard of ≤1 total coliform/100 mL set by the U.S. Environmental Protection Agency (USEPA). Krishna (1989) summarized the results of two water quality studies conducted on cisterns in private homes and in public housing in the U.S. Virgin Islands; out of a total of 346 samples, approximately two-thirds of the samples did not meet the Safe Drinking Water Standards. In a recent study of hotels and guest houses in the U.S. Virgin Islands, Ruskin and Krishna (1990) showed that except for some of the large well-maintained establishments, most water samples from moderately-sized and smaller hotels and inns (less than ninety-nine rooms) did not meet the USEPA standards. Wirojanagud et al (1989) indicated that all their sampling points in Thailand were bacteriologically contaminated. It is now obvious that a large proportion of cisterns do not provide water that is entirely safe for human consumption. In most cases, the contamination is from environmental sources such as trees, birds, rodents, etc., rather than from human sources (Fujioka and Chinn, 1987; Waller, 1990; Ruskin and Krishna, 1990). Bacterial contamination is generally more prevalent in cistern waters than contamination from heavy metals.

TECHNIQUES FOR IMPROVING WATER QUALITY

The solutions to water quality problems are often sitespecific. However, there are a number of general approaches which can be recommended to minimize contamination and to improve the quality of cistern water supplies.

1. Roof maintenance: Maintaining smooth roof surfaces can increase water supplies for collection and reduce the possibilities for trash, dirt, moss and other objects to accumulate on the roof and contaminate the runoff. The roof should not contain asbestos and if the roof is painted, the paint should preferably not contain

metals such as mercury or lead. Trees and branches which overhang the roofs should be removed in order to minimize the problem of birds, rodents, lizards, etc. which usually frequent vegetation.

2. Screen installation: One or more screens should be installed to prevent objects from washing into the cistern. The material accumulated in front of the screens should be regularly cleaned out so that the passage is free and clear for runoff to flow into the cistern.

3. First-flush devices: There are several types of first-flush or foul-flush devices which have been developed and discussed in the literature. Michaelides (1989) tested various types of foul-flush diverters and showed that a simple pipe diverter working on an overflow principle was significantly more efficient than other designs. Installing foul-flush diverters is more important in those areas where significant periods of dry weather occur between rainstorms. Depending upon the availability of local materials and personnel, an appropriate choice of a foul flush device can be made.

4. Cistern cleaning: Cisterns should be emptied and thoroughly cleaned once a year, or in the case of large cisterns once every two or three years. This will result in the removal of any sludge or other material that may be accumulated at the bottom of the cistern.

5. Disinfection: The following are some simple methods of disinfection:

a. Chlorination: In the U.S. Virgin Islands, we recommend chlorination by adding ordinary household bleach (which contains 5.25% of sodium hypochlorite as the active ingredient) to cistern water. Depending upon the quality of the runoff water, chlorination may be required at least twice a month. A residual chlorine level of 0.2 mg/L should be maintained at all times, if possible. Five fluid ounces (160 mL approximately) of household bleach (5.25% sodium hypochlorite) may be added for every 1000 gallons (4000 L approximately) of water, or 4 mL bleach per 100 L of water. For smaller volumes of water, a convenient dosage would be to add 1 drop of household bleach per liter of water. Chlorination in excess of the above dosages must be avoided because it can be harmful, leading to carcinogenic effects.

b. Ultra-violet light: Ultra-violet radiation is an effective disinfection method for clear water, but when the water is turbid, the disinfection efficiency is greatly reduced. Ultra-violet radiation may be applicable to larger cistern water systems rather than for smaller cisterns.

c. Exposure to Sunlight: A series of studies were conducted in Hawaii to demonstrate that sunlight is an effective disinfectant of indicator bacteria such as fecal coliform, fecal streptococci as well as some pathogenic bacteria such as Salmonella sp. (Fujioka and Narikawa, 1982; Fujioka and Chinn, 1987). When cistern water was placed in clear glass bottles and exposed to sunlight for 4 hours, the total coliform level of 500 CFU/100 mL and the fecal coliform level of 650 CFU/100 mL were both reduced to zero. Fecal streptococci which were 210 CFU/100 mL were also reduced to zero in four hours. Exposure to sunlight may be a very economical method of disinfection in developing countries.

d. Boiling: Where small quantities of water are needed for drinking, boiling is an effective method of disinfection. Water can always be cooled/refrigerated after boiling in order to be used for drinking.

e. Colloidal silver compounds; Owen and Gerba (1987) documented the wide application of Microdyn* in Mexico. Microdyn is a trade name of a colloidal suspension of ionic and molecular silver, finely dispersed in a protein carrier. It has been apparently used for surfacing cistern and tank walls since many years in Mexico, and laboratory studies indicated that it was effective in controlling enteric bacteria and pathogens (ibid). Because of the very small amounts required (1 drop of 0.32% solution per liter of water), it may be a convenient and useful method for application in developing countries.

CONCLUSIONS

Maintaining good water quality is necessary for human health and well-being. This is particularly important when cistern stored water is used for drinking purposes. Regular water-testing, to at least determine the presence of coliforms, should be introduced in areas where cistern water is used for drinking. Depending upon the quality of the water present and the resources available, a number of possibilities exist for improving the water quality. Several simple techniques include roof maintenance, installation of screens and first-flush devices, cistern cleaning, and disinfection methods such as chlorination, ultra-violet radiation, exposure to sunlight, boiling, and the use of small quantities of silver compounds. As cistern water systems increase rapidly around the world, we should ensure that the quality of the water from these cisterns is significantly improved, so that the technology will continue to be viable and attractive in the 1990s and beyond.

*Mention of trade names or commercial products does not constitute their endorsement by the author.

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RAINWATER QUALITY : PATHOGENS AND HEAVY METALS

Wanpen Wirojanagud *

ABSTRACT

The quality of rainwater samples collected from collecting system (roof and gutter), storage containers (both outdoor and indoor) were evaluated both bacteriologically, using indicator organisms and pathogen isolation, and chemically by analysing heavy metal concentrations. The source of bacteriological contamination was investigated employing the ratio of fecal coliform to fecal streptococci (FC:FS). Information on saitary practices was also investigated.

Approximately 60-91 %, 34-78 %, 43-78 %, and 10-33 % of samples collected from collecting system and storage containers did not meet the drinking water quality standard expressed in terms of total bacterial count, total coliform, fecal colliform, and E.Coli, respectively. About 79-84 % of samples collected from roof and gutter had FC:FS ratios of less than 1, indicating the source of contamination was animal. While about 39 % and 47 % of samples collected from in-house containers had FC:FS ratios of less than 1 and greater than 4 respectively, which indicated the contaminating sources were both animal and human. The contamination induced by human was mainly caused by unsanitary practices on water handling and usage of the villagers.

Pathogenic contamination was found approximately 1.1 % of samples collected from such sampling points. The pathogens identified were Salmonella gr.E.and gr.C, V. parahaemolyticus, and Aromonas. The heavy metals analysed in this study included Cd, Cr, Pb Cu, Fe, Mn and Zn. Most of the heavy metal concentrations taken from various sampling points compared favorably with WHO drinking water standards with two exceptions, Mn and Zn. However, Mn and Zn are considered to affect the asdthetic quality of drinking water only and were therefore not significant to health.

The findings from this study indicate that any health risk evolving from the consumption of stored rainwater would be due to bacteriological contamination rather than heavy metal contamination.

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1. INTRODUCTION

Stored rainwater is potentially a safe and economic supply of drinking water if it is kept free from any contaminants. Rainwater from roof catchment systems may be subjected to contamination from dirt or decaying debries on the roofs as well as the roofing material itself. The stored water may also be contaminated by unclean storage containers. Sanitary practices may also affect the quality of stored rainwater.

2. OBJECTIVES

This study purposes to investigate the quality of rainwater and the health risks associated with its consumption. The specific objectives of this study are :

1) to evaluate the rainwater contamination bacteriologically, in terms of indicator in terms of indicator organisms and pathogens, and chemically, in therms of heavy metal concentrations ;
2) to determine the natural route of contamination of rainwater by sampling at various sites from the point of collection, storage to final consumption in the household;
3) to in-vestigate other factors affecting the contamination of rainwater, particularly sanitary practices ; and
4) to develop recommendations to reduce the levels of contamination in order to improve the quality of rainwater for drinking.

3. METHODOLOGY

3.1 Sampling station

Three villages were selected for this study, namely, Ban-Kok-Phan Pong, Ban-Dang-Noi, and Ban Non-Tun (Figure 1). For each village 6-7 households were selected as sampling stations.

3.2 Sample collection

The sampling design is shown in Figures 2 and 3. The sampling points and number of collected samples are summarized in Table 1, which include :

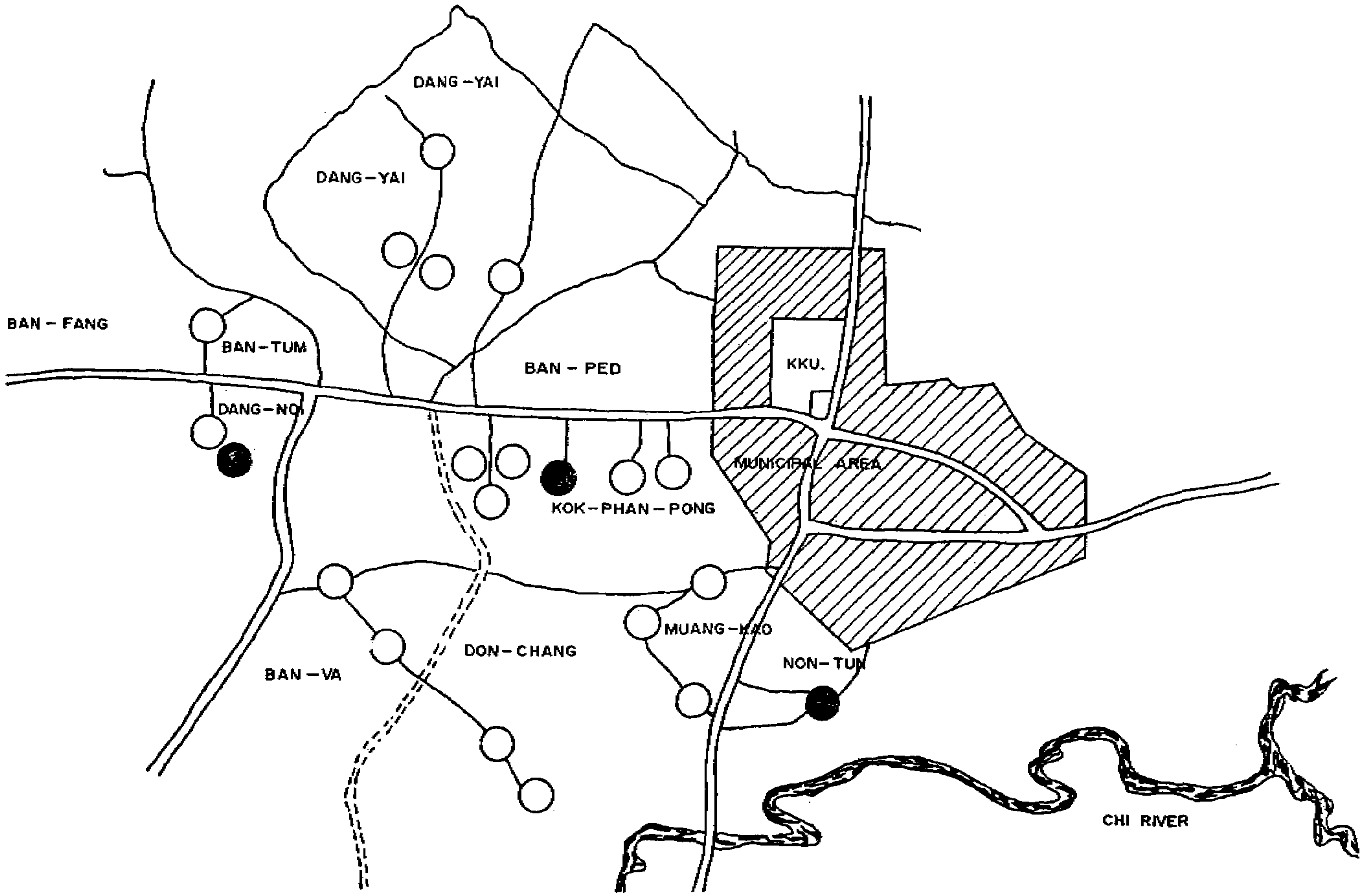

Figure 1. Location of the Villages Selected as Sampling Station.

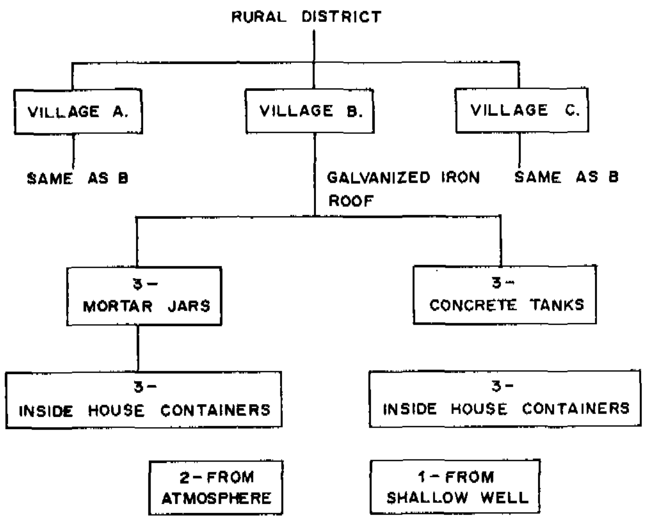

Figure 2. Research Design for Field Water Sample Collection.

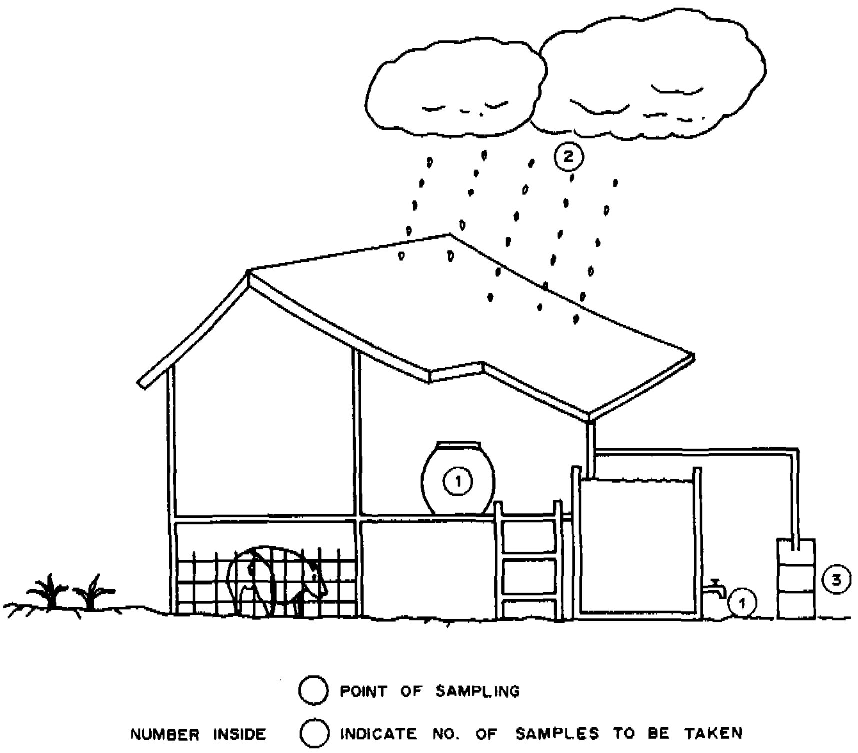

Figure 3. Points of Sample Collection.

TABLE 1 Sampling points and Number of Samples

Sampling Points	Village 1 Kok-Phan-Pong	Village 2 Dang-Noi	Village 3 Non-Tun
Roof and Gutter*			
-Bottom	7	6	6
-Middle	7	6	6
-Top	7	6	6
Storage Container			
-Tank	3	3	3
-Jar	4	3	3
In-house Container	3	6	1

* Rainwater samples from roof and gutter were collected in 3-vertical-connected-containers of the automatic sampler. Bottom, middle, and top, represent the position of the 3 containers which collected the first rainfall in the bottom container and the following few minutes of rainfall in the middle and top containers. These are presented in all following tables.

(1) Atmospheric rainwater - An attempt was made to collect atmospheric rainwater to provide a baseline for a rainwater quality comparison. This type of collection required the household owners to participate in the sample collection. Each owner was instructed by the research team in how to properly procure the rainwater sample. However, it was found that this method of instruction and collection was not sufficient to insure a sterile sampling procedure and many of the samples were evidently contaminated. It was, therefore, assumed that the quality of atmospheric rainwater does not exceed the standard of drinking water.

(2) Roof and gutter - Rainwater samples from galvanized iron roofs with gutters were collected using composite automatic samplers. Three composite samples were taken from each household.

The composite automatic sampler was specifically designed with the capability of collecting rainwater samples from roofs and gutters at variable time interval. The sampler composes of 3 cylindrical containers connected in vertical series (Figure 4). An automatic water sampler is connected to the bypass of the storage container. When it rains, rainwater from the roof and

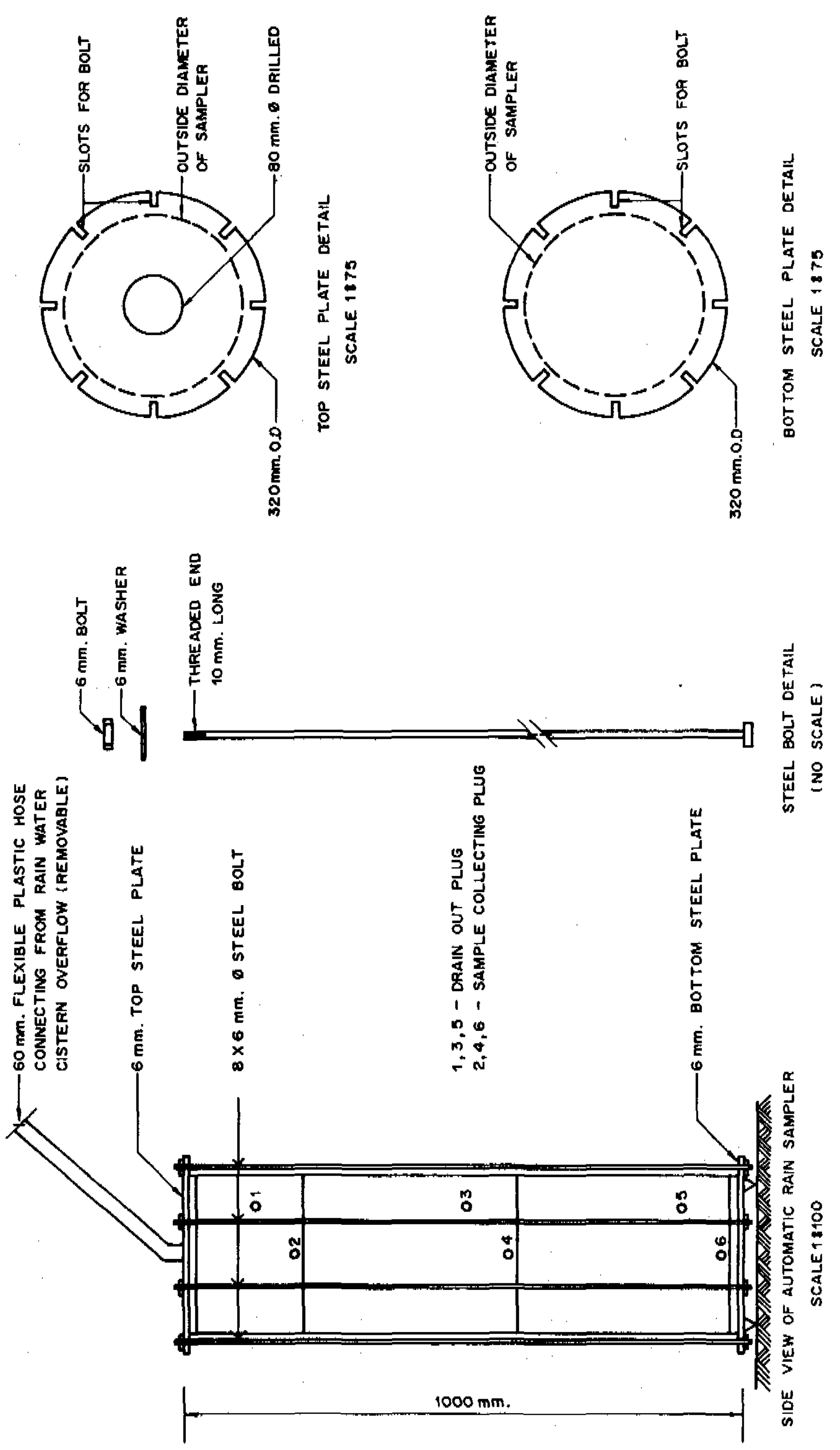

Figure 4. Composite Automatic Roof and Gutter Water Sampler.

gutter will be collected in the bottom, middle and top containers, respectively.

(3) Rainwater containers - Rainwater containers are divided into two types : tanks and jars. A cement tank (10-12 cubic meters) and a mortar jar (approx. 2 cubic meters) were used in this study. Only two year - old containers were selected, thus the effect of age is controlled.

(4) In-house container - To identify secondary contamination, samples were also taken from in-house containers. Most of the in-house containers are small pots made of clay which are used as drinking water vessels. Water from collection tanks are transported to these clay pots by carrying vessels. This was considered one of the possible routes of secondary contamination as well as poor sanitary techniques on the part of the homeowner.

3.3 Laboratory Analysis

The bacteriological study, determined the following organisms:

Indicator organisms:	total plate count
	total coliform
	fecal coliform
	Eschericia coliform (E. coli)
	fecal streptococci
Pathogens:	Salmonella
	Shigella
	Aromonas

The heavy metal analysis comprised chromium (Cr), cadmium (Cd), lead (Pb), copper (Cu), iron (Fe), manganese (Mn), and Zinc (Zn).

3.4 Sanitary Practices

The sanitary practices investigated in this study included: the household structure, drinking water sources, characteristics of collection system, characteristics of storage containers, water handling and usage practices, cleaning practices, exereta disposal facilities, solid waste disposal, and personal hygiene practices. Information on sanitarty practices was obtained by questionnaire, conversation, and visual observation by the research assistants who spent one complete week in the selected village.

Table 2. Analysis of Bacteriological Quality of Rainwater from Various Sampling Points

Sampling Points	Total Number of Samples	Results as % of Total Number of Samples							
		Total Bacterial Counts		Total coliform		Fecal coliform		*E.coli*	
		Meet Standard	Doesn't meet Standard	Meet Standard	Doesn't meet Standard	meet Standard	Doesn't Meet Standard	Meet Standard	Doesn't Meet Standard
Roof and Gutter	416	9	91	42	58	42	58	90	10
Tank and Jar Storage Container	189	40	60	66	34	57	43	88	12
In-house	100	12	88	22	78	22	78	67	33

4. RESULT AND DISCUSSION

4.1 Evaluation of the Bacteriological Quality of Rainwater

Bacteriological quality of rainwater collected from various sampling points were compared to the WHO recommendations for drinking water quality (1971), as summarized in Table 2. The standard bacteriological parameters include :(a) total bacterial count not greater than 500 cells/ml, (b) MPN coliform not greater than 2.2 cells/100 ml, (c) MPN fecal coliform not to be present (0/100 ml), and (d) E.coli not to be present (0/100 ml).

The percentage of various samples exceeding these standards were 60-91 %, 34-78 %, 43-78 %, and 10-33 % for total coliform, fecal coliform, and E.coli, respectively. The highest percentage of contamination encountered in samples were from in-house storage containers followed by samples from roof and gutter systems and lastly, tank and jar storage containers. It could be concluded that the contamination at all sampling points was possible.

4.2 The Route of Bacteriological of Contamination

The water handling routes were classified into 2 types as follows.

Handling route 1 - Rainwater from roofs and gutters flows directly into a storage container which is the rainwater's last point of storage before consumption.

Handling route 2 - Rainwater passes through the same route as above, but then transferred from the storage container to the in-house storage container before it is consumed.

The result of bacteriological quality for both routes are shown in Figures 5 and 6. The result of Handling route 1 indicates that contamination originated from the roof and gutter systems and that settling or die off of bacteria reduces the level of contamination. Handling route 2 showed that rainwater was contaminated not only by dirty roof and gutter systems, but also by the method used to transport water from the storge tanks and jars to the in-house storage containers.

4.3 The Source of Bacteriological Contamination

The source of bacteriological contamination was evaluated using the ratio of fecal coliform to fecal streptococci (FC:FS). A FC:FS

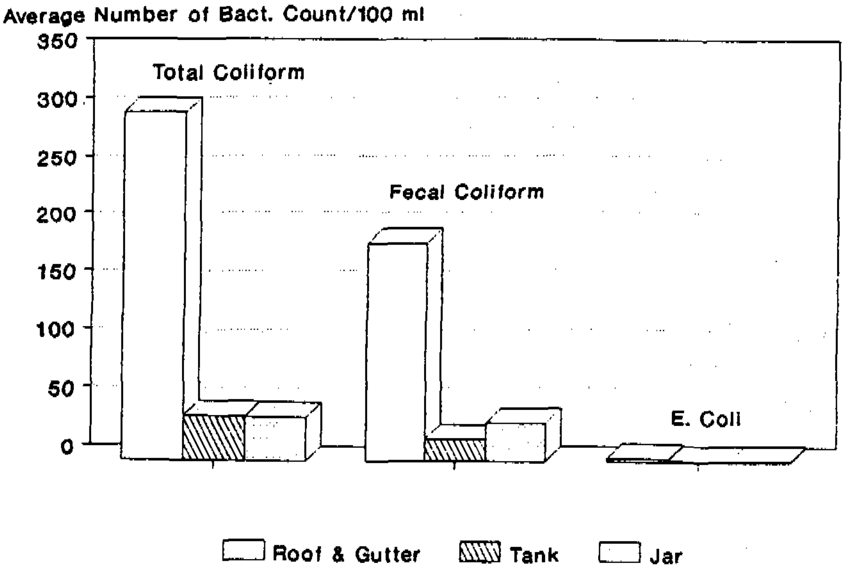

Figure 5. Quality of Rainwater from Handling Route 1 in Terms of the Average Numb of Specific Bacterialiological indicators.

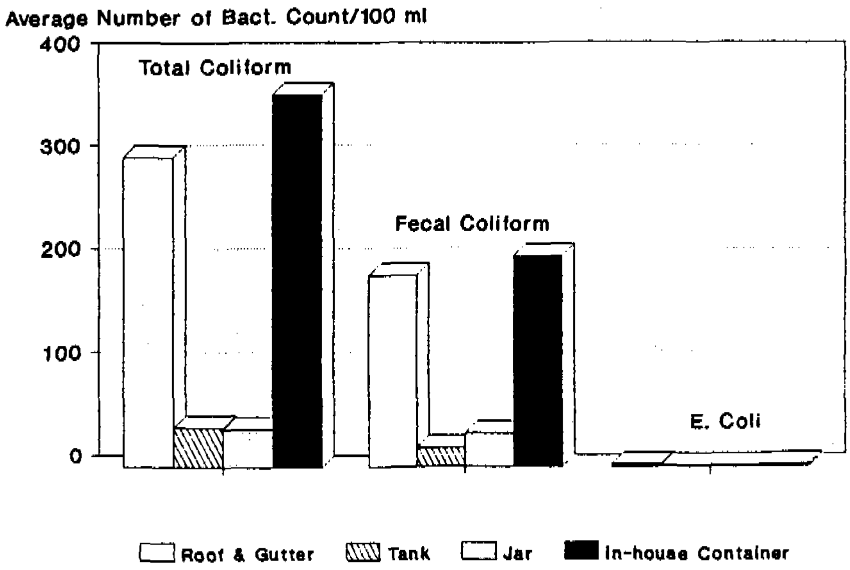

Figure 6. Quality of Rainwater from Handling Route 2 in Terms of the Average Numb of Specific Bacterialiological indicators.

ratio of greater than 2-4 indicate that the contamination was human rather than animal origin, while a ratio of less than 1 indicates the contamination was of animal origin. A ratio of 1-2 indicats that the contamination source originated from either human or animal origin.

The FC:FS ratios are summarized in Table 3. About 79 % of the samples collected from roof and gutter systems and 84 % of the samples collected from rainwater storage tanks and jars had FC:FS ratios of less than 1, indicating that the source of contamination were of animal rather than human origin. Approximately 39 % of the samples collected from the in-house storage containers had FC:FS ratios of less than 1 and 47 % had FC:FS ratios of greater than 4, indicating that the contamination was from both animal and human origins. It might be concluded that the human contamination occurred due to unhygienic water handling practices.

4.4 Pathogenic Contamination

Table 4 shows the results from the pathogenic isolation of rainwater. Pathogenic contmination was found in samples taken from roof and gutter systems, from storage tanks, and from in-house storage containers. No pathogens were isolated from storage jars. The isolated pathogens from these samples were salmonella gr E and C. Aromonas sp., Vibrio parahaemolyticus. These pathogens are known to cause diarrheal disease in humans. However, the pathogens were isolated in only about 0.6 % of the sample collected.

4.5 Heavy Metal Contamination of Rainwater

The heavy metals analysed in this study included Cd, Cr, Pb, Cu, Fe, Mn, and Zn. Most of the heavy metal concentrations did not exceed WHO standards for drinking water (1971) with the exception of Mn and Zn (Figure 7.) However, both Mn and Zn are considered to affect the aesthetic quality of water only and are not considered to be significant healthwise.

The results of Zn and Mn contamination are detailed in Table 5. There was a range of 9-20 % of the roof and gutter system samples which failed the WHO standards for Mn and 4-26 % of the samples failed for Zn. Only 2 % of the samples taken from the in-house

Table 3. Ratio of Fecal Coliform to Fecal Streptococci (FC:FS) from Various Sampling Points

Sampling Points	Number of Samples	Results in % of Samples FC : FS			
		>4	>2	1-2	<1
Roof and Gutter	405	8	4	9	79
Storage Container					
Tank	92	8	4	8	80
Jar	95	9	3	4	84
In-house Container	100	47	7	7	39

Table 4. Analysis of Pathogenic Contamination in Water Collected from Various Sampling Points

Sampling Points	Total Number of Samples	Number of Samples Contaminated by Pathogen (s)	% of Pathogenic Contamination	Name of pathogen
Roof and Cutter	395	1	0.2	*Salmonella group E*
Storage Gontainer				
Tank	89	2	2.2	*Aeromonas sp.,Salmonella group C*
Jar	97	0	0.0	
In-house Contanier	99	1	1.0	*Vibrio parahaemolyticus*

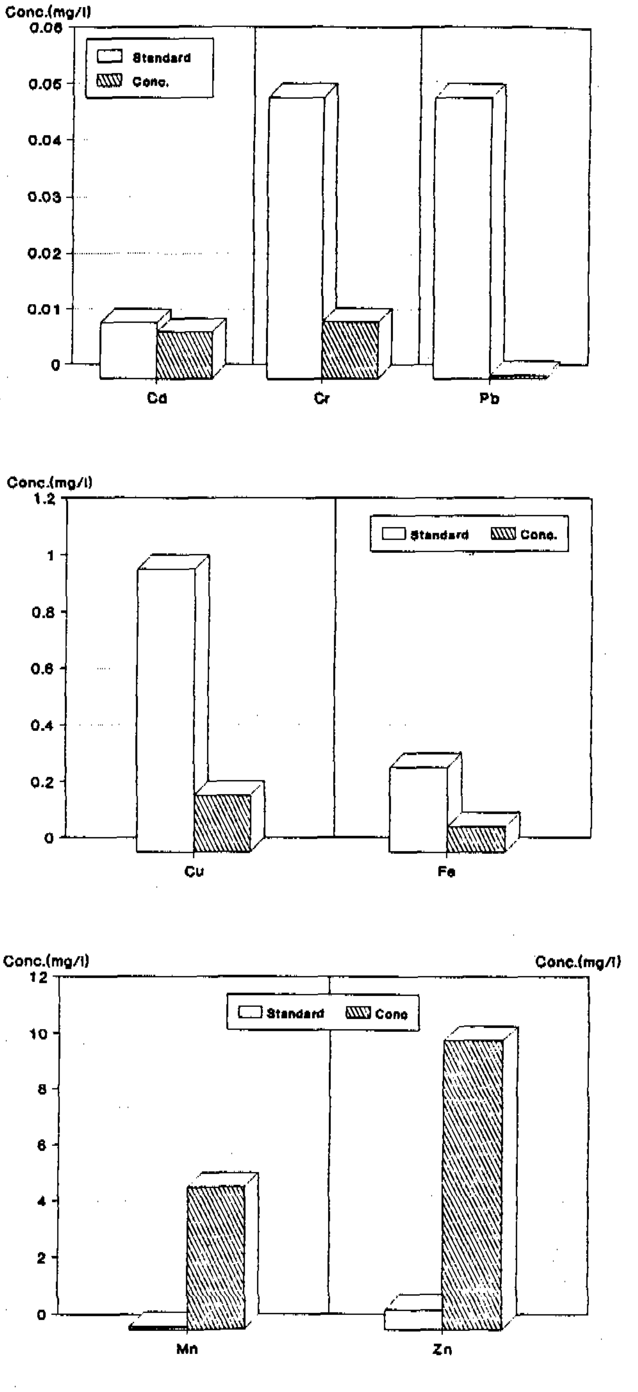

Figure 7. Heavy Metal Concentrations Compared with WHO Standards.

storage containers failed WHO standards for Mn. No samples taken from the storage tanks of jars exceeded the standards in any of the analysed parameters. This indicates that the initial route of contamination originated at the roof and gutter but recontamination also rook place at the site of the in-house storage container. However, it should be noted that roof and gutter systems were considered the major source of contamination. It was also found that the first rainfall samples had higher contamination levels of Mn and Zn than the preceeding rainfall samples, suggesting that Mn and Zn were leached initially from the galvanized iron roofing material and then washed into the storage containers. The lower concentration of heavy metals in the upper layers of stored rainwater may be due to the metals settling to the bottom of the storage containers via either adsorption (e.g. Zn) or precipitation (e.g. Mn)

In addition, pH may affect the dissolution of heavy metals. Table 6 shows the pH of the samples collected from the roof and gutter systems ranged from 6.35-7.80, the pH of the storage containers ranged from 9.1-9.2, and the pH of the in-house containers was 8.2. A high pH of stored rainwater may also cause the dissolved form of heavy metals to become insoluble and therefore, deplete the stored rainwater's heavy metal concentration.

4.6 Sanitary Practices

It was concluded that the sanitary practices played an important role in the bacterial contamination of stored rainwater. Not only did unhygienic practices during collection, storage, and transfer of rainwater affect the bacteriological contamination, but also the unsanitary surroundings of the household itself affected the bacteriological quality of the rainwater.

5. Conclusions

(1) Bacteriological contamination of stored rainwater was evident.
(2) A possible route of contamination was from both unclean collecting systems (roof and gutter) and unclean storage containers (tank and jar).
(3) The source of contamination was of animal origin.
(4) The heavy metals contamination of stored rainwater was found but the concentration of these heavy metals did not exceed

the WHO standard drinking water quality (1971), except Mn and Zn. These two heavy metals are not a significant health hazard.

(5) The findings from this study indicate that any health risks evolving from the consumption of stored rainwater would be due to the bacteriological contamination rather than heavy metal contamination.

(6) Rainwater contamination was also caused by poor sanitary practices of the vilagers in rainwater collection, handling and usage, toilet practices, solid waste disposal, and unsanitary conditions of the household.

(7) Rainwater is potentially the safest and the most economical source of drinking water in Northeast Thailand with improvements to hygienic collection procedure, storage and sanitary practices.

Table 5. Analytical Results of Heavy Metal Concentration

Sampling Points	Total Number of Samples	Results in % of Total Number of Samples			
		Mn		Zn	
		Meet Standard	Doesn't Meet Standard	Meet Standard	Doesn't Meet Standard
Roof and Gutter					
-Bottom	93	98	20	74.20	26
-Middle	125	91	9	94	6
-Top	100	91	9	96	4
Storage Container					
-Tank	86	100	0	100	0
-Jar	96	100	0	100	0
In-house Container	90	98	2	100	0

Table 6. pH of Rainwater Collected from Various Sampling Points

Sampling Points	pH
Roof and Gutter	
-Bottom	7.80
-Middle	7.55
-Top	7.65
Storage Container	
-Tank	9.10
-Jar	9.20
In-house Container	8.20

ACKNOWLEDGEMENTS

The paper is based on the final report "Evaluation of Rainwater Quality: Heavy Metals and Pathogens", submitted to the International Development Research Centre (IDRC). The authors would like to acknowledge IDRC for providing the financial support to make this study possible.

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QUALITE DES EAUX DES CITERNES DE CAPTAGE D'EAU DE PLUIE AU SAHEL

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RESUME

Malgré plusieurs siècles d'existence, le système de captage des eaux de pluie par le toit rencontre plusieurs difficultés dans les pays en développement et les pays sahéliens en particulier. Parmi ces obstacles, nous pouvons citer l'incertitude des populations quant à la possibilité de conserver l'eau potable pendant longtemps.

Pour promouvoir cette technologie, le CREPA et le CIEH sont entrain de tester ce système à Ouagadougou. Au point de vue physico-chimique, les citernes conservent très bien la qualité des eaux. Après neuf mois de conservation, les paramètres physico-chimiques respectent les normes de potabilité. Concernant la bactériologie, des contaminations intermittentes ont été constatées. Seulement, en raison de l'absence de matière organique à l'intérieur des citernes, les micro-organismes ne survivent pas.

ABSTRACT

Despite its existence for several centuries, the development of rainwater roof catchment system faces great difficulties in African countries, particularly in the Sahel. Obstacles for its expansion include the scepticism and uncertainty of local populations concerning the safety of rainwater when stored for long time.

In order to promote this technology in African countries, CREPA and CIEH have established a program for construction of rainwater cistern systems throughout Ouagadougou in Burkina Faso. Also, CREPA has extended this program to include all other countries which are members of the Centre through demonstration projects. At the samr time, CREPA examines regularly the water quality during conservation. According to WHO standards, rainwater stored is drinkable. Sometime , pollution due to animals is noticed. But, the lack of organic matters in stored rainwater precludes the growth of micro-organisms

In conclusion, when well constructed, the rainwater cistern system can be an alternate source of water supply.

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INTRODUCTION

L'alimentation en eaux des collectivités urbaines et rurales constitue un des programmes prioritaires retenus par les gouvernements des pays en voie de développement en général et des pays sahéliens en particulier. Pour nombre de ces pays, le problème se pose en terme de qualité et de quantité.

Le lancement de la décennie 1981-1990, malgré des résultats tangibles, n'a pas comblé tous les espoirs. En zone urbaine, le taux de desserte reste en deçà du minimum requis, alors que plusieurs agglomérations périurbaines et rurales sont pratiquement démunies. En effet, une étude de l'OMS, portant sur 71 pays en voie de développement, montre que 78 % de la population rurale n'a pas de facilité d'accès à l'eau potable en 1975 (1). Dans ces régions, différents types de technologies, parmi lesquelles les forages, les puits à grand diamètre et l'alimentation en eau par gravité, ont été adoptés.

L'impluvium est une des solutions alternatives pour la résolution de ces problèmes d'approvisionnement en eau. C'est un système de captage des eaux de pluie par le toit pour satisfaire les besoins essentiels pendant la saison sèche. C'est une technologie dont l'utilisation remonte à des milliers d'années mais qui demeure peu connue.

La vulgarisation des impluviums se heurte, entre autres obstacles, au scepticisme des populations qui se traduit par la question suivante : "est-ce que l'eau ne se détériore pas suite à une longue conservation?" Autrement dit, ce système de stockage permet-il de conserver la qualité de l'eau pendant une longue durée? C'est le voile que le Centre Régional pour l'Eau Potable et l'Assainissement à faible coût (CREPA) et le Comité Interafricain d'Etudes Hydrauliques (CIEH) tentent de lever en suivant régulièrement la qualité de l'eau de pluie emmagasinée dans quatre citernes construites en zone rurale à la périphérie de Ouagadougou au Burkina Faso.

PRESENTATION DU SITE

Le site expérimental est l'école primaire de Roumtenga, village périphérique à 15 Km de Ouagadougou. La pluviométrie moyenne de la région est de 800 mm/an. La période pluvieuse s'étend de juillet à septembre, soit trois mois sur douze. Cette période coincide avec les vacances scolaires. La source d'eau la plus proche de l'école est un forage, située à environ 400 m. Quelques analyses bactériologiques effectuées sur l'eau du forage ont mis en évidence la présence de coliformes totaux et fécaux.

L'école compte trois classes pour un effectif de 112 élèves en 1989/1991. La superficie totale de la toiture du bâtiment est de 214 m^2. La quantité d'eau de pluie stockable à partir de ce toit a été estimée à 139 m^3. Les besoins ont été évalués à 63 m^3. Ainsi quatre citernes en ferrociment de type thaïlandais ont été construites.

Les caractéristiques des citernes sont les suivantes:

volume	16	m^3
hauteur	2.0	m
diamètre	3.2	m

La figure 1 schématise le dispositif expérimental.

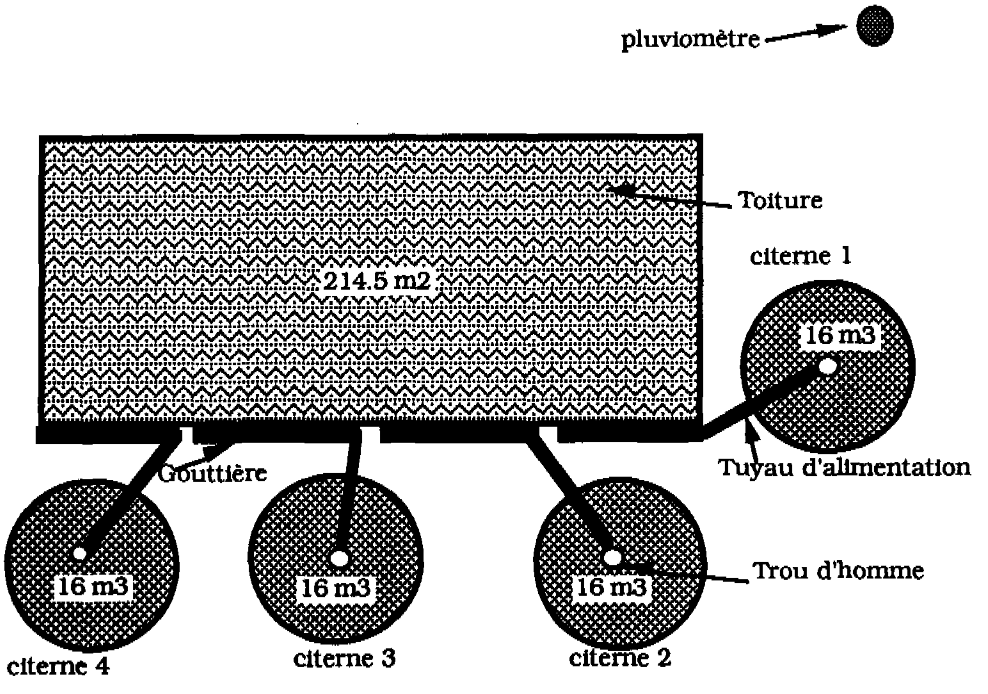

Figure 1: Schéma du dispositif expérimental

Chaque citerne est reliée à une gouttière occupant le quart de la longueur de la toiture par un tuyau en PVC de 100 mm de diamètre. Les premières eaux de rinçage de la toiture sont déviées grâce à un té placé sur le tuyau. L'extrémité du té est obturée lorsque le toit est bien nettoyé, ce qui permet ainsi une alimentation de la citerne. Un trou d'homme est aménagé au sommet de la toiture de la citerne pour accéder à l'intérieur du réservoir en vue d'un entretien éventuel. Un trop-plein assure l'évacuation du surplus d'eau. En effet, compte tenu de la pluviométrie, le volume stockable dépasse la capacité des citernes. La prise d'eau s'effectue par le biais d'un tuyau calé à environ 15 cm du fond de la cuve. Un second tuyau permet la vidange et le curage. Pour assainir les alentours, un puits perdu est aménagé à côté de chaque citerne.

A quelques mètres des citernes, un pluviographe à lecture directe est installé pour déterminer la pluviométrie.

METHODOLOGIE EXPERIMENTALE

Au cours de la saison pluvieuse, des échantillons d'eau sont prélevés directement du pluviomètre installé sur le site ou à partir d'un dispositif permettant de recueillir l'eau de pluie. Les paramètres suivants sont ensuite déterminés:

- pH;
- conductivité,
- dureté;
- les ions calcium et magnésium;
- l'alcalinité;
- Mn_2^+, NO_3^- ,NO_2^-, fer total, K^+, Na,$^+$, Cl^-

Cette démarche permet d'avoir une idée de la qualité de l'eau de pluie avant son stockage dans les citernes.

En raison de l'insuffisance des quantités d'eau accumulées en septembre 1989, des transvasements ont été opérés de manière à avoir de l'eau de pluie pendant toute la saison sèche qui dure 9 mois. Les citernes vidées ont été ensuite remplies avec de l'eau du réseau d'adduction de la ville de Ouagadougou. Finalement seule les citernes 1 et 3 contenaient de l'eau pluviale.

Durant la première année (1989/1990), des échantillons sont prélevés des citernes au rythme d'une fois par semaine pour des analyses physico-chimiques et bactériologiques. Du 31-10-89 au 8 -2-89, les paramètres mesurés sont:

- pH;
- conductivité;
- coliformes totaux et fécaux;
- streptocoques.

Ces paramètres ont été ensuite complétés par l'alcalinité, la demande en oxygène par l'oxydabilité au permanganate de potassium, les ions sodium, potassium, nitrites, nitrates, fer total.

Le tableau 1 résume les opérations effectuées sur les quatres citernes pendant la première année.

Les renseignements les plus significatifs sur le comportement à long terme de l'eau stockée au cours de cette première campagne sont obtenus avec la citerne 3 dont le contenu a duré 162 jours sans subir de mélange.

Au cours de la seconde année 1990/1991, la fréquence des prélèvements est réduite à 2 par mois. Les analyses sont limitées au pH, à la conductivité, dureté, calcium, magnésium, coliformes totaux et fécaux, streptocoques fécaux. Au bout de neuf mois une analyse plus complète est effectuée avec détermination des ions chlorures, sodium, potassium, magnésium et certains métaux lourds dont le zinc, le cuivre, l'argent, le fer total.

citerne N°	Date	Durée (j)	Source	Paramètres mesurés
1	jusqu'au 16-02-90	109	eau de pluie initiale	I
	28-02-90 11-05-90	73	citerne 3 (eau de pluie)	II
2	jusqu'au 01-12-89	31	eau de pluie	I
	11-12-89 16-02-90	67	réseau d'adduction d'eau (premier remplissage)	II
	28-02-90 11-05-90	73	réseau d'adduction d'eau (deuxième remplissage)	II
3	05-12-89 11-05-90	162	eau de pluie des citernes 2 et 4	II
4	31-10-89 01-12-89	93	eau de pluie	I
	11-12-89 08-02-90	59	réseau d'adduction d'eau (premier remplissage)	II
	28-02-90 11-05-90	73	réseau d'adduction d'eau (deuxième remplissage)	II

I : température, pH, conductivité, coliformes fécaux et totaux, et streptocoques fécaux.
II : paramètres I plus alcalinité, dureté, oxydabilité, ions calcium et magnésium.

Tableau 1 : Opérations effectuées sur les quatres citernes au cours de la première campagne 1989-1990

RESULTATS ET DISCUSSIONS

Le tableau 2 présente les résultats moyens des paramètres physico-chimiques caractérisant l'eau de pluie.

Paramètre	valeur	Paramètre	valeur
pH	6.8	conductivité (µs/cm)	12.5
Calcium (mg/l)	0.8	Magnésium (mg/l)	0.4
Dureté (°F)	0.4	Titre alcalimétrique (°F)	0
Titre alcali. complet (°F)	2.4	Manganèse (mg/l) *	0
Nitrates (mg/l) *	0	Nitrite (mg/l) *	0
Fer total (mg/l) *	0	Potassium (mg/l) *	0
Sodium (mg/l) *	0	Chlorures (mg/l) *	0

* une seule mesure

Tableau 2: Résultats d'analyse de l'eau de pluie

Il ressort du tableau 2 que les eaux de pluie sont très faiblement minéralisées. En effet, la conductivité électrique est très basse.

Le pH est proche de la neutralité avec une valeur moyenne de 6.8. Les valeurs extrêmes sont 6.5 et 7.1.

Le tableau 3 résume les valeurs moyennes des paramètres physico-chimiques des eaux stockées dans les citernes au cours de la première année.

Paramètre	Citerne 1	Citerne 2	Citerne 3	Citerne 4
Conductivité (µs/cm)	283	171	208	150
pH	9.2	8.9	9.1	8.3
Titre alcali. complet(°F)	13.3	4.8	9.4	5.2
Dureté (°F)	3.6	4.9	2.3	5.2
Calcium (mg/l)	13.1	17.3	8.4	17.5
Magnésium (mg/l)	0.4	1.3	0.6	1.8
Oxydabilité (mg O2/l)	0.9	1.4	0.8	1.5
Nitrites (mg/l)	0	0	0	0
Nitrates (mg/l)	0	0	0	0
Sodium (mg/l)	31.1	3	13.4	4.6
Potassium (mg/l)	47.2	12.2	37.2	11
Fer total (mg/l)	0	0	0	0
Chlorures (mg/l)	11.9	7.8	8	10

Tableau 3: Caractéristiques des eaux de pluie stockées pendant la première année (valeurs moyennes)

En comparant les tableaux 2 et 3, nous remarquons qu'il s'est opéré une modification de la qualité de l'eau de pluie par le système de collecte et de stockage. La conductivité a considérablement augmenté dans la citerne, ce qui traduit une augmentation de la minéralisation des eaux stockées. Cette minéralisation pourrait provenir de l'intrusion de poussières dans les citernes à travers les orifices des ouvrages (tuyaux d'alimentation, trop-plein) et/ou l'attaque des parois cimentées des citernes. Cette dernière hypothèse paraît plus vraisemblable en ce sens qu'en nous référant au diagramme d'Hallopeau-Dubin, nous constatons que l'eau de pluie est agressive donc susceptible d'attaquer les parois des citernes. Par conséquent, le pH se trouve également influencé et passe de 6.8 à plus de 9 pour les eaux de pluie (citernes 1 et 3) et 8 pour les eaux du réseau d'adduction (citernes 2 et 4). Les matières azotées sont inexistantes dans les eaux. La teneur en matières organiques, exprimée en milligramme d'oxygène par litre et déterminée à partir de l'oxydabilité au permanganate de potassium est négligeable.

Les eaux du réseau d'adduction sont de qualité comparable à celle des eaux directement captées dans les citernes. Ceci s'explique par le fait que l'alimentation de la ville s'effectue à partir de barrages de retenues d'eau de pluie.

Le tableau 4 ci-après donne une idée de la qualité des eaux stockées dans les citernes 2, 3 et 4 au bout de 9 mois de stockage (2 ème année de suivi: juillet 90 à mars 91)

Paramètre	Citerne 2	Citerne 3	Citerne 4
pH	10.3	9.3	8.4
Conductivité (°s/cm)	102	113	142
Titre alcali. complet (°F)	3.5	5.4	6.1
Dureté (°F)	2.04	3.21	3.88
Calcium (mg/l)	5.12	10	11.2
Magnésium (mg/l)	1.8	1.7	2.6
Fer total (mg/l)	0.04	0.05	0.02
Zinc (mg/l)	0.04	0.01	0.02
Cuivre (mg/l)	0.09	0.16	0.08
Argent (mg/l)	0	0	0
Manganèse (mg/l)	0	0	0
Potassium (mg/l)	4.2	3.9	2.8
Sodium (mg/l)	0.7	2.9	1.8
Chlorures (mg/l)	1.2	2.3	1.7

Tableau 4 : Caractéristiques des eaux le 15 mars 1991 (neuf mois de stockage)

Pendant la deuxième année, la conductivité est plus faible comparée à l'année antérieure. Le pH reste encore élevé dans l'ensemble des citernes. Les paramètres mesurés lors de la première année sont relativement identiques à ceux obtenus au cours de la deuxième année. Les métaux lourds sont quasi inexistants dans les eaux.

Globalement, les normes OMS (2) vis à vis des paramètres physico-chimiques sont respectées. Dans les citernes 2 et 3, le pH dépasse légèrement la valeur 8.5, considérée comme limite . Seulement, en l'absence d'un réseau d'adduction d'eau, il est possible de dépasser cette valeur (2).

L'évolution des paramètres au cours du temps est représentée par les figures 2 à 7.

Le pH est assez constant. En revanche, les autres paramètres croissent dans le temps. La turbidité diminue progressivement pour prendre enfin une valeur nulle. Cette tendance peut être expliquée par le phénomène de décantation progressive des particules fines avec le temps.

Concernant la qualité bactériologique, des contaminations intermittentes essentiellement dues aux streptocoques sont constatées. Ces contaminations seraient vraisemblablement d'origine animale. Cette pollution accède dans les citernes à travers les tuyaux d'alimentation, les trop-pleins, et éventuellement les trous d'homme. En dépit de l'autoépuration qui se produit, suite à l'absence de matière organique, des mesures complémentaires sont nécessaires pour empêcher la récurrence de la pollution des citernes. En attendant l'expérimentation de ces mesures, la désinfection au chlore est utilisée.

CONCLUSION

Les impluviums, bien conçus et mis en œuvre, peuvent constituer une solution alternative à l'alimentation en eau des zones déshéritées. En effet, nous avons pu constater qu'après neuf mois de conservation, les eaux restent, du point de vue physico-chimique, potables. Concernant la bactériologie, des contaminations intermittentes d'origines animales sont remarquées. Ce dernier constat oblige à envisager des systèmes de déviation des premières eaux de rinçage des toitures efficaces ainsi que des méthodes de protection des citernes contre les poussières susceptibles d'introduire des matières organiques qui favoriseraient la survie des micro-organismes. La pauvreté des eaux de pluie en sels minéraux peut être compensée par les autres aliments. Du point de vue de cette minéralisation totale, rappelons que les eaux stockées sont tout à fait comparables à l'eau servant à l'approvisionnement de la ville de Ouagadougou.

Le doute quant à la bonne qualité de l'eau étant pratiquement levé, il demeure que le coût des installations est encore élevé pour une bonne vulgarisation de cette technologie. Le CREPA s'attèle présentement à l'étude pour la baisse des coûts d'investissement en testant des matériaux locaux comme les mœllons et les parpaings à la place du ferrociment. Des citernes de 20 m^3 ont été déjà mises en place avec ces matériaux locaux et les résultats sont encourageants. Des pilotes de démonstration sont également prévus dans les 13 pays membres dans le cadre de la promotion de ces technologies.

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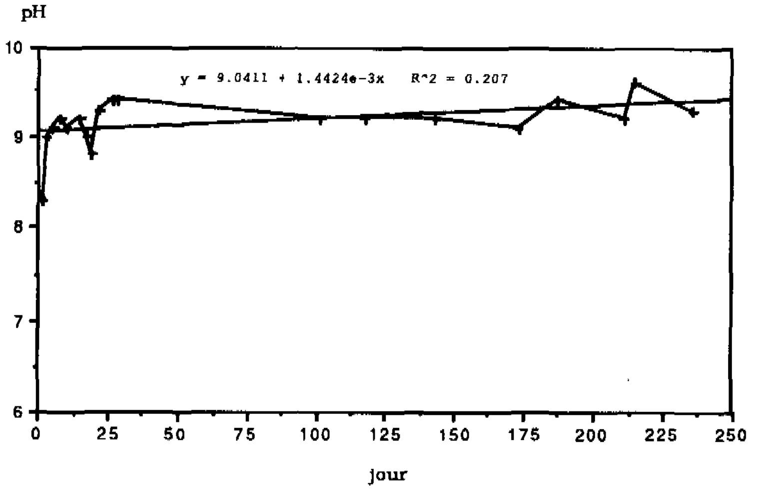

Figure 2: Evolution du pH dans la citerne 3.

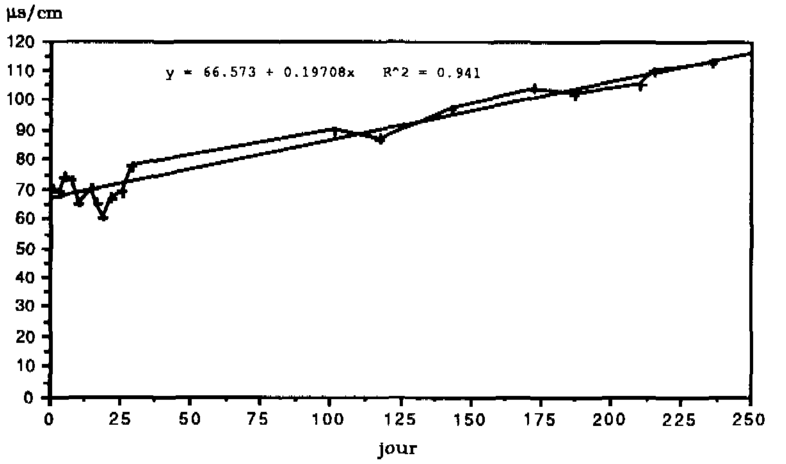

Figure 3: Evolution de la conductivité dans la citerne 3.

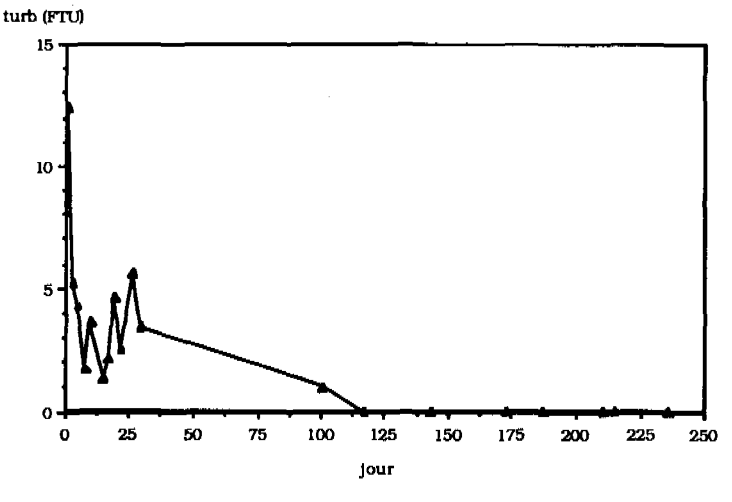

Figure 4: Evolution de la turbidité dans la citerne 3.

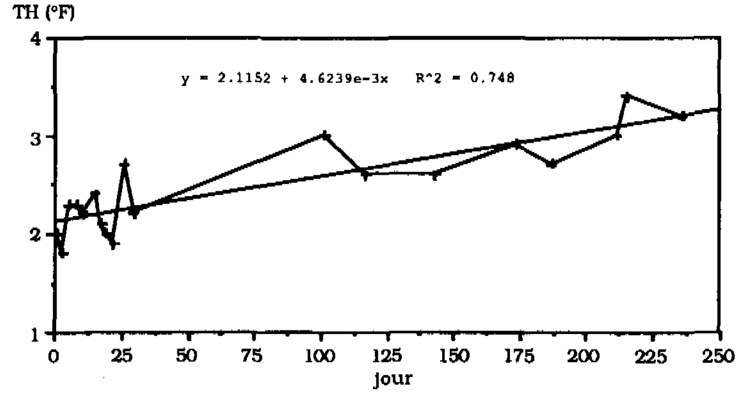

Figure 5: Evolution de la dureté dans la citerne 3.

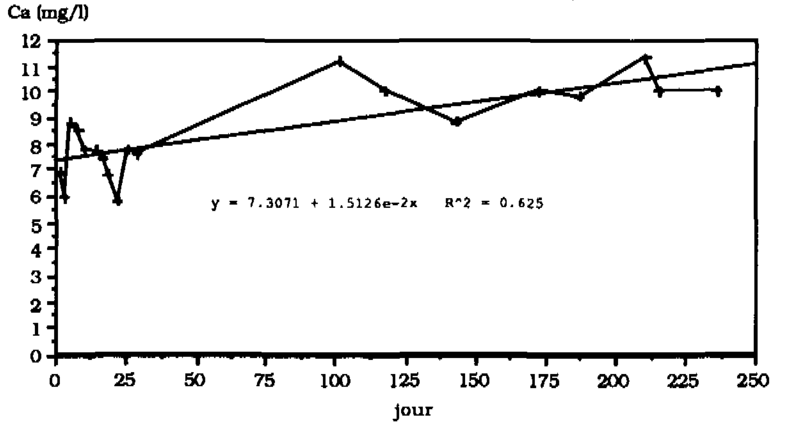

Figure 6: Evolution de la teneur en calcium dans la citerne 3.

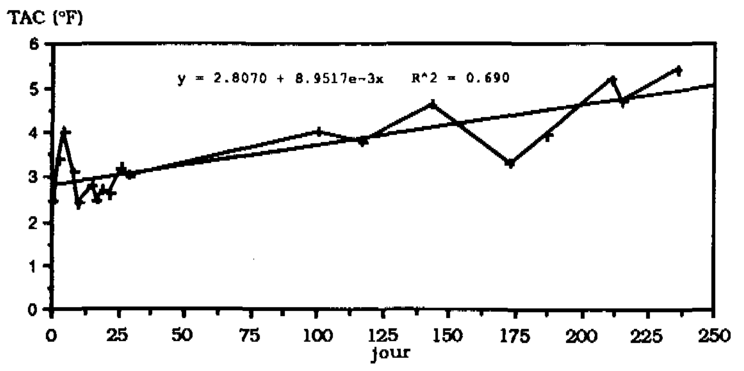

Figure 7: Evolution de l'alcalinité dans la citerne 3.

Microbial Levels in Cistern Systems: Acceptable or Unacceptable

Dennis J. Lye*

Abstract

The acceptance of cistern systems as a source of potable water and as a possible source for non-domestic use is dependent upon the quality maintained within the entire system. Microbial levels measured within a cistern system are reliable indicators of water quality and of deteriorations that may give rise to offensive odors and tastes. The number of microorganisms commonly found within most contemporary cistern systems is usually lower than surrounding surface waters but these microbial levels may still be unacceptable for many alternative uses. Our laboratory is studying the bacterial populations growing and residing within cistern systems. During periods of rainfall collection and heavy usage, the microbial populations of single-chamber cistern systems do not decrease significantly during subsequent storage (self-purify). The storage of rain water in cistern systems may actually be conducive to the growth of certain bacterial strains in numbers beyond those found in natural water sources. Our studies have shown that certain types of maintenance of individual, single-chamber catchment systems may actually increase the levels of certain microbial strains when compared to similar systems receiving no treatment at all. More work is required to identify those parameters necessary for the proper storage and maintenance of high quality cistern water.

Introduction

Very little information is known about the chemical and biological content of cistern water when collected under various conditions and from a variety of catchment areas (Ingham and Kleine 1982, Jenkins and Kleine 1978, Kincaid 1979, Lye 1987). There have been relatively few reports about the microbiological quality of

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cistern water because most systems are exempt from the mandates of drinking water legislation. Although cistern systems have been reported to be poorly maintained, no epidemiological studies have been documented for users of cistern water. There are no detailed studies to show the relationship between numbers of any microorganisms and the incidence of disease or minimum infective dose.

Rain water catchments were intentionally not included in the definitions of surface water or ground water in the United States. However, draft regulations now under development will define the criteria necessary for assuring water derived from rain water catchment areas is of acceptable water quality (i.e. "safe" from protozoa, viruses, and bacteria). The ultimate use of the cistern water (domestic or non-domestic) will dictate the levels of water quality needed. Without some type of disinfection procedure, cistern systems will probably never deliver water with low microbial counts (Ruskin, Lye, and Krishna 1990).

Ruskin and Callendar (1988) have reported that water stored in cistern systems does not "self-purify" like many natural surface waters. They also reported that chlorination is effective in controlling bacterial populations for only 3 to 5 days before regrowth occurs. Because cistern water samples give consistently high levels of bacteria, the bacterial isolates probably reflect those strains that are capable of growing within the cistern system. Information about the levels and diversity of bacteria commonly encountered in unchlorinated, individual, single-chamber storage water systems would be useful to users of these types of water especially since they often routinely assume their water is of higher quality then alternate sources.

Investigators have attempted to speciate bacteria isolated from various types of potable water. Those laboratories working with cistern systems have found a great variety of microorganisms present in their cistern surveys. This report concerns some of the bacterial populations we have found and preliminary comparisons with bacteria from other better studied water distribution systems.

Material and methods for the procedures used is this report have been reported elsewhere in detail (Lye 1987, Lye and Dufour 1991a).

There are many good reviews of the various microbiological problems which may be associated with raw waters (Dutka and Kwan 1980, Evison 1979). There are very few detailed epidemiological studies showing relationships between the levels of opportunistic, pathogenic microorganisms and the incidence of disease they may cause.

The application of indicator microorganisms for assessing the microbial quality of surface water is limited by the scarcity of information concerning relationships between the levels of indicator and bacterial pathogens naturally occurring in the environment (Olivieri, Kawata, and Kruse 1978). There is a need to develop procedures which assay the aquatic system's ability to support and maintain particular bacterial populations rather than having to rely on the presence of a particular bacterial group or species.

Regrowth of total coliforms has occured following disinfection. There is some evidence that many microorganisms do not settle out upon impoundment of water. If disinfected with chlorine or ozone, bacterial populations decrease rapidly in thirty minutes followed by increases to original levels after four to eight days. Settling and die-off patterns of bacteria in impounded water (with relatively short detention times) suggests that the equivalent of stilling basins should be combined with disinfection procedures (Davis 1979).

Table One shows the total heterotrophic bacterial levels found in some selected cistern water systems and a possible relationship to maintenance of these systems. Twelve of the cistern systems did not receive any type of maintenance (including diverter usage, cleaning of storage chamber, and chemical disinfection) for at least one year prior to sampling. These systems contained almost a ten-fold lower concentration of bacteria in the water supply.

Table One. Microbial Levels of Cistern Systems Surveyed in Northern Kentucky, USA.

No. of Cisterns	Type of Maintenance	Storage Chamber Total Heterotrophic Levels
12	no diverter usage no cleaning no disinfection	3.0×10^4 CFU/ml
17	at least one of the above three types of maintenance	1.5×10^5 CFU/ml

The age of the cistern did not influence the levels of heterotrophs found. Rainfall in the area averages about 300 heterotrophic bacteria per ml.

Future regulations concerning cistern systems will have to take into account the different classes of water quality needed for certain applications. Current cistern systems are often under very heavy demand for water quantity as well as quality. There have been numerous instances where researchers have easily isolated any type of bacteria that they looked for (including potential pathogens). A specific example would involve the presence of Legionella in cistern systems. Past outbreaks of Pontiac Fever thought to involve cistern water (Schlech et al. 1985). have increased the concern for the quality of this type of potable water and its uses where aerosols are generated.

Table Two shows the results of a very simple, preliminary servey where five different cistern systems where sampled for the presence of Legionella-like microorganisms. Legionella-like isolates were found in three (60%) of the how water faucet samples where the temperatures of the hot water heaters were consistently maintained

Table Two. Occurence of Legionella-like Isolates within Cistern Systems.

	Cistern Systems Sampled									
	1		2		3		4		5	
	hot	cold	hot	cold	hot	cold	hot	cold	hot	cold
Water temp. (°C)	52	21	63	22	52	22	52	21	63	21
Total CFU/ml	$2X10^3$	$1X10^6$	$2X10^3$	$8x10^2$	$2X10^3$	$1X10^2$	$1X10^5$	$6X10^3$	$1X10^2$	$5X10^5$
Total Coliforms present	2	3	0	0	13	36	0	300	0	0
CFU on BCYE medium	190	34	0	15	225	7	18	25	0	0
Possible Isolates of Legionella	YES	NO	NO	NO	YES	YES	YES	NO	NO	NO

All counts are CFU per ml.

at 52°C. Legionella-like isolates were not found in the two (40%) hot water systems maintained at 63°C. When the 52°C systems were subsequently raised to 63°C, no Legionella-like isolates were found upon sampling two weeks later.

The characterization of extracellular activities present in different types of water systems would allow more accurate comparisons of the biological quality of the water within different systems (Lye 1989, Lye and Dufour 1991b). Table three shows the percentage of isolates exhibiting cytolysis, hemolysis, and/or proteolysis from untreated surface water, treated distribution water, and cistern water from the Northern Kentucky region of USA. The bacterial isolates from cistern water systems expressed the highest percentage of hemolytic and cytotoxic activities. The number of cytotoxic isolates from cistern water was more than twice the number found in surrounding surface water and was five times those found in treated distribution water.

Preliminary studies (data not shown) have suggested that microbial water quality can be influenced by rather simple designs of cistern systems. For example, the use of multiple-chamber storage systems instead of single-chamber systems may increase water quality. The type of maintenance and disinfection procedures currently used require additional study.

Table Three. Percentage of Isolates from Potable Systems that Exhibited Putative Virulence Factors.

Total (%)	# Gelatinase positive	# Hemolysis positive	#Cytotoxic positive
Surface Water			
4884 (100)	3663 (75)	879 (18)	98 (2)
Treated Water			
4738 (100)	459 (10)	2071 (44)	58 (1)
Cistern Water			
1557 (100)	488 (31)	725 (47)	84 (5)

Stricter regulation of rain water storage systems will probably be upon us in the near future. Traditional usage of cistern systems may have been overlooked in the past, but increasing water demand is putting pressure upon the alternative uses of this type of water.

Because of the difficulty in monitoring for particular micro-organisms, cistern water quality should place greater emphasis on improved design and treatment of cistern systems. Since local conditions vary greatly, several different methods or designs will probably be useful for attaining goals concerning removal or inactivation of hazardous microorganisms commonly found in rain water catchment systems.

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PROPOSAL FOR DISSEMINATING FERROCEMENT RAINWATER TANK TECHNOLOGY IN THE PROVINCE OF CAPIZ THE PHILIPPINES

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ABSTRACT

Ferrocement has been used as the sole building material in the construction of 30 rainwater cisterns which constitute the pilot project for introducing rainwater catchment systems in the Province of Capiz. These tanks which were built in three localized areas have been successfully tested for their structural stability and their use has been found to be socially acceptable. The main objectives of the current proposal are to disseminate the acquired ferrocement technology to communities throughout Capiz and to extend the number of tanks by a further 540. Selected members of the target communities will be trained and communication materials will be designed, tested and produced to support the dissemination activities. A revolving fund will provide loans to families who want to build tanks but do not have the resources to purchase the construction material required. Health education and communication organization elements will also be built into the project activities to ensure that the ferrocement tanks will have the desired impact in improving the health of the communities and that the technology is fully adopted through a participatory approach by members of various communities.

INTRODUCTION

Capiz is one of the four provinces in the Island of Panay and lies to the south Manila. It has a land area of 2633 square kilometres and has a population of 490,000. The province does not have a large centralized water supply system that can provide potable water to rural households because of the high capital costs involved in implementing such a system. Villagers are therefore faced with the

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perennial problem of inadequate and, very often, unsafe water supply that has resulted in a high incidence of water-borne of related diseases (Integrated Provincial Office, 1987). The problem is aggravated by unfavourable conditions such as low groundwater table and, when available, brackish water. In the past, most villages have obtained their water from inefficiently designed and constructed rainwater collection systems, open dug wells, shallow wells, springs and other untreated surface water sources. Seeing the urgent need for increasing the availability of safe drinking water in Capiz, in 1986 the Provincial government approached the International Development Research Centre (IDRC), Canada for assistance following which a pilot-scale project involving the establishment of 30 Rain Water Cistern systems was approved. The planning, design and construction aspects of the pilot project in Capiz have been described elsewhere (Appan et al, 1989). The methodology for propagating such a technology by harnessing communal participation has also been highlighted (Salas, 1989). After the completion of the pilot-scale project in 1986, in line with the 'total approach' concept (Appan et al 1987) that was pursued, a large-scale project is to follow. In this project, the acquired knowledge and experience in both Ferrocement technology and community participation is to be utilised. The current project is a manifestation of this idea. The IDRC and the Canadian International Development Agency (CIDA) have jointly undertaken to fund this project in which 540 ferrocement tanks are to be built.

OBJECTIVES

The overall objective of the proposal is to promote the use of Ferrocement Rainwater Catchment system (FRCS) throughout Capiz Province so as to bring about an adequate supply of potable water for the people of Capiz.

The specific objective of the project include:

(a) the training of trainers for FRCS technology;
(b) the training of villagers as technicians;
(c) the setting up of a Revolving Fund to help tank recipients buy materials for the building of tanks;
(d) the building of 540 tanks.

The long-term objective is to develop the Capiz Development Corporation Inc (CDCI), a Non-Government Organization (NGO) that is the executive arm of the project, into a national and regional centre for the dissemination of FRCS technology.

CHOICE OF FERROCEMENT AND ITS INTRODUCTION IN CAPIZ

While the adaptation and concept of rainwater catchment is far from being a new idea, one of the main reasons for not utilising such systems of abstraction in a large scale, particularly in developing countries, has been the high cost of previously recommended construction materials such as reinforced concrete for building water storage tanks. However the recent upsurge in the use of ferrocement, a cheaper and durable material, appears to have largely overcome this problem.

some of the major reasons for adopting ferrocement as the construction material in rural areas are:

(a) it is cheaper than reinforced concrete;
(b) most of the necessary components (except cement) are readily available;
(c) the construction methodology can be acquired with not much of formal training;
(d) minimum formwork for construction is required;
(e) the tanks can be easily fabricated in various sizes and shapes;
(f) the tanks are durable, have high resistance to impact and are impermeable, only minimum maintenance is required for the constructed tanks ,and repairing of tanks is relatively easy.

To ensure that the technology is understood before adapting it, two sanitary engineers were sent to the National University of Singapore and to Dian Desa (an Indonesian NGO group with a proven track record) for training in the design and construction of ferrocement tanks. This operation was the preliminary aspect of the IDRC approved and funded pilot project for the implementation of 30 ferrocement tanks in Capiz. After their return, these two engineers became trainers of 15 other engineers and technicians. In turn, this core group trained villagers from the three pilot villages for constructing the ferrocement tanks.

IMPLEMENTATION TECHNOLOGY

The systematic approach proposed has taken into consideration the various envisaged components of the proposal. The major factors taken into consideration are:

(a) The project team and their functions.

A properly trained and adequately staffed project team is needed to establish the pool of 540 FRCS trainers/technicians and to design and operate the Revolving Fund. Existing staff will be provided with training to upgrade their organizational and management skills. New staff will have to be recruited to provide the necessary support and expertise for the successful implementation of this project.

The Project Team will comprise the following units:

MANAGEMENT

Project Director
Project Manager

ADMINISTRATION/FINANCE ENGINEERING EXTENSION

Project Administrator
Project Engineer
Project Extensionalist
Finance office
Engineers (3)
Assistant Project Extensionalist
Book Keeper
Workshop Engineer
Provincial Health Officer
Loan Officers (2)
FRCS specialists (3)
Communicators (2)
Clerk/Typists (2)
Research Assistant
Community Organizer (2)
Driver-mechanics (2)

The Project Manager will assist the Project Director in the overall day-to-day management and coordination of activities.

The Project Administrator will be responsible for the administrative and financial affairs of the project, including the management of the revolving fund. The Project Engineer will be responsible for the technical aspects and act as the subject matter specialist at training courses. He will also be responsible for supervising the construction and monitoring of the tanks. The Project Extensionalist will be responsible for the design of training of 54 trainees and 486 technicians. In addition to these duties, he will act as the specialist on community participatory process and health education to the team. In this capacity he will help ensure that participatory methods are employed in field activities and that the delivery of FRCS technology is accompanied by appropriate education on the use of clean and safe drinking water . The Project Director, Project Manager, Project Engineer and Project Extensionalist will make visits to two organization in Thailand viz., the Faculty of Engineering in Khon Kaen University and the Population and Development Authority (PDA). These attachments are aimed at sharing their experience in FRCS technology (Nopmongool and Patamatamkul 1984, Vadhanavikkit et al 1984, Bunyaratpan and Sinsupan 1984) and studying their approach towards implementing large rainwater collection programs (Hayssen 1986). The Project Manager will also visit Dhaka in Bangladesh to study the operation of the Grameen Bank, a small farmer credit scheme which could serve as a model for the structuring of the revolving fund (FAO, 1987). A number of one-day workshops will be organized for all the members of the project team before the commencement of field activities. The workshops will be aimed at familiarizing members of the team with the background and goals of the whole project. A Workshop Facilitator will help the team generate ideas on the methods to be adopted by the project in operationalising its activities. Using the same participatory approach ,the members will also identify areas in which the team, as a whole, will require further training so as to help it better to implement project activities.

(b) Development of training modules and materials.

Modules for the trainers' and technicians' courses will be developed as the first activity in the project. A series of small workshops involving members of the Engineering and Extension Units of the project will be conducted to develop the curricula and identify the training support materials required for both courses. A specialist on adult education and training will be invited to participate in the workshops. The curriculum for the technicians course will linclude information on the importance and correct usage of clean water, involvement of the family/community in development projects, choosing the most appropriate site, all aspects of frcs construction, maintenance of completed works etc. The Trainers' course will emphasize on the experience accrued in FRCS technology in Capiz, different technology options, analysis of rainwater patterns and design of rainwater catchment systems, selection and training of adults, community participation, financing, managing and monitoring FRCS activities etc. Training support materials will be designed and prepared by Communicators from the Extension Unit together with the finalisation of curricula. The curricula and training support materials will be tested on the first two courses organized for trainers and technicians. A consultant on evaluation methods and consultant on adult education will attend both course to help in evaluating and refining the curricula and support materials.

(c) Establishment of the Revolving Fund.

The fund will be set up to provide loans to properly trained FRCS technicians for purchasing materials required for the construction of tanks. A board of trustees for the fund will be set up and the Management Unit will draft rules and regulations governing the operation of the fund. All monies for the fund will be kept in a separate bank account. The financial records of the fund and bank account will be audited at the end of every calendar year. The Project Director and Manager will study the Grameen Bank of Bangladesh and the PDA Rainwater Tank Program in Thailand and use them as models in designing the operational system for the revolving fund. They will also be able to draw on the experiences of CDCI's existing cost recovery scheme for the pilot project. In this system, farmers raise piglets supplied by CDCI which are later sold and the proceeds returned in payment for the materials borrowed (Appan et al, 1989). The financial and credit management system for operating the Revolving Fund will be designed and set up by the Project Director. Manager and Administrator with the assistance of a consultant. All staff in the Administration and Finance Unit will be trained in the various operational procedures of the fund prior to its launch.

(d) Participants for the technicians' and trainers' courses.

The technicians' course will be publicized over the provincial radio stations and through brochures distributed to village officials and leaders.
Suitable applicants will be shortlisted and the following criteria will be used in selection:

(a) Living in areas where there is an acute shortage of safe water but receiving adequate rainfall for roofwater collection systems;

(b) Willingness to undergo training and contributing their timeand labour towards the construction of tanks.

(c) Ability to repay the cost of materials in installments with or without assistance for cost recovery. For the trainers' courses, an average of 3 participants in each of the technicians' courses will be selected.

(d) The criteria used in their selection will be the ability to lead and train other villagers, willingness to run training courses and a good understanding of FRCS technology.

(e) Conduct of technicians' and trainers' courses for technicians. A total of 16 courses will be conducted; each course involving about 30 participants. A total of 486 participants will be trained. The course (curriculum mentioned above) will be highly practical in nature with the greater part of the trainees' time spent on the actual construction of a 10,000 litre tank. These courses (which will be conducted by trainers) will aim to incorporate sessions on the importance of clean water and advantages of community participation towards solving development problems. For the trainers, 6 courses will be conducted, each courses having 9 participants. A total of 54 trainers will undergo this course, which will be divided into two parts. The first part will cover mainly the areas outlined earlier. In the second part of the course, the participants will conduct an actual technicians course as described earlier under supervision.

(f) Implementation of FRCS technology. The technicians and trainers who successfully complete their training are eligible for loans from the Revolving Fund to purchase the required materials. The trainers will also be encouraged and provided with assistance to conduct training courses for members of their communities who may also obtain loans from the fund. With these loans, the villagers will be able to purchase the raw materials for constructing the water tanks. a contract establishing the terms and conditions of the loan, including repayment period will be signed by every villager who borrows from the fund. A low interest rate will be fixed and repayment periods are anticipated to vary from 2 to 5 years, depending upon the income level of the borrowers. Representatives of the project team will visit the houses where the tanks are to be built after signing the loan contracts or when the householders indicate that they have obtained the resources required for construction. During the visits the project team members will assist the villagers in identifying the most suitable sites for locating the tanks, check the roofs and gutters to ensure that they are compatible with the proposed tanks and conduct an educational program for all members of the households on the importance of clean water and its management.

(g) Monitoring and evaluating: A consultant on evaluation methods will work with the project team from the early stages of the project. Once the monitoring system has been designed, it will be operated by the project staff. The information ,data and feedback gathered will be reviewed and analyzed at regular meetings involving the consultant of the project.

IMPACT OF THE PROJECT AND CONCLUSION

The long-term impact of this project would be an increased supply of potable water in Capiz Province which , in turn, would lead to an improvement in the health of the people through a better control of water-borne diseases. The project will be instrumental in training a core group of villagers as trainers and technicians in FRCS. They will be dispersed amongst the rural communities and assist them in constructing their own rainwater collection and storage systems. During the life of this project, 540 tanks with storage capacities ranging from 4,000 to 10,000 litres will be built. As a result, more than 600 families will be provided with a reliable source of drinking water. The core group of villagers will be provided with basic skills in health education and community organization in addition to the FRCS technology. This will, hopefully, ensure that the technology will be introduced to communities through a participatory approach. The communities adopting the technology will at the time be sensitized to the importance of safe water and the management of its usage. The design, launching and management of the Revolving Fund is a significant component of this project. This fund will be initially directed towards FRCS where repayments made by borrowers will ensure that a continuous source of credit will be available to villagers who may need to help in purchasing the required building materials. The concept of the Revolving Fund adapted and fully utilised should have added potential as a source of capital for the villagers. This fund can be further developed to help in other areas where credit is required by farmers. Finally, it is hoped that the community participatory processes that the project would have initiated and introduced to the villagers in the form of group training and the Revolving Fund, will help stimulate communities to apply similar processes to help them to solve many of their other problems.

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FABRIDAM ENGINEERING AND ITS APPLICATION IN TAIWAN

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ABSTRACT

In Taiwan, with unevenly distributed aboundant annual rainfall and the steep slope of rivers rushing the rain water flow in rapid speed to the sea, fabridam is highly regarded as one of the best suit for storage and diversion of rain water because of its elastic characters of anti-wearing and compaction resistance.

If properly designed using precast method in mesium or small size of canal, fabridam may perhaps be widely and applicably adopted, for its effective (unigue) function of auto-operation which will save more labour cost and fit for economical considerations.

The Following papers is a brief description on fabridam engineering proposed to be discussing.

1. Introduction

Taiwan is an island located in subtropical climate area with annual rainfall about 2500 milimeters, where the water resources seems to be aboundant but the temporal and spatial distribution of rainwater is quite uneven. For instance, nearly 70% of annual rainfall occurs in summer by typhoons and thunderstorms, and the rest time of the year comes relatively dry seasons. In this regard, the amount of usable water is quite limited, and storing the surplus water in the wet season becomes very urgent.

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Besides, owing to the precipitous mountain ranges along the island and the short rapid stream of rivers, most hydrorelated structures are always undertaken serious impacts on heavy sedimentation and erosion during flooding. Therefore, the development of effective and economic approach of engineering may have been considered as one of the best solution to meet the needs as mentioned above.

Fabridam, with its unique characteristic of easily passing bad materials as well as floating debris through the river channel, durable resistance of dam body against damage such as perforations, abrasion, and functions of easy operation is recommended as an effective approach for various applications. If properly designed by use of more economical material and simplified installation method such as prefabrication or precast, fabridam engineering with lower construction cost may be the best suit to small and medium-sized rivers. With this, we hope the Application of fabridam Engineering in Taiwan will be numerous and perspective.

2. Principle of fabridam

Fabridam consists of a tube of rubber-coated synthetic fiber which is inflated with either air or water, it is installed across a river with a control module to store water and regulate the water level for various purposes. Moreover, it can be deflated automatically in flood conditions. The principles are shown below on fig. 2.1 and fig. 2.2, and a comparison of the two inflation method is shown on table 2.1.

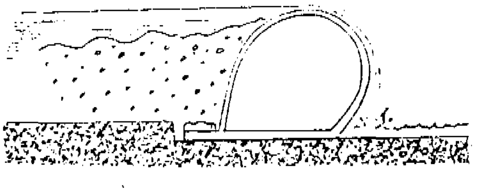


Fig 2.1 Inflation section

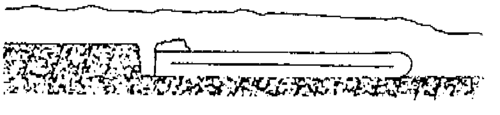


Fig 2.2 Deflation section

Table 2.1 Comparison between air inflation type and water inflation type

Type / Parameters	Water-filled type	Air-filled type
Temperature	At extremely cold place, the filled water becomes frozen.	Internal pressure of the bag changes where air temperature changes greatly.
Foundation		In the case of soft foundation, air-filled type is more advantageous than water-filled type.
Overflow depth	Maximum overflow depth is 50% of the dam height in general	Maximum overflow depth is 20% of the dam height in general
Type / Parameters	Water-filled type	Air-filled type
Stability of bag shape during operation	Water flows with a regular depth over the whole span	When inside pressure decreases, a water flow concentration appears (V notch)
Water level control	Easier than that of air-filled type	Difficult when V notch forms
Peripheral length of the body	Compared to air-filled type, the length increases	
Inflation and deflation time	Longer time for same tube diamter of air-filled type due to friction loss	
Supply and exhaust pipe	Larger diameter, but pipe possibly plugged by sediment from and through the intake water	Pipe diameter may be smaller than that of water-filled type
Other structures	Sedimentation treatment facilities and water tank are necessary in many cases	

As mentioned above, the inflation type is slightly different by its inflation media. The air-filled type seems to have less problems in acqusition of air, while the water-filled type has the problems of water quality and its disposal. That is, when river water is used for inflation, it is necessary to build screen or sedimentation pool to ensure the pumping equipment in good operation. Besides, shortage of river water supply during dry season may also be troublesome. In addition, there is another solution by using of pumping ground water or domestic water to storage tank for its frequently operation, if regardless of its expensive cost.

The air-filled type of fabridam seems more cheaper than that of water-filled type in economical concerns. But the air-filled type can hardly maintain a stable water level on dam crest during operation, when inside pressure of the dam body decreases and a water flow concentration appears to form a "V" notch which may results in serious downstream scouring and foundation erosion. On the other hand, the water-filled type of fabridam doesn't have such problems and it seems suitable for frequently operation.

3. Design of fabridam

Before design of fabridam is employed, various alternatives should be brought into consideration concerning of operation and design requirements, the selection of fabridam may as well compare with that of steel gate in order to help the final decision, including not only the portion of weir structure but also all-over engineering cost, construction plan, the requirement of future maintenance, and management cost as well. Table 3.1 Listed below are the comparison between fabridam and steel gate deserved considering.

In Taiwan, due to the remarkable adventages of fabridam being inflated to form a desirable over-flow section without installing piers and operation bridge on the dam crest, a water-filled fabridam named "Bee-T'an weir" was built on Hish-Tien-chi in Taipei suburban area. Unfortunately, after the weir was installed, its fabridam body was cut by evil resident with sharpened material and broken in a hole about one square meter, which almost caused the weir fail to operate immediately. As a result, selection of relative fabridam projects become more conservative since than.

Consequently, in repair of the fabridam, dewatering of the foundation and keeping the working place dry by lowering the river

Table 3.1

		Fabridam	Steel Gate
service life		10 yrs. and over (estimated)	20 yrs. and over (estimated)
maintenance	lubrication	unnecessary	3-4 months regularly is necessary
	painting	unnecessary	1-2 yrs.regularly is necessary
auto-operation		without need of power supply when deflation	power supply or heavy balanced device needed
civil structure	foundation	only computing service loading	computing the loading of gate, bridge,piers,etc.
	piers	long-span is available and flow interruption is less	short-span with piers to interrupted the flow section
	operation bridge	unnecessary	unnecessary
durability and security		weaker in abrasion and puncture resistance than that of steel gate	stronger in puncture resistance

water level become necessary, and it must be done in very short time to meet the need of water user's requirement. Therefore, it is advisable to build a diversion stucture or water releasing facility, which is lower than the foundation slab to help deainage. While Bee-T'an weir was re-installed in 1987, a drain gate was also built in the middle portion of the foundation.

4. Material of fabridam

Fabridam, after completion, will be subjected to impacts of climatic conditions and weather variations. Henceforth, such as ozon, sun-rays, ultraviolet-rays, abrasion will deteriorate the bag body throughout its service life time. In addition, as it always undergoes with the upstream water pressure and over-flow loading, the required tensile stress thus exerted should be correspondent with the design requirement. On the other hand, the rubber-coated fabridam body is not such kind of common rubber, but the kind of synthetic rubber to reduce it thickness for construction purposes, so the unit price may be a little more expensive than that of common rubber.

5. Installation of fabridam

Before placing concrete of foundation, diversion work should be well arranged to unwater the working site and install the bag body anchoring bolts, fittings and gages according to their designed scale. In order to ensure those embedded bolts and components to be effectively adjustable, it seems advisable considering of the design of pouring secondary concrete after those embedded components having been precisely adjusted.

As for installation of bag body, since the components and aparatus for inflation and deflation of bag body, such as piping system anchoring, clamping devices and operation equipment embedded in the foundation, have been safely fixed, it may be easily installed and proceed to their adjustment for operation.

The installation period of fabridam in relation to civil works such as metal fittings, pipe embedding should be incorperated into civil construction plan consideration. As for the period of bag body erection, the weather condition comes to be a important factor, for the working site must be kept dry enough lest the residual air bubbles in chemical admixure pavement on concrete surface of foundation should reduce the construction effects because of moisture content. Therefore, it should be fully consided of, including unexpected construction waiting time.

Furthermore, if the project manager passibly acts as a accomodator of construction between civil works and bag body works, a drain gate could be designed to diverse water during installation and later on serve as a outlet work after completion.

6. Operation of fabridam

Because a economical and reliable fabridam should be designed without interfering the flow section during flooding condition, and be capable of resisting stresses induced by reservior water pressure, an over flow-depth of 30cm-50cm is specified into the design considerations and for operation convinence of flow regulation. If the upstream water level becomes higher the designed over-flow depth, the fabridam will be deflated to assure the safty discharge of downsteam or other practical usages. To satisfy with those purposes, the operation system and its facilities should be well designed not only automatically but mannually with simplifed and easily operative method to meet the requirement lest the electric power supply should be invalid during flooding.

In addition to mannual operation equipment, some automatic devices including mechanical types such as float type and electrical type were used accordingly to link with the upstream water level detector and mechanically opens the values by way of a buoyance float or the weight of water, or siphon suction to deflate the dam body inflated by air or water through the engine-or motor driven blower or pump and ancillary devices such as valves. Fig. 6.1 and Fig. 6.2 show the typical mechanism of air-inflated and water-inflated type of operation system.

Fig. 6.1
Air-Inflated Type
(Standard System)
Inner standing water is drained in exhausting automatically.

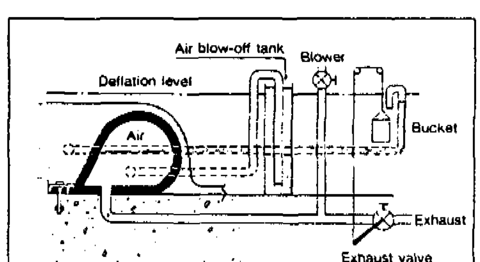
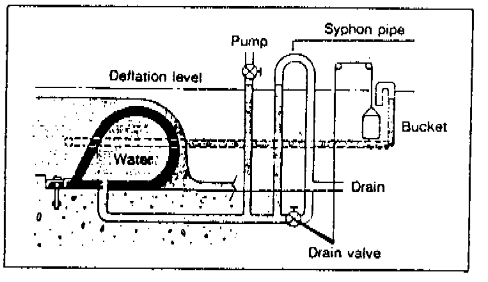


Fig. 6.2
Water-Inflated type



7. Perspective of fabridam in Taiwan

Although a movable weir could be designed in type of fabridam instead of steel gate according to the site conditions, in view of patrol and security, the prevention of bag body from being illegally destroyed appears to be a matter of great importance in Taiwan. For example, the Bee-T'an weir is a three span fabridam installed on Hish-Tien Chi, which was cut by sharpened material and turned to be invalid after completion. With this regard, the selection of fabridam to large-scale hydrolic engineering projects seems unsuitable, unless the monitoring and protective system are well arranged.

However, with rapid development of prosperous society and economic growth in Taiwan, the utilization of water resources as well as the demand of water supply is getting urgent day by day. As a result, the development of smallsize intake facitity in application of fabridam engineering may bring a bright future and get popular if fabridam could be designed and constructed with precast methods to minimize the construction time, reduce the engineering cost, and simplify the pipe connection while the labour cost become relatively high. That will be helpful to the future development of fabridam engineering.

As shown below on Fig. 7.1, Fig. 7.2 and Fig. 7.3 are some conceptional examples of precast fabridam, shadowed drawing indicate the precated portion of canal integity and operation chamber, and the unshadowed drawing show the other portions including in-situ pipe connection and inplace concrete casting.

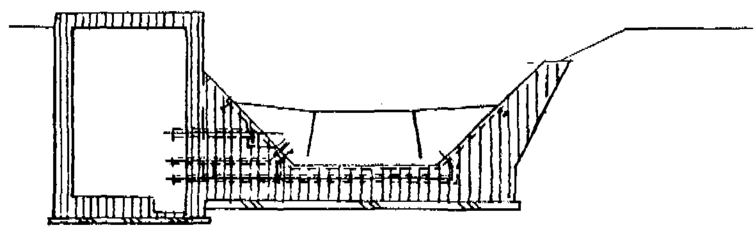


Fig. 7.1 small-sized fabridam in one precasted integrity

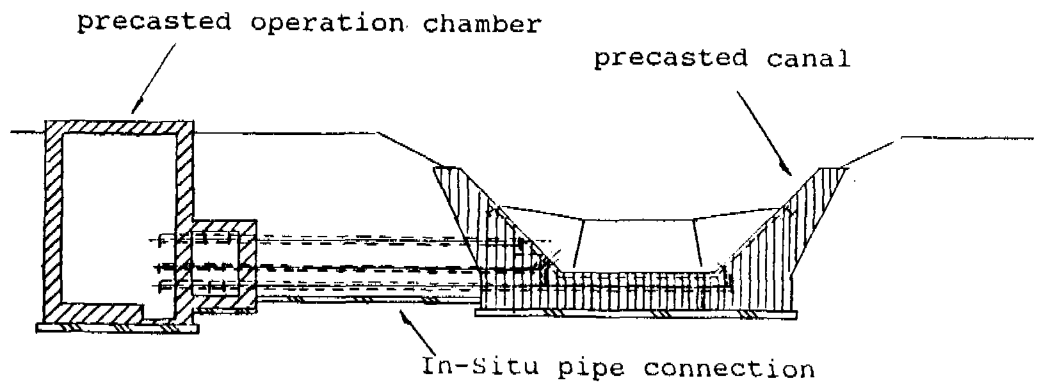


Fig. 7.2 medium-sized fabridam in two precasted divisions

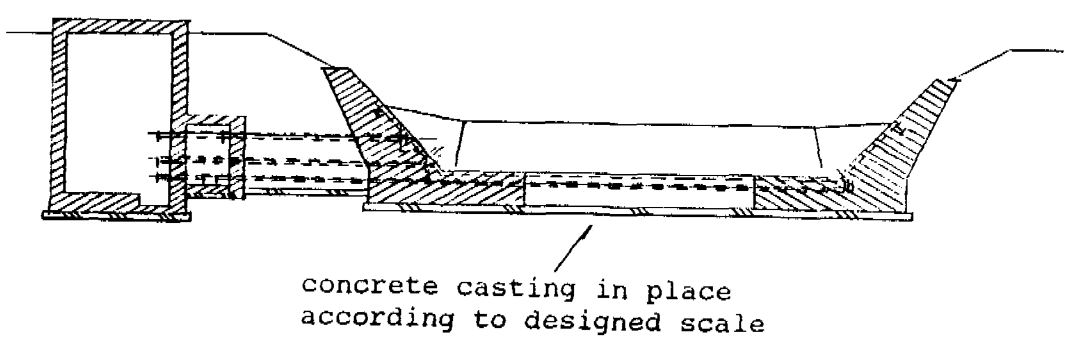


Fig. 7.3 large-sized fabridam with three precasted divisions

8. Conclusions

(1) The applications of small- or medium-sized fabridam on rainwater storage and diversion facilities are considered to be widely available and necessarily acceptable in Taiwan if they were properly designed with precast method and manufactured with standard scale in the factory that may reduce the engineering cost and shorter the construction time.

(2) Owing to the river run-off water with heavier sedimentation in Taiwan, except for particular functional requirements the air-filled type of fabridam is still recommanded for the less engineering cost and maintenance expense, and the adventages of avoiding the troublesome works of inflation medium (water) supply and exhaust pipe desilting.

(3) With the unique characteristic of automatic operation of fabridam engineering, the design of waterways and related structures upstream may minimize their freeboard, wasteway, appurtenant and protective facilities, etc.

(4) Fabridams, without need of regular painting and lubrication, may reduce and save the maintenance costs.

(5) With the recent development of fabridam engineering and their material technoloyies, the great improvement of ultraviolet-rays resistance and weatherability, ect. turn out to be useful and effective in prolonging the service life. Unquestionably, the applications of fabridam engineering surely have their poteniality of development and will be popularly adopted.

FABRIDAM INSTALLATION IN TAIWAN

NO.	DATE COMPLETED	HEIGHT X WIDTH (meters)	LOCATION	INFLATION BY	INSTALLATION PURPOSE
1	1997. 5	1.5 × 40.0	Hish-Tien Chi (Bee-T'an), Taipei 碧潭攔河堰橡皮閘門	Water	Irrigation 灌溉 Recreation 觀光
2	1980. 4	1.5 × 40.0	Shuang Creek, Taipei 士林雙溪出口九孔閘門改建	Air	Tidal Control 防潮 Irrigation, 灌溉 Flood control 洩洪
3	1982. 4	1.2 × 46.0	Chiu-Cho-Shui Crk.,Chang-hua 舊濁水溪排水系統改善工程	Air	Irrigation& 灌排 drainage
4	1983. 9	1.4 × 10.0	Chi-Kan drainage, Tainan 溪墘排水系統改善工程	Air	Irrigation& 灌排 drainage
5	1983. 9	1.0 × 8.0	Hou-Hu-Bei, Miao-Li 竹南地區排水系統改善工程	Air	Irrigation& 灌排 drainage
6	1984. 1	2.5 × 25.0	Chiu-Hu-Wei Creek, Yun-Lin 舊虎尾溪排水系統改善工程	Air	Irrigation& 灌排 drainage
7	1985. 6	1.7 × 13.4	Kern-Chien, Tainan 柴前分線補助水源(橡皮壩)工程	Air	Irrigation& 灌排 drainage Tidal control 防潮
8	1986. 12	1.5 × 60.0	Lieu-Du, Kee-Lung 六堵淨水場橡皮壩換修工程	Air	Water Supply 給水 Flood control 洩洪
9	1987. 2	(1.7 × 35.2) +(1.0×36.2) +(1.0×33.7)	Hish-Tien Chi,(Bee-T'an), Taipei 碧潭攔河壩改善工程	Air	Irrigation 灌溉 Recreation 觀光
10	1988.	1.2 × 3.5	Ma-Lien Creek, Kee-Lung 基隆擴建一第二水源改善工程	Air	Water Supply 給水 Flood control 洩洪

HONG-LO TRANSBASIN RAINWATER HARVESTING WORKS FOR THE CHENG-KUNG RESERVOIR IN PENGHU

LI-JEN WEN*

ABSTRACT

The Penghu Pescadores located in the west of Taiwan Proper are scarce in water. The annual precipitation is only about 1,000 mm which is much less than the measured evaporation of 1,800 mm. The water supply there entirely relies on the surface runoff and groundwater. In the dry year, the domestic water supply entirely depends on the groundwater even up to 100% as most of the reservoirs dry up.

Due to lack of geological and meteorological data, hydrologic analysis was extremely difficult for planning reservoirs especially in the early stage of development. At present, there are five surface-water reservoirs and one underground reservoir with a total effective capacity of 3.9 million cubic meters, of which the Cheng-kung Reservoir with a capacity of 1.04 million cubic meters is selected for study.

This paper is to review the hydrologic analysis of the Cheng-kung Reservoir and to illustrate its transbasin rainwater harvesting system which was completed in the recent year. It is emphasized that continued efforts on collection of geological and hydrological data are to be made for application of the improved methodology in hydrological analysis for planning cisterns on the water-scarcity off-shore islands.

INTRODUCTION

The Penghu Pescadores located in the west of Taiwan Proper consist of 64 islands with a total area of 126 square kilometers. The water sources there are scarce as the annual average precipitation is about 1,000 mm which is much less than the annual pan-evaporation of 1,800 mm. The annual average available water per capita is 1,185 tons which is only one fourth of 4,828 tons in Taiwan Proper (Tsao et. al., 1979). The main water sources are

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rainwater storage in reservoirs and groundwater to be pumped up from wells. There are five existing reservoirs with a total effective capacity of 2.7 million cubic meters, of which the Cheng-kung Reservoir is the largest one having a capacity of 1.04 million cubic meters.

The Cheng-kung Reservoir was completed in 1963 and started water supply for domestic use in 1965. Though it supplied an annual average amount of water up to 1.06 million cubic meters in the first four years, the reservoir supplied 0.14 million cubic meters in 1979, and could not supply water at all in 1980 because of a prolonged serious drought. In order to increase the storage of water for the Cheng-kung Reservoir, the subject rainwater harvesting project was planned in 1980 and completed in 1985.

This paper is to review the hydrologic analysis of the Cheng-kung Reservoir and to introduce its transbasin rainwater harvesting system.

FEATURES OF CHENG-KUNG RESERVOIR

The Cheng-kung Reservoir is the first reservoir completed in the water-scarce pescadores for domestic water supply in 1973. The reservoir has an effective storage capacity of 1,040,100 m^3 formed by a concrete gravity dam of 10.5 meters in height and 290 meters in length. It does not have a base inflow and is only a rainfall collector with a catchment area of 3.04 km^2. The hydrologic analysis for the reservoir planning was made merely depending on the estimated runoff coefficient and daily rainfall data. It was reported that the originally adopted runoff coefficient was over estimated as the reservoir has rarely had overflows from the spillway since its completion in 1973. In other words, the reservoir has not supplied enough water as planned since the completion. Table 1 shows the yearly water supply situation of the reservoir.

According the analysis made by the Agricultural Engineering Research Center (Tsao et. al., 1979) on the actual water supply, reservoir storage and rainfall data, the rainfall-runoff relationship is as follows:

$$Y = -2.66379 + 0.26967X - 0.00164X^2 + 0.00001X^3$$

where Y = monthly runoff in mm
X = monthly rainfall in mm

The above equation is shown in Figure 1, and its correlation coefficient is 0.916.

The result of this study revealed that the originally designed capacity of the reservoir was too large under the geological and climatic conditions in Penghu.

Table 1. Yearly Water Supply of Cheng-kung Reservoir

year	Yearly Water Supply	Total Water Demand for Makung Area	Percent of supply from reservoir	Annual Rainfall
	(m^3)	(m^3)	(%)	(mm)
1975	1,257,712	1,715,402	73.3	1,456.9
1976	848,857	2,206,641	38.6	584.8
1977	959,892	2,362,329	40.6	942.8
1978	660,111	2,381,614	27.7	587.0
1979	149,294	2,150,515	6.9	580.6
1980	0	1,920,138	0	393.1
1981	548,905	2,601,114	21.1	1,166.7
1982	1,256,585	3,136,044	40.1	1,202.9
1983	1,355,648	3,117,484	43.5	957.3
1984	384,993	2,497,545	15.4	687.7
1985	353,135	2,778,643	19.3	1,056.6
1986	605,943	3,362,846	18.0	1,017.9
1987	894,673	3,482,041	25.7	782.0
1988	244,655	3,515,078	7	642.8
1989	418,070	4,070,050	10.3	866.0

Remarks: The shortage of water was supplemented by groundwater.
Source: Taiwan Water Supply Company

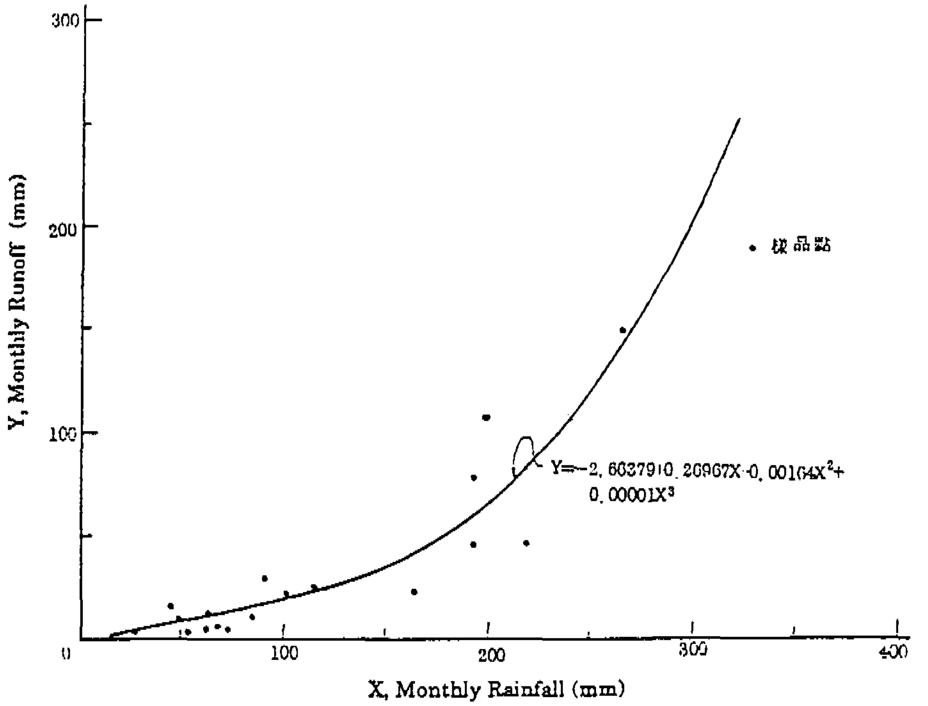

Figure 1. Rainfall-Runoff Relationship of Cheng-kung Reservoir

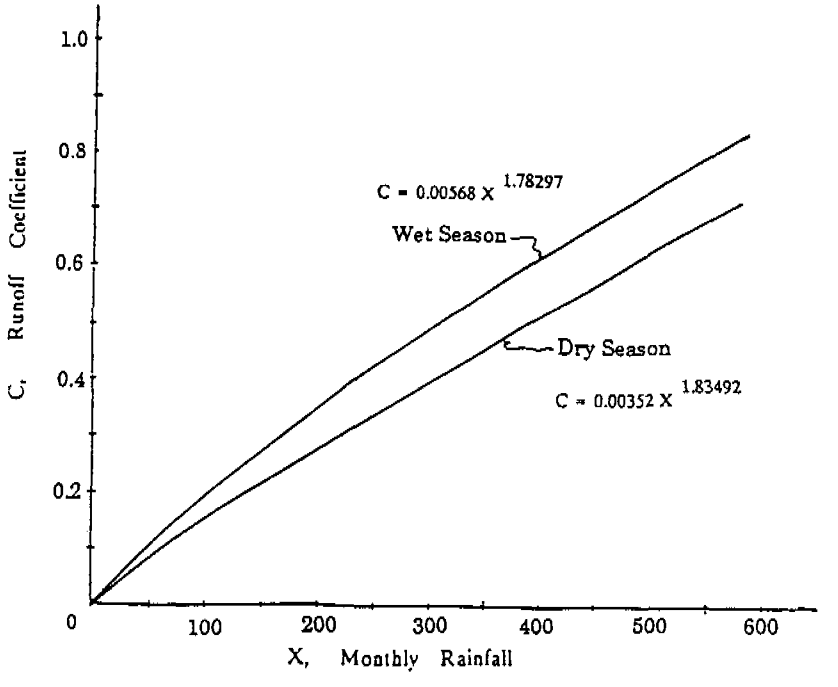

Figure 2. Runoff Coefficient-Rainfall Relationship in Peng hu

TRANSBASIN DIVERSION SYSTEM

Hydrologic Analysis

On the Penghu Pescadores, there are no perennial stream flows. Because of lack of hydrologic observation data, hydrologic analysis shall entirely rely on the available daily rainfall records, and assumed runoff coefficient data. Therefore, empirical formulas are used for the determination of floods and inflows into the reservoir. In many cases, the following rational formula has been applied:

$$Q = \frac{1}{3.6} C.I.A$$

where C = runoff coefficient, in decimal
I = rainfall intensity, in mm/hr
A = catchment area, in km^2

in which, I may be determined by Monobe formula as follows:

$$I = \frac{Rd}{24} \left(\frac{24}{Tc} \right)^{2/3}$$

where Rd = Daily rainfall, in mm
Tc = Time of concentration, in hr

in which, Tc is usually determined by Rziha formula as follows:

$$Tc = \frac{L}{W}$$

$$W = 72 \left(\frac{H}{L} \right)^{0.6}$$

where, L = Length of waterway, in km
W = Advance velocity of water, in km/hr
H = Elevation difference between the highest point and the project point in the catchment area, in km

For flood estimation, the Rd value of 200 year-frequency was used, and the C values of 0.98 for the rainy season and 0.935 for the dry season were used for the Cheng-kung Reservoir planning in the early year.

In the estimation of runoff for rainwater collection, varied

Table 2. Joint Operation of Cheng-king Reservoir and Transbasin Diversion System-based on high and fixed runoff coefficient values used for Cheng-king reservoir planning in the early year

Year	Estimated Runoff			Supply from Reservoin		Deficit		Overflow
	Reservoir $m^3 10^3$	Diversion System $m^3 10^3$	Sum $m^3 10^3$	Volume $m^3 10^3$	Percent of Demand	Volume $m^3 10^3$	Percent of Demand	$m^3 10^3$
1956	2,684	718	3,402	1,229	64	691	36	1,423
1957	1,299	344	1,643	1,920	100	0	0	0
1958	1,625	440	2,092	1,764	88	229	10	0
1959	2,389	664	3,053	1,920	100	0	0	652
1960	1,766	471	2,237	1,914	98	6	2	299
1961	2,100	559	2,659	1,925	100	0	0	222
1962	1,376	393	1,769	1,920	100	0	0	0
1963	1,203	321	1,524	1,317	68	603	32	0
1964	459	158	617	785	41	1,130	59	0
1965	1,262	337	1,599	1,388	72	532	28	0
1966	2,199	586	2,785	1,733	90	193	10	252
1967	1,507	402	1,909	1,920	100	0	0	0
1968	2,841	760	3,601	1,920	100	0	0	927
1969	2,626	636	3,262	1,920	100	0	0	1,192
1970	1,644	439	2,083	1,911	99	14	1	0
1971	1,207	323	1,530	1,688	88	238	12	0
1972	3,092	822	3,914	1,717	90	203	10	1,691
1973	2,074	1,772	3,846	1,891	99	29	1	1,527
1974	2,385	636	3,021	1,920	100	0	0	768
1975	2,952	787	3,739	1,926	100	0	0	1,338
1976	1,041	248	1,289	1,881	99	39	1	0
1977	2,243	597	2,840	1,336	70	584	30	915
1978	1,159	309	1,468	1,644	86	276	14	0
1979	1,095	294	3,389	1,275	66	647	34	0
1980	843	228	1,062	977	51	961	49	0
Sum	45,089	13,244	58,333	41,626		6,375		11,206
Average	1,804	530	2,334	1,665	87	225	13	448

Remarks
1. Annual Water Demand: 1,916,250 m^3 in normal year
2. Evaporation is deducted
3. Deficit is to be supplemented with groundwater

Table 3. Joint Operation of Cheng-kung Reservoir and Transbasin Diversion System-based on varied runoff coefficient values

Year	Estimated Runoff			Supply from Reservoin		Deficit		Overflow
	Reservoir $m^3 10^3$	Diversion System $m^3 10^3$	Sum $m^3 10^3$	Volume $m^3 10^3$	Percent of Demand	Volume $m^3 10^3$	Percent of Demand	$m^3 10^3$
1956	1,853	495	2,348	1,078	56	842	44	546
1957	666	177	843	1,247	65	672	35	0
1958	982	263	1,245	1,119	58	801	42	0
1959	1,467	393	1,860	1,563	81	363	19	0
1960	1,086	289	1,375	1,307	68	613	32	0
1961	1,302	347	1,649	1,527	80	393	20	0
1962	715	192	907	846	44	1,074	56	0
1963	656	175	831	719	37	1,207	63	0
1964	186	50	236	205	11	1,715	89	0
1965	674	180	854	742	37	1,178	63	0
1966	1,399	377	1,776	1,564	81	356	19	0
1967	808	216	1,024	904	47	1,022	53	0
1968	1,754	468	2,222	1,672	87	248	13	0
1969	1,723	462	2,185	1,915	99	5	1	0
1970	883	236	1,119	1,318	67	602	33	0
1971	603	159	762	683	36	1,243	64	0
1972	1,968	526	2,494	1,495	78	425	22	398
1973	1,962	527	2,489	1,821	95	99	5	224
1974	1,511	402	1,913	1,826	95	94	5	0
1975	1,938	518	2,456	1,698	88	228	12	179
1976	500	133	633	1,036	54	884	46	0
1977	1,400	376	1,776	1,328	69	592	31	0
1978	549	148	697	807	42	1,113	58	0
1979	162	45	207	148	8	1,778	92	0
1980	135	36	171	121	6	1,801	94	0
Sum	26,882	7,190	34,072	28,689		19,278		1,347
Average	1,075	288	1,363	1,148	60	771	40	54

Remarks
1. Annual Water Demand: 1,916,250 m^3 in normal year
2. Evaporation is deducted
3. Deficit is to be supplemented with groundwater

runoff coefficients have been adopted instead of a high fixed value as used in the early stage when the Cheng-kung Reservoir was planned. Table 2 shows the result of the hydrologic analysis for the joint operation of the Cheng-kung Reservoir and the transbasin diversion system with the monthly rainfall data from 1956 through 1970 and the high and fixed C values, and Table 3 shows that based on the varied C values obtained from the 4-year operation of the Cheng-kung Reservoir (PWCB, 1981). In comparing Table 2 and Table 3, one can easily realize that the Cheng-kung Reservoir can hardly be full with water.

The varied C values in terms of monthly rainfall data computed from the long operation records of the Cheng-kung Reservoir are listed in Table 4(PWCB, 1989) and are drawn by the writer in Figure 2.

For reference, the relationships between runoff coefficients and rainfall data obtained in Okinawa of Japan are shown in Figure 3 (Yoshinaga et. al. 1990).

Engineering Plan

In order to increase the water supply of the Cheng-kung Reservoir, the Taiwan Provincial Water Conservancy Bureau (PWCB) initiated a transbasin rainwater harvesting planning works with the assistance of the Council of Agriculture (COA), Executive Yuan (Cabinet) in 1980. The plan was to extend an interception ditch along the contour line to the neighboring basin to increase the catchment area of 1.86 km^2 for rainwater collection. The annual increase of water supply for the joint operation of the Cheng-kung Reservoir was estimated at 300,000 M^3. The system was completed in 1985 and the total construction cost was NT$35,000,000. (US$1,370,000). The main engineering features are as follows:

(1) Leading canal of 3 cms in capacity: 2,263 m in length, including culverts, flumes and other necessary facilities.
(2) Interception waterway of 3 cms in capacity: 486 m in length, including inlets, outlets, spillways, gates etc.
(3) Water collection ditch of 0.596 - 1.48 cms in capacity : 1.273 m in length, including culverts, bridges etc.

The engineering layout of the project work is shown in Figure 4.

CONCLUSION

The Penghu Pescadores are scarce in water. The water supply there entirely relies on the surface runoff and groundwater. In the dry year, the domestic water entirely depend on the groundwater even

Table 4. Runoff Coefficients of Wet and Dry Seasons-computed from the Operation Results of Cheng-kung Reservoir

Monthly Rainfall (mm)	Runoff Coefficients	
	Wet Season (May-Sept)	Dry Season (Oct-April)
0 ~ 10	0.00	0.00
10 ~ 30	0.06	0.04
30 ~ 50	0.10	0.08
50 ~ 80	0.15	0.11
80 ~ 100	0.19	0.15
100 ~ 150	0.25	0.20
150 ~ 200	0.32	0.26
200 ~ 250	0.39	0.32
250 ~ 300	0.46	0.38
300 ~ 350	0.53	0.44
350 ~ 400 >	0.59	0.50

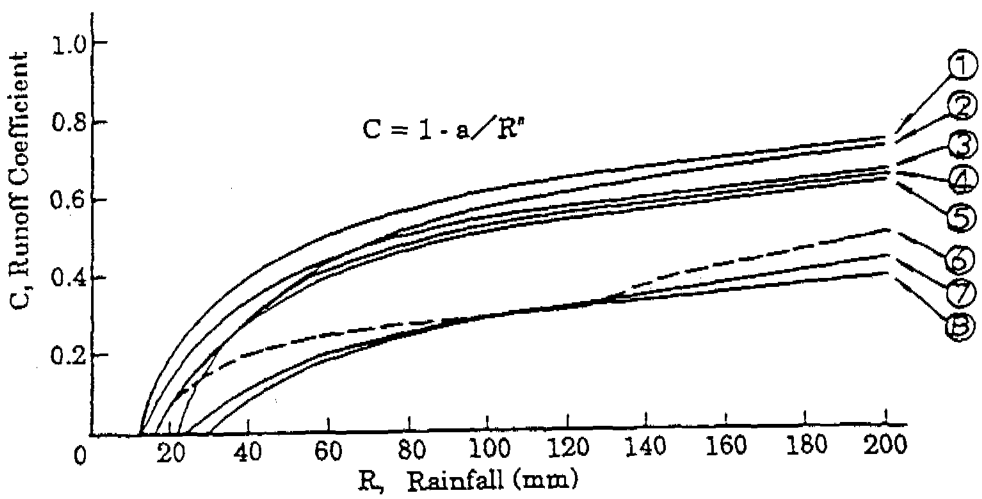

Figure 3. Runoff-Rainfall Relationship in Okinawa

Remarks:

No.	Location	a	n	Soils
①	Nago	3.14	0.456	Kokuto acid red soil
②	Miagijima	3.47	0.449	Casing soil
③	Hashokan	2.84	0.396	Casing soil
④	Nojo	3.34	0.424	Alkali gray soil
⑤	Ginoza	3.19	0.404	Kokuto acid red soil
⑥	(From Journal of Japanese Society of IDRE)			
⑦	Tsugashijima	2.55	0.278	Shimajiri acid red soil
⑧	Miakojima	2.10	0.231	Shimajiri acid red soil

Figure 4. Engineering Layout of the Hong-lo Transbasin Rainwater Harvesting Works

up to 100% as most of the reservoirs dry up. Strong monsoon winds preclude the growth of forests and windbreaks on the islands. Even though, the continued efforts are to be made on reforestation as well as soil and water conservation measures in order to secure water resources on Penghu.

Due to lack of geological and meteorological data, hydrologic analysis is extremely difficult. As aforementioned, the Cheng-kung Reservoir was not designed to a optimal size. When the transbasin diversion system was planned in 1970. the writer was in opinion that the system capacity should be less than the half of the proposed 8 cms which followed the same pattern of designing the reservoir. In the latter years, reservoirs are designed in such a relatively conservative manner that they can be fully utilized. Furthermore, rainwater harvesting from the neighboring catchment area is recommended to be practiced in order to increase the water supply of a reservoir.

Needless to say, continued efforts on collection of geological and hydrological data are to be made for application of the improved methodology in hydrologic analysis. Furthermore, the long-time data of reservoir operation are to be collected and included in hydrologic analysis not only for the existing surface reservoirs but also for an underground reservoir which was completed recently. The result of justified analysis certainly produces precious data for future application in planning reservoirs on the water-scarce offshore islands.

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Solar Electricity in Rain Water Cistern System

Mitsuo Ide
Takashi Yoshida
Akira Higuchi

ABSTRACT

Water is the origin of life and precious resources to us. For the purpose of getting water, communities were composed, farming managed, and manufacturing done. And stable supply of water has helped progress of agricultural techniques, development of industrial economy, and improvement and conversion of industrial structures.

In order to get water resources, we can make the following statements.

1. River water
2. Water from lakes, marshes, and reservoirs
3. Rain water
4. Water from underground and spring
5. Reutilization of water
6. Replacing sea water to fresh water, etc.

In order to get water resources in the isolated islands and the top of depth of mountains, utilization of rain water and spring water is easy and economical.

We had investigated and studied to get and stabilize the supply of rain water at the isolated islands of Tokai district in Japan. Besides we devised an apparatus by solar energy (not by commercial energy) available for the isolated islands.

The outline is following:

1. Quantity and quality of rain water
2. Collecting works of rain water
3. Solar cells and pump facilities
4. Water supply apparatus
5. Sterilizer

Water Use Engineering Laboratory Yoshida Iron-work Co., Ltd.

INTRODUCTION

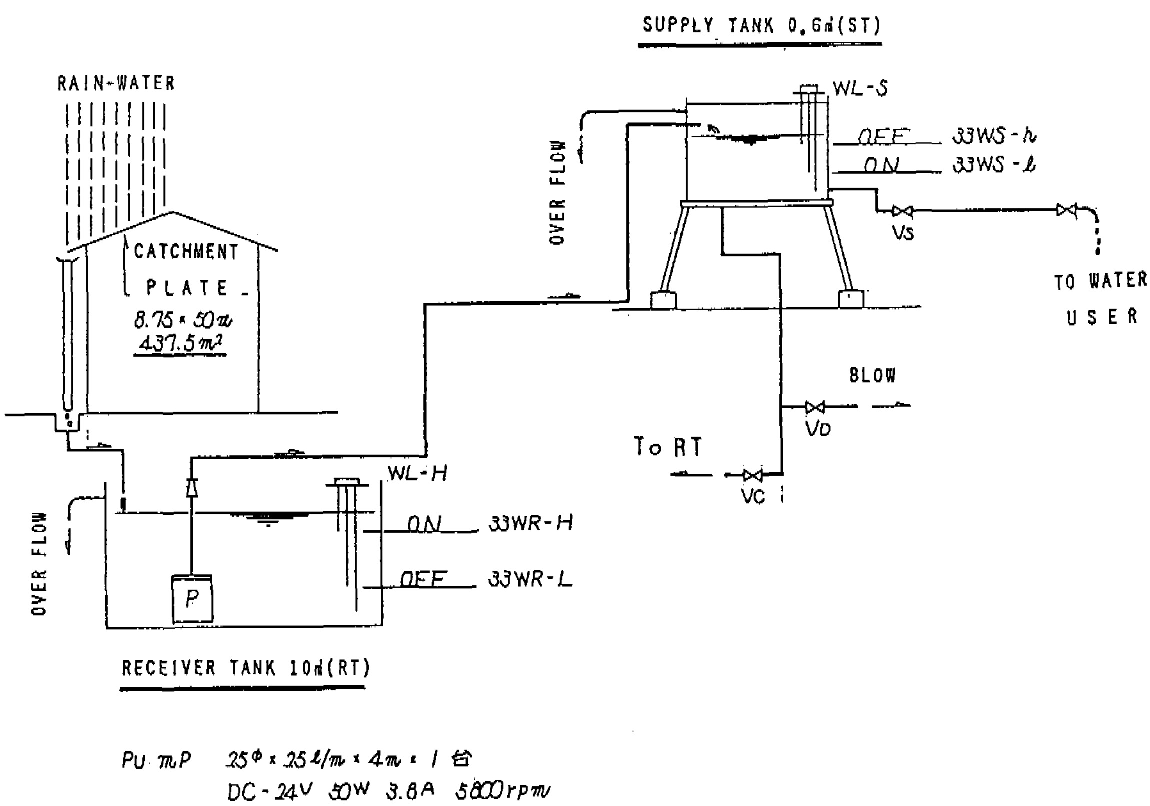
As a mean of assuring the water resource for remote islands of Japan, various ways can be considered such as canalization from the Main Island, dissalinization of sea water, use of rain water, etc.

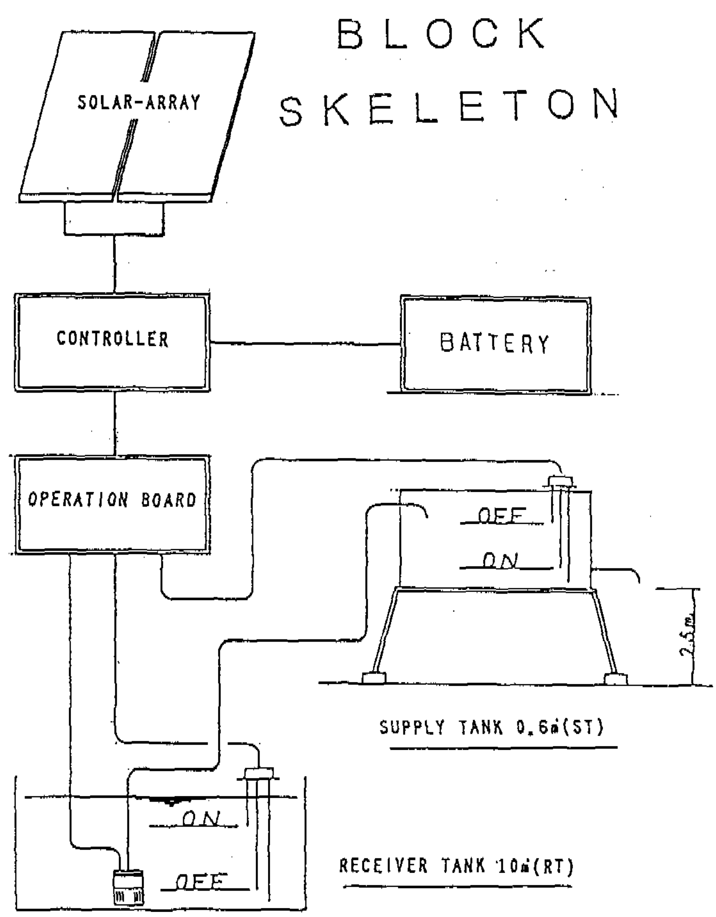
In this opportunity, we have decided to study the use of rain water pumped by energy generated from solar cell, considering economical factors and with premise of rural electrification.

General on Test Plant

(1) Site: City of Yokkaichi, Mie Prefecture
(2) Test Period: Jul. 1st, 1990-Dec.20, 1990
(3) Facility/equipment

FLOW - SHEET





List of Equipments			
		Q'ty	Note
Solar Module	LA36IJ48 (917x448)	4 UNITS	Cell 144
Controller		4	
Operation Board	In Door Type	1	
Battery	6V - 60 AH	4	
Pump	25φx25ℓ/mx4mx 50W-5,800 r/m	1	Submersible
Catchment Plate	wave-shaped plate 8.75x50 = 437.5m²	1	
(RT) Receiver Tank	1.1x12Lx0.811 10m³	1	
(ST) Supply Tank	SS-41 1φx0.811 0.6m³	1	

3. Data

Inclined irradiance at Yokkaichi, Mie prefecture

	Jan	Feb	Mar	Apr	May	Jn	Jul	Aug	Sep	Oct	Nov	Dec
Q	308	334	390	384	418	355	363	387	336	341	321	303
F	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Q'	355	387	452	445	483	412	421	449	390	396	372	351

$Q' = 1.16 \times Q \times F$ MWH/cm² day

Slope Angle of Array $Q_2 = 35°$

Correction Factor F

Standard Irradiance Q' min = 351 MWH/cm² day

K_1 ...Charge Efficiency 0.9

K_2 ...Dirty Coefficient 0.9

K_3 ...Safety Factor 0.77

D ...Days without sunshine 2.5

Kb...Correction Factor 0.665

PL...Average Power of load:

Loads:			
	Pump	50W	4hr = 200
	Light	10W	8hr = 80
	Control system	3W	24hr = 72
			352 WH

$$PL = \frac{352\ WH}{24\ hr} = 14.67 = 15\ (W)$$

Method of Experience

(1) Method of water collecting

The rain water which falls on the wave shaped roof of existing factory is gathered automatically into the RT, to be transferred to ST by pump.

Then, water is supplied according to demand by gravity.

(2) Purposes of water use

These are following:

Elimination of deformation originated in the boiler and sheet/plate welding in the factory process, water for cooling system, and for miscellaneous purposes.

Even after the experience, this equipment/facility is working in order to supply industrial necessities.

(3) Pump operation method

The pump operation took place by full automatic control of level gauges of RT and ST.

During whole test period no trouble was found and it was completely maintenance free.

(4) Reason of battery installation

When solar pump is used, it is common practice to drive the pump directly by solar cell, without the use of battery.

However, in our case, battery is employed in the sake of uniform 24-hr supply of water demanded by factory necessities and for illumination of sorrounding area of the factory for safety and lighting of insect gathering lamp.

In addition, by comparison study of cost and investigation on capacity of ST, battery input, etc., it was concluded that the use of battery is more economical.

* indicates the case in which effective water collecting was not possible due to receiver tank overflow caused by concentrated rainfall by typhoon.

* For factory demand, when short of rainfall is found, city water was used.

* About RT, because of limitation in $10m^3$ due to its instal-lation site, the water actually collected was 54% of total rainfall estimated in $666m^3$.

Weather Data and Result of Experience

TEST DATA	JUL			AUG			SEP			OCT			NOV			DEC	
	1-10	11-20	21-31	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20
(A)	25.6	31.2	31.0	33.4	31.3	31.0	30.5	27.0	25.2	24.3	22.4	20.2	20.9	19.3	16.5	15.4	11.0
(B)	82	78	77	69	81	73	69	82	80	74	73	69	70	70	75	64	65
(C)	35.7	62.9	85.7	73.2	68.7	70.1	77.6	35.3	24.7	46.0	51.3	74.7	66.3	66.7	39.0	65.1	51.1
(D)	133	48	37	18	26	66	18	358	143	94	24	84	147	12	200	10	4
(E)	4.7	1.8	1.0	0.6	0.7	2.2	0.7	*1 5.4	*2 2.7	*3 3.1	0.9	*4 2.3	*5 4.6	0.5	*6 2.9	0.4	0.2
(F)	3.15'	1.11'	37'	24'	36'	1.28	28'	3.36'	1.48	2.7'	36'	1.32'	3.5'	20'	1.56'	16'	8'

A) Temperature °C

B) Relative Humidity

C) Sunshine, Hour Total

D) Total Rainfall, mm

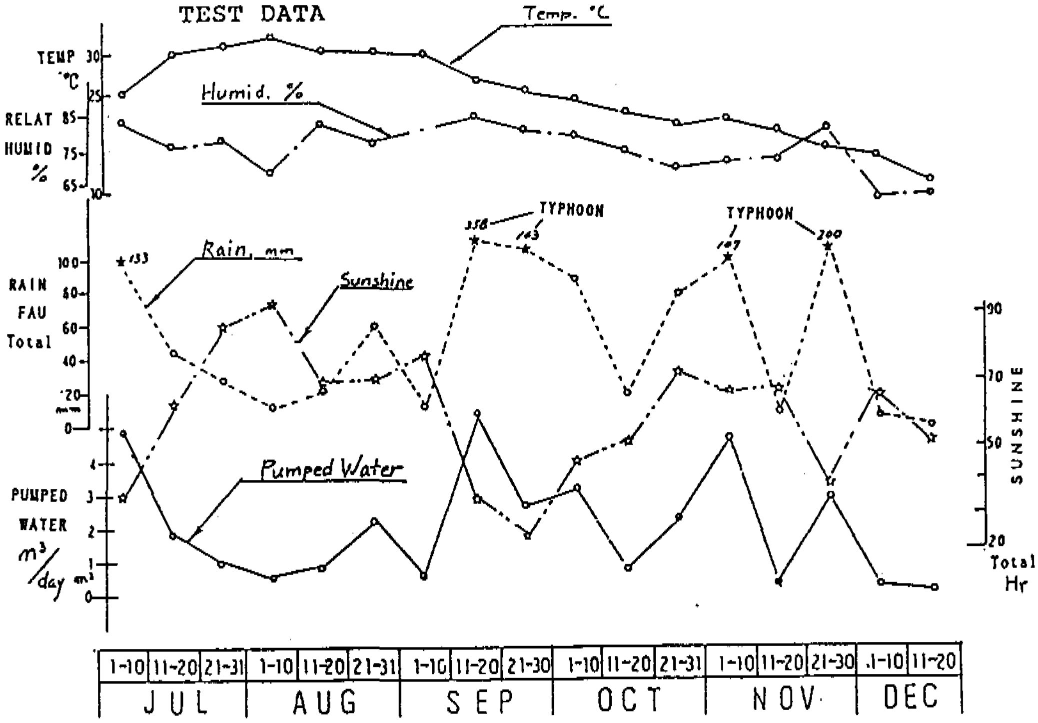
E) Water Catchment, m^3

F) Pump Operation Time, Hr.

Note: 1. It was estimated that 95% have come from roof and 5% from surface water penetration.

2. Total water pumped is estimated as being $357m^3$

TEST DATA



* There was no contamination of water because of rain water collected from roof. But when concentrated rainfall occurred, some amount of sand penetrated, caused by water flowing on the ground surface.

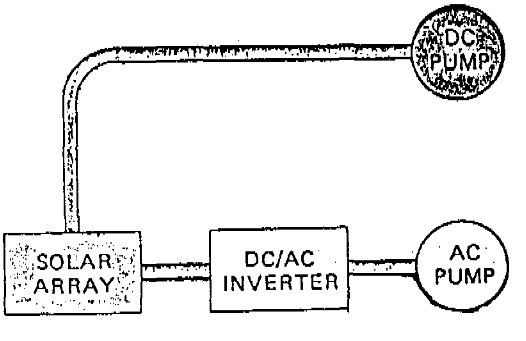
* It is necessary to consider rainwater penetration from ground surface and from under ground-side water canal.

* About RT , it is convenient to make it underground by excavation, and make it unpermeable by liquid vinyl or rubber.

Photovoltaic Pumping System

(1) Characteristics of Solar Cell
    1) No operation cost
    2) Easy installation and maintenance
    3) Cleanliness and quietness
    4) Reliability and independence from fuel suppliers

(2) Composition of the System



(3) Pump Selection
    In general the pumping system can be classified in various types according to head and flow rate required, quality of water, condition of installation, etc.
Therefore, it is necessary to select the system in consideration of these factors, making correct combination of pump and solar cells.
    1) DC Submersible Pump
    This pump is adequate when required flow rate is relatively low (less than 100m^3/day) and a total head no more than 20m.
    For DC motor greater than 200w, brush is usually used, so its maintenance becoming necessary.

2) AC Submersible Pump

This pump is good in case where DC pump indication is not adequate, and for use with head higher than 20m.

3) Self Priming Centrifugal Pump
and Mixed Flow Pump

The mixed flow pump is generally used when high rate of flow is required for total head up to 30m. Because this pump is installed on the ground, the place of installation can be changed relatively with ease, provided that its installation takes place at no more than 2 or 3m height.

The AC pump requires the use of INVERTER, a device that converts DC to AC, so its application showing some limitation on efficiency and cost.

Anyhow, if needed capacity is greater than 750w it becomes more advantageous than DC pump.

(4) System Selection

The pumping system can be classified in system "without battery" and "with battery".

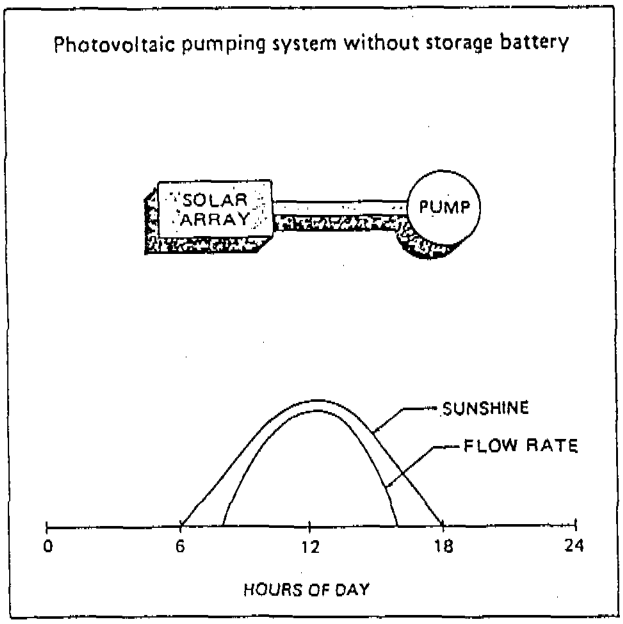
In the system without battery , the electricity that comes from solar array is directly conducted to the pump, which in turn supplies water.

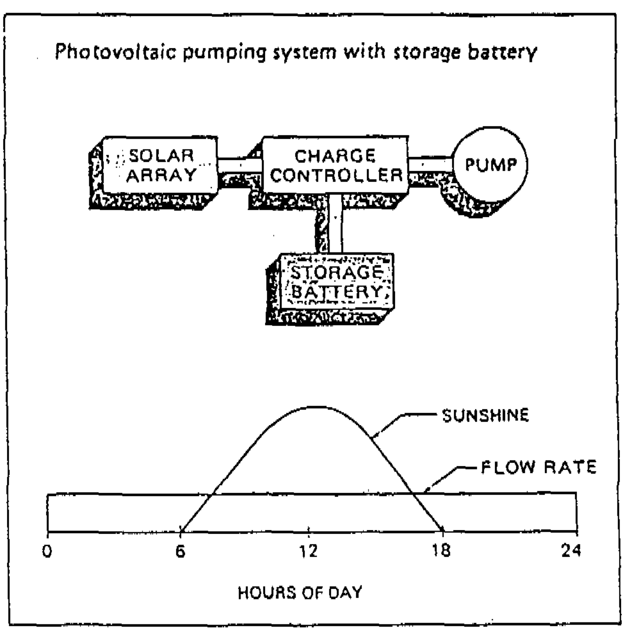
So, the flow rate depends on the intensity of sunshine,and in the case where required water supply varies in quantity and time, that is ,when we want some determined quantity of water in certain instant, it is necessary to install a reserve tank.

In the system with battery, the energy that comes from sun is stored in the battery that can be also used at night. In this way the battery accumulates temporarily the energy, fullfilling the role of supplying energy to consumer in a stable way.

In the case of system without battery the capacity of reserve tank is determined in function of water supply required in an hour, so initial cost study becomes necessary.

The relationship between flow and sunshine according to hours of day is shown below, in both "without" and "with battery" cases.


Photovoltaic pumping system without storage battery
SOLAR ARRAY
PUMP
SUNSHINE
FLOW RATE
0
6
12
18
24
HOURS OF DAY


Photovoltaic pumping system with storage battery
SOLAR ARRAY
CHARGE CONTROLLER
PUMP
STORAGE BATTERY
SUNSHINE
FLOW RATE
0
6
12
18
24
HOURS OF DAY

(4) Calculation of Solar Cell Capacity

1. Conditions

1) Locaion:	Yokkaichi, Mie Prefecture
2) Latitude:	34.9° N
3) Load:	Pump, control system and illumination light
4) Voltage:	24V DC
5) Average Power of load	PL = 15w
6) Average Daily Irradiance through month:	Q'(Cal/cm²)

2. Calculation

1) Capacity of Solar Cell: Pm(Wp)

$$Pm = PL \times \frac{2400}{Qmin} \times \frac{1}{K_1 K_2 K_3}$$

$$= 2400 \times \frac{1}{351} \times 15 \times \frac{1}{0.9 \times 0.9 \times 0.77} = 164.4w$$

Qmin = min. value of inclined irradiance

K_1 = charging efficiency

K_2 = dirty coefficient

K_3 = safety factor

Standard Module: 48 Wp/unit

$$\frac{164.4}{48} = 3.43 \fallingdotseq 4 \text{ units}$$

Type Code of Standard Module: LA36IJ48

2) Capacity of Battery = Be (Ah)

$$Be = \frac{PL \times 24D}{Kb \cdot V}$$

D = days without sunshine

Kb = correction factor

$$Be = \frac{15 \times 24 \times 2.5}{0.665 \times 24} \fallingdotseq 56.39 \fallingdotseq 60$$

Be = 60AH

(5) Calculation of output of Driving Machine

Pump net capacity...P(kw)

$$P = \frac{0.163\gamma QH}{\eta_p} \quad (kw)$$

Driving Machine Output...PM(kw)

$$PM = \frac{P(1+\alpha)}{\eta_f}$$

Q = Flowrate (m^3/min)
H = Total head (m)
γ = Fluid density
η_p = Pump efficiency

For solar pump
α...margin 0.2
η_f...transmission efficiency 1.0

(6) Motor power and Solar cell

Solar cell...100mm x 100mm = 0.01m^2(eff. area)
36 cells = 1 Module = 0.36m^2 (eff. area)
1 Module = 48w (peak) 917mm x 448mm from

$$[Pm = PL \times \frac{2.400}{Qmin} \times \frac{1}{K_1K_2K_3} \times \frac{1}{48} = \text{No. of Module}]$$

Motor Power	No. of Module	Module area	Note
50w	2	0.9 m^2	
100	4	1.7	
150	6	2.5	
200	8	3.3	
750	28	12.5	
Without battery, irradiance of 600m'.Wh/cm^2day			

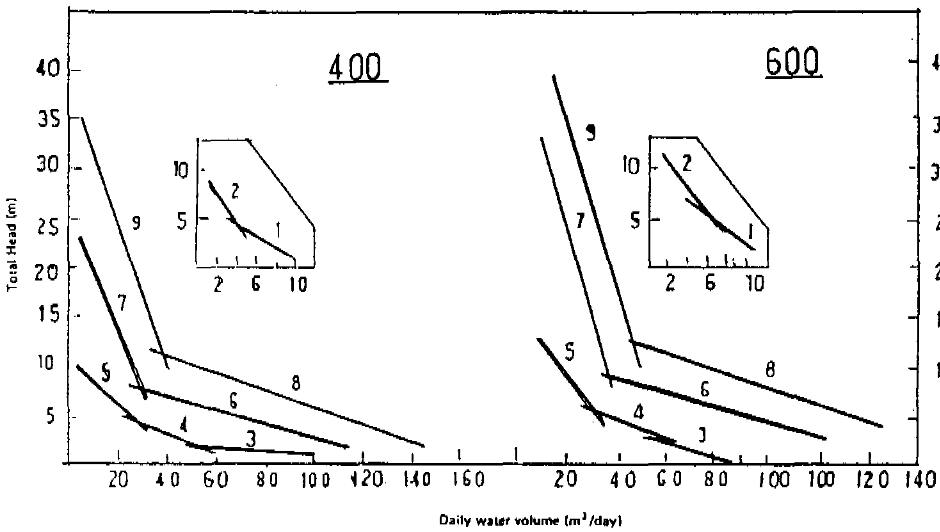
(7) Standard Types of Pump and Solar Cell

Usually the selection of pump is made considering total head and flow rate of liquid to be pumped.

The DC pump is generally indicated for case with low head and small amount of liquid, and AC pump for high head and high flow rate.

By diagram below (no battery, 6 hrs. of pump operation) we can see, for instance , if the head is 5m and flow rate of $20m^3$/day, the indicated pump is NO.5.

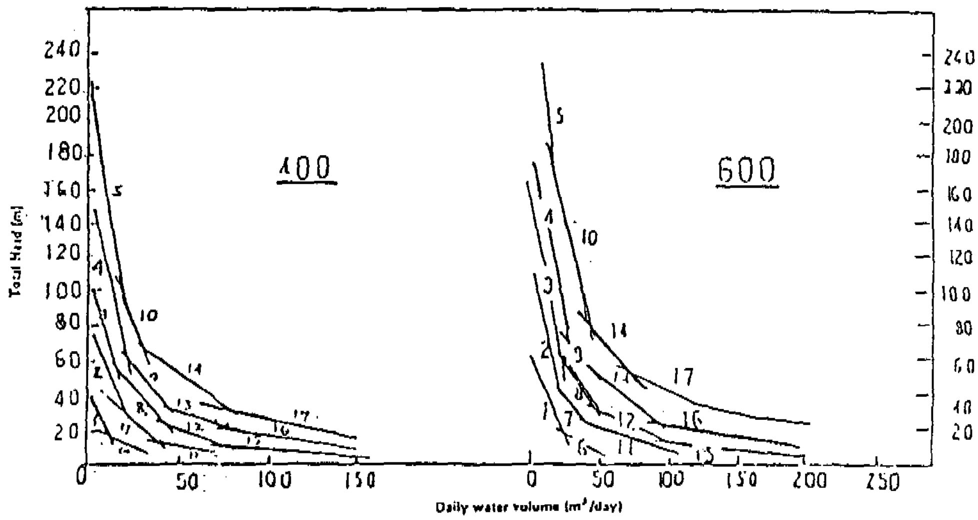
■Selection of DC Submersible Pump



Pumping capacity at different head under the irradiance of 600 mWh/cm²·day (400 mW)
(Data based on actual field test result in Japan)

Type	Motor Power	Module No.	Type	Motor Power	Module No.
1	50w	2	6	750w	18
2	50	2	7	750w	18
3	200w	8	8	750w	28
4	200w	8	9	750w	28
5	200w	8			

■Selection of AC Submersible Pump



Pumping capacity at different head under the condition of 600 mWh/cm²·day (400 mW) ·
(Data based on actual field test result in Japan)

Type	Motor Power	Module No	Type	Motor Power	Module No
1	0.55kw	18	10	3.7kw	126
2	1.1	32	11	1.1	36
3	1.5	54	12	1.5	54
4	2.2	72	13	2.2	72
5	3.7	126	14	3.7	126
6	0.55	18	15	1.5	54
7	1.1	36	16	2.2	72
8	1.5	54	17	3.7	126
9	2.2	72			

For pump driving 3 phase motor is used.

(8) Irradiance for various countries

Count station	Annual
ASIA	
Taiwan	
Taipei	314
Taito	426
Indonesia	
Jakarta	332
Hong Kong	
Kings Park	347
Malaysia	
Kuala Lumpur	396
Philippines	
Quezon City /Manila	391

Country Station	Annual
Singapore	
Singapore	370
Stilanka	
Colombo	498
Thailand	
Bangkok	406
AFRICA	
Algeria	
Bechar	496
Tamanrasset	543
Angola	
Luanda	543

Country Station	Annual
Egypt(ARE)	
Cairo	479
Cape Verde	
Praia	499
Central African Republic	
Bangui	410
Ethiopia	
Addis Ababa	451
Ghana	
Kumasi	376
Guinea	
Bissau	473
Kenya	
Nairobi / Degoretti	459

Unit : Radiation (cal/㎠·day)

CONCLUSION

In structural point of view, we have chosen for the experience the simplest way in concern of maintenance. So, it resulted in a trouble-free system for whole test period.

However, the worthiest system to be considered is that fitted with receiver tank, as far as economy is concerned.

As its construction material we can name plastic and rubber sheet, concrete , etc., and the selection must be done case by case, according to local conditions.

INVESTIGATION INTO FEASIBILITY OF USAGE FOR DOMESTIC USE OF COLLECTED RAIN WATER FROM OPEN AREAS IN URBAN REGIONS IN JAPAN

Tadafusa Uchida*

ABSTRACT

The purpose of this study is to examine the feasibility of collecting rain water for reuse not only from roofs, but also open areas, such as park and public lands. I examined the recovery rate and quality of collected rain water through the use of permeable test pieces representing several types of ground compositions.

The results are as follows:

1. The recovery rate of collected rain water ranges from 40-70% of the total rainfall during the course of one year and these values depend upon the compositions of the test pieces.
2. The quality of collected rain water from non-fertilized test pieces satisfies the Japanese flush water requirements for toilets, and it can be used for a wide variety of purposes, including sprinkler systems.
3. The collected rain water from fertilized test pieces contains a high concentration of organic and inorganic substances during the first stages, so its reuse must be restricted to plant cultivation.

However, during the last stages, its quality is almost equal to that of non-fertilized test pieces, so it could be used for a wide variety of purposes.

<SYMBOLS>

Outlines and abbreviations of test pieces

A: test piece consisting of only sandy soil

B: test piece consisting of sandy soil at the bottom and on the top, small stones at the center.

C: test piece consisting of sandy soil at the bottom, small stones in the center and lawn cover on the top

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D: test piece consisting of sandy soil at the bottom, small stones in the center and permeable bricks on the top
E: test piece containing organic fertilizer
F: test piece containing organic and inorganic fertilizer

1. INTRODUCTION

In Japan, water supply systems are spread widely over the land mass and serve approximately 95% of the population. Thus, most of us can safely use tap water at any time and anywhere. However, in urban areas, such as Tokyo, where many office buildings and industries are clustered together, water shortages sometimes result in times of draught. Therefore, additional resources are needed.
On the other hand, in case of heavy rain fall, city-type flooding can occur due to the increased runoff coefficient.
As a countermeasure, some buildings are equipped to collect rain water from the roofs and store it in underground tanks, which utilize space between two concrete beams. It is then reused for flushing toilets, supplying sprinkler systems and gardening.
Most research in this area examines rain water reuse systems from roofs. This rain water is easy to collect and contamination is nominal, but little research has focused upon rain water reuse systems from open areas.
In this paper, rain water reuse systems are simulated in redevelopment regions in urban areas in Japan, and to ensure the successful reuse of the rain water, I employed permeable test pieces, which are estimated to be used widely in urban areas in the future. I then investigated quantity and quality of collected rain water from the test pieces and evaluated it for several uses.
Furthermore, two test pieces were set, which were fertilized, and evaluated as to the quality of collected rain water.

2. OUTLINE OF EXPERIMENTS

2.1 APPARATUS

Fig.-1 shows an outline of the apparatus. The size of each apparatus is 1mx1mx0.3m^H
Fig.-2 shows the cross-section of four test pieces which are non-fertilized.
Perforated pipes are set near the center of the test pieces to collect permeated rain water. Collection pipes are also set at the bottom.

Collection pipes of rain water are only set at the bottom.
Table-1 shows physical properties of the materials, which consist of the test pieces.
Necessary conditions for plant cultivation are ventilation, permeation, water storage and drainage. And if it is roof garden, it must be light weight.
I examined the above conditions and actual plant cultivation systems in the Tokyo area and selected these test pieces.
The materials of the test pieces have a higher saturated permeability coefficient than that of the soil (10^{-3} - 10^{-5}) around the Tokyo district.

Table-1 Physical Properties of Materials

Materials	Porosity (v/v%)	Saturated permeability Coefficient (cm/s)
sandy soil	50	1.2×10^{-2}
gravel	40	more than 5.0×10^{-1}
reform soil for lawn	73.5	7.8×10^{-2}
permeable brick	40 ~ 50	$5.0 \times 10^{-2} \sim 10^{-1}$
black soil & organic compost	47	1.0×10^{-3}
black soil & inorganic compost	40	5.8×10^{-3}
white loam	-	more than 5.0×10^{-1}

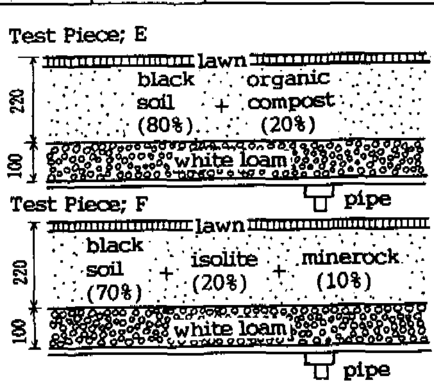

Fig.-3 Cross-section of Test Pieces (Fertilized)

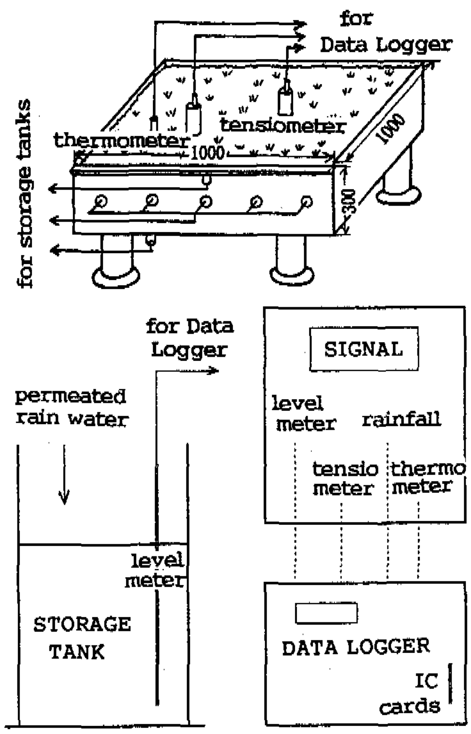

Fig.-1 Outline of Apparatus

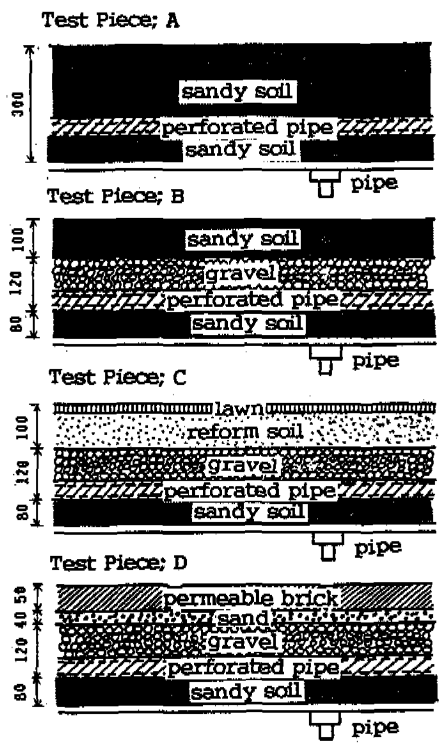

Fig.-2 Cross-section of Test Pieces (Non-Fertilized)

2.2 EXPERIMENTAL CONDITIONS

The test pieces are set on the top of a roof which is located in our research institute in Tokyo.

2.3 MEASUREMENT METHODS

(1) QUANTITY
Permeated rain water from each collection pipe was channeled to storage tanks which were located below the test pieces. Increased rain water was measured with level meters set in the each storage tank. Signals of the level meter were transmitted to the Data Logger which had several IC cards, then data were collected continuously.
The quantity of the collected rain water was measured only from A,B,C,D test pieces.

(2) QUALITY
Sampling was conducted irregularly, when the tank's storage was a half or a third of the tank's volume. Then an analysis of water quality was conducted as to PH, COD, SS and electric conductivity.

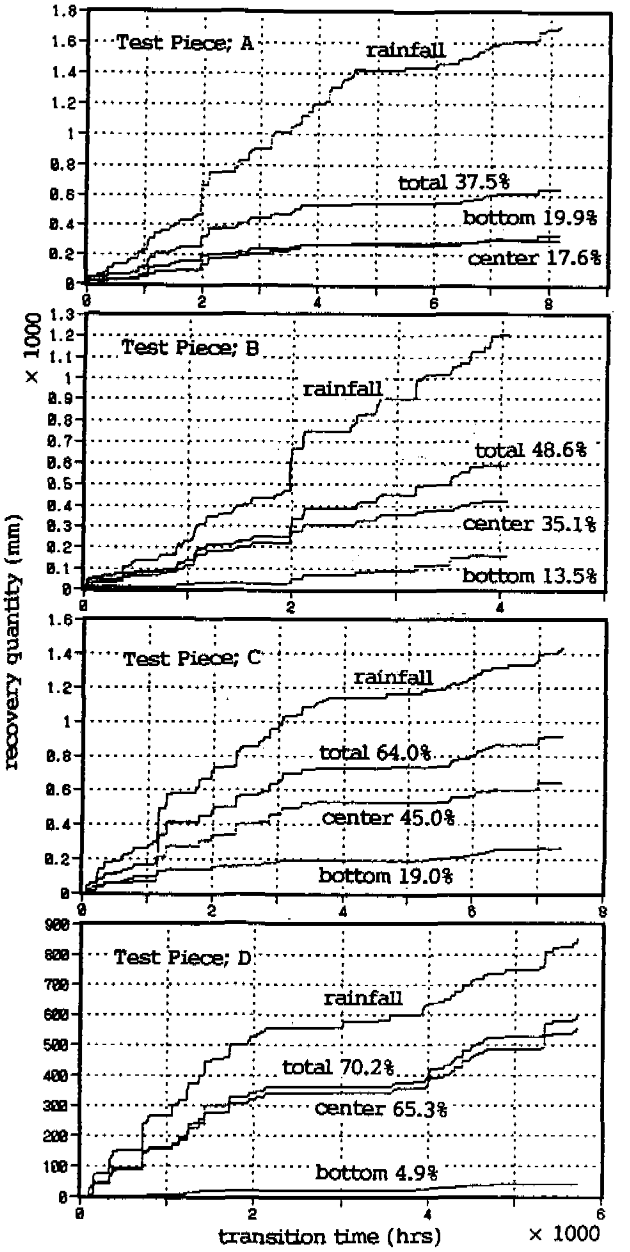

Fig.-4 Transition Time and Recovery Quantity

3. RESULTS AND DISCUSSION

3.1 TRANSITION TIME OF RECOVERY RATE AND QUANTITY

Fig.-4 shows transition time of recovery quantity and recovery rates of the four test pieces.
This Figure indicates that:

A. Recovery quantity is large when rain falls continuously and after heavy rainfall.
B. Recovery quantity from center pipes is large after heavy rainfall (except the A test piece) thus center pipes and large permeable materials which are set near the center of the test pieces are apparently more effective.

Table-2 shows recovery quality and rates of each of the four test pieces through the measurement term.
This table indicates that:

A. The amount of recovery rates are D>C>B>A, thus the test piece which consists of large saturated permeable materials, yields a grater amount of reusable water than when small saturated permeable materials are used.
B. The recovery rate of each test pieces ranged from 40 - 70% of the total rainfall, depending upon the test pieces.
C. B, which contains large permeable materials in the center of the test piece has a larger recovery rate than A, which has small permeable materials in the center of the test piece.

Thus, the large permeable materials set in the center of the test piece are more effective in obtaining a high recovery quantity.

Table-2 Recovery Quantity and Rate from each Test Piece

Test Piece	Measurement Term	Amount of Rainfall (mm)	Amount of Recovery		Recovery from Center		Recovery from Bottom	
			Quantity (mm)	Rate (%)	Quantity (mm)	Rate (%)	Quantity (mm)	Rate (%)
A	'89 5/10 ~'90 4/16	1712	643.5	37.9	302	17.6	341	19.9
B	'89 5/10 ~'89 10/26	1203	584.9	48.6	421.9	35.0	163	13.5
C	'89 6/14 ~'90 4/16	1432.5	916.5	64.0	644	45.0	272.5	19.0
D	'89 8/21 ~'90 4/16	850	597.0	70.2	555	65.3	42.0	4.9

3.2 TRANSITION TIME OF RECOVERY QUALITY

To evaluate the possibility of the collected rain water for several usages, analyses of water quality were conducted. Test piece B was not analyzed for its quality continuously, because of its short term representation in the field.

<PH>
Fig.-5 shows relationship between rainfall and PH.
This Figure indicates that:
Since soil has a large ability of ion exchange, even if acid rainfall (4.0 - 6.5) is conducted through this represented term, the permeated rain water is neutralized approximately PH 7.

<ELECTRIC CONDUCTIVITY>
Fig.-6 shows the relationship between rainfall and electric conductivity.
This Figure indicates that:
The value of electric conductivity during the first stage of each test piece is high, and after 800mm rainfall, 100 - 300 ì S/cm from both A and C test pieces, 200 - 500 ì S/cm from D test piece.
During this stage the value of electric conductivity is the same as the quality which I analyzed from the drinking water which was supplied from the water supply system in Tokyo last summer.

<COD>
Fig.-7 shows the relationship

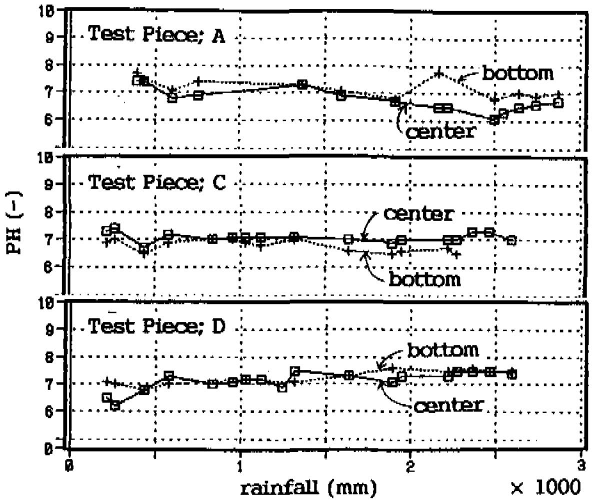

Fig.-5 Rainfall and PH

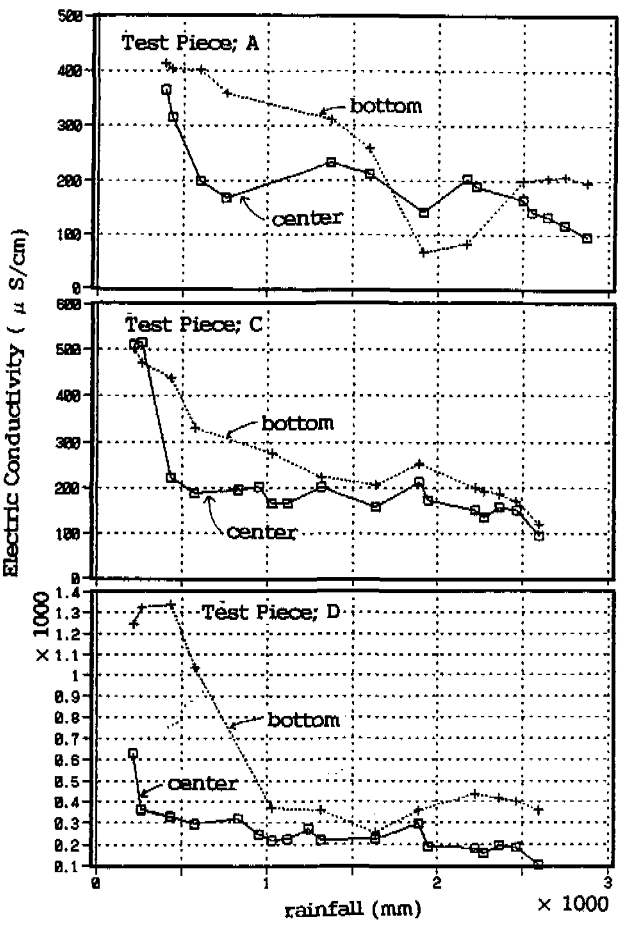

Fig.-6 Rainfall and Electric Conductivity

between rainfall and COD.
This Figure indicates that:
The COD value from each test piece is less than 8mg/l.
When these values are compared with the Ministry of Construction quality standards for water used for flushing toilets, which is less than 30 mg/l, these values satisfy this requirement.
However, C test piece is not fertilized even if lawns are planted on the top of the test piece throughout this measurement term. Thus higher COD values would be obtained in ordinary plant conditions, if fertilizer is already inserted or added.
<SS>
Fig.-8 shows the relationship between rainfall and SS.
This Figure indicates that:
A. The SS values ranged consistently between 1 - 4mg/l through this term (except one point of A test piece at the first stage) since all the perforated pipes were wrapped with cloth and collection pipes at the bottom were covered with cloth.
B. There is no quality regulation for this item for flushing toilets, but if it to be used as a long term water reuse system, it will need to be removed and cleaned periodically.
Table-3 shows averages and standard deviations of the collected rain water from each test piece, and also shows the

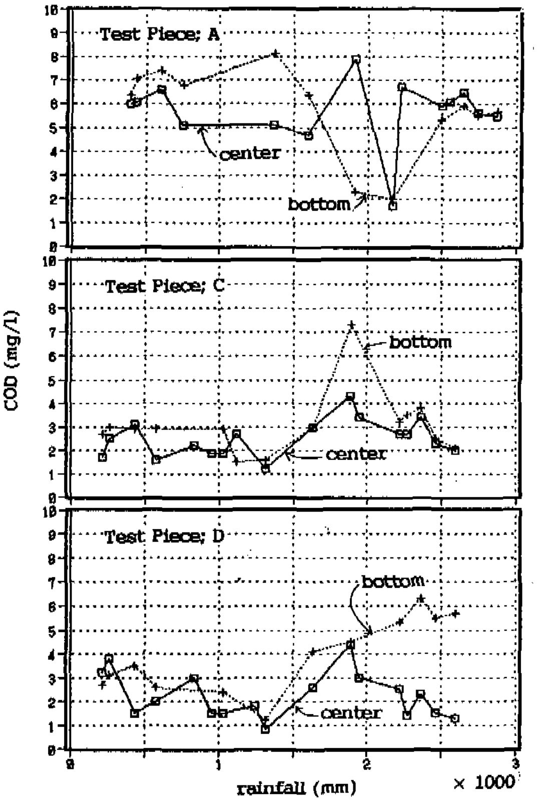

Fig.-7 Rainfall and COD

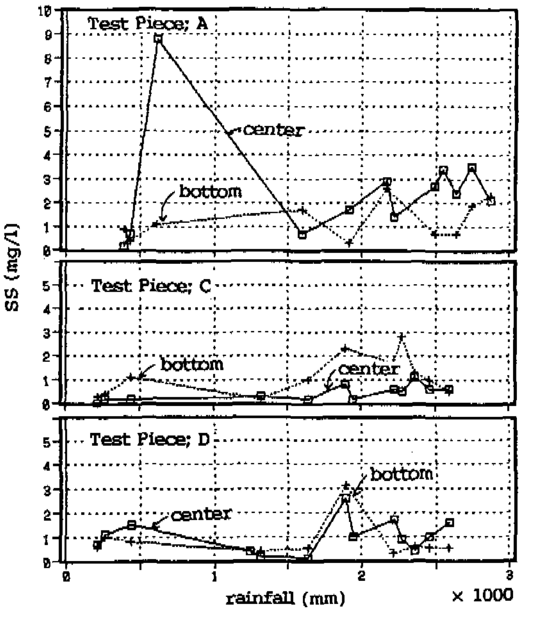

Fig.-8 Rainfall and SS

Table-3 Quality of Collected Rain Water (Measurement Term: '89 7/10~'90 12/1)

Test Piece		Items of Analysis																	
		PH (-)				electric conductivity (μS/cm)				SS (mg/l)				COD (mg/l)				BOD (mg/l)	
		N	R	AVE	STD	N	R	AVE	STD	N	R	AVE	STD	N	R	AVE	STD	N	AVE
A	center	14	7.4 ~6.1	6.8	0.4	14	365 ~95	192	71.8	12	8.8 ~0.2	2.5	2.1	14	7.9 ~1.7	5.7	1.3	1	0.3
	bottom	12	7.8 ~6.8	7.2	0.3	12	414 ~68	259	115	10	2.6 ~0.3	1.3	0.8	12	8.1 ~2.0	5.7	1.8	1	0.8
C	center	17	7.4 ~6.7	7.1	0.2	17	516 ~96	212	114	12	1.1 ~0	0.4	0.3	17	4.3 ~1.2	2.5	0.8	1	0.5
	bottom	13	7.0 ~6.5	6.8	0.2	13	503 ~119	274	119	11	2.8 ~0.2	1.1	0.8	14	7.3 ~1.5	3.1	1.3	1	0.7
D	center	18	7.5 ~6.2	7.1	0.3	18	630 ~103	260	111	13	2.6 ~0.1	1.0	0.7	17	4.4 ~0.8	2.2	1.0	1	1.0
	bottom	12	7.6 ~6.8	7.3	0.3	12	1340 ~253	658	416	10	3.1 ~0.3	0.8	0.8	12	6.3 ~1.2	3.9	1.5	1	0.7
Regulation of Tap water				5.8~8.6		* less than 500mg/l				*** ——				** less than 10mg/l				*** —	
Regulation of Cooling Tower				6.0~8.0		* less than 500mg/l				*** ——				*** ——				*** —	
Replenishment of Cooling Tower				6.0~8.0		* less than 200mg/l				*** ——				*** ——				*** —	
Regulation of Toilet				5.8~8.6		*** ——				*** ——				less than 30mg/l				less than 20mg/l	
Rain water (last summer)				4.0~5.0		10~100				missing value				2.0~3.0				missing value	
Tap water (last summer)				7.0~7.5		250~300				0				0.5~1.0				missing value	

* Total Solids ** Potassium permanganate consumption (≒2×COD) *** No Reglation

water quality requirements of drinking water, toilets, cooling towers and replenishment of cooling towers in Japan. The quality of collected rain water is satisfactory for use in flushing toilets, and because electric conductivity is high only during the first term, it could be used for cooling towers as well.

(2) FERTILIZED TEST PIECES(E,F)

Fig.-9 shows the relationship between rainfall and water analysis.

This Figure indicates that:

<PH>

The permeated rain water was neutralized approximately PH 7 the same as the non-fertilized test pieces except at 200mm rainfall.

<ELECTRIC CONDUCTIVITY>

With the increased rainfall, electric conductivity decreased. At 200mm electric conductivity of E and F test pieces indicate 2500, 1200 ì S/cm respectively. However, at 800 mm rainfall, in the case of the discharge fertilizer ingredients,electric conductivity indicates 300 - 500 ì S/cm the same as non-fertilized test pieces.

<COD>

At the first stage, the COD value from E is as large as 70 mg/l, after 200 mm rainfall changes to approximately 20 mg/l.

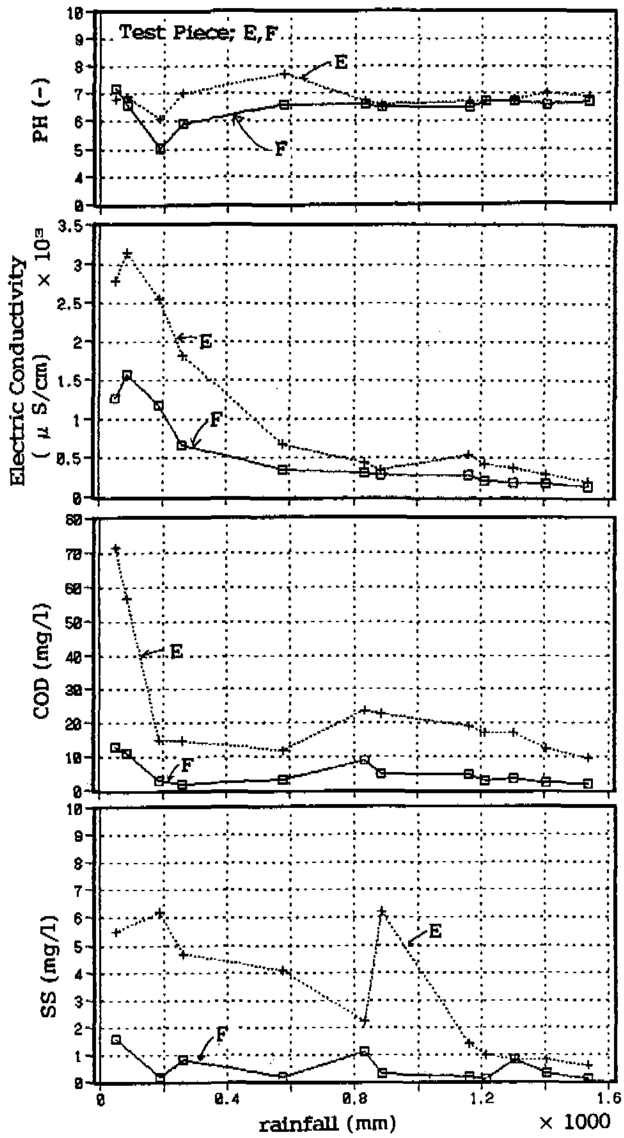

Fig.-9 Rainfall and Water Analysis

The COD values from F are less than E, as indicated at the first stage and at 600 mm 12mg/l, lmg/l respectively.

In the case of over 30 mg/l, it can't be reused for toilets, but it can be reused effectively for plant watering, which needs water and fertilizer.

<SS>
However, the SS values decreased with the increased rainfall, indicating low value steadily through out this term; the SS values from E and F are approximately 6mg/l and 1mg/l respectively.

4. CONCLUSION

In this paper the quality and the quantity of permeated rain water from open areas were examined.
The recovery rates ranged from 40 - 70% of the total rainfall, which were different from those of composed materials.
The quality of permeated rain water from non-fertilized test pieces was sufficient for flushing toilets. However from fertilized test pieces where there was a high concentration of organic and inorganic materials during the first stage, its reuse must be restricted for plant cultivation only. After 200mm rainfall the quality of reusable water from fertilized test pieces was almost equal to that from non-fertilized test pieces.
After this I would like to investigate more closely rain water reuse systems from open areas as well as from roofs, in order to develop more effective urban water systems for the future.

5. ACKNOWLEDGEMENTS

I would like to thank Mr. TAZAWA for appropriate advices and Mr. FUKUMURO for appropriate experiment and water analysis.

MODERNIZATION OF RAIN WATER CISTERN SYSTEM IN TOKYO, JAPAN

Masami ICHIKAWA*

I. Introduction

Generally speaking, Japanese Islands are plentiful in annual precipitation about 1,600 mm in average, however, annual precipitation is different from place to place and from time to time. Small islands located in the southern part of Tokyo (Fig. 1) such as Izu islands and Ogasawara islands, there are primitive rain water cistern such as Toshima, Shikine-jima, Hachijo-jima and Aogashima (Fig. 1) (Ichikawa 1989), (Omura 1960).

However, Tokyo Metropolitan area are modernized in architectures, cultures and so on especially after the World War II. Many tall buildings are characterized and low with large roofs buildings such as Shin-Kokugi-Kan, Tokyo Dome and etc. in Tokyo.

I would like to explain about the water resources for miscellaneous uses to collect the low and large roofs buildings with the modernized rain water cistern systems in Tokyo.

II. Rain Water Cistern in Shin-Kokugi-Kan

The building was constructed in old site of Kokugi-Kan in Jan. 1985. Shin-Kokugi-Kan has new type of water cistern systems. Shin-Kokugi-Kan has 1,000 m^3 in volume of rain water cistern, and collect rain water precipitated on the large roof. The large roof of Shin-Kokugi-Kan with 8,360 m^2 in area is convenient to collect the rain water. Flash water of toilet and supply water of cooling tower in the Shin-Kokugi-Kan has intended to provide the rain water collection on the large roof of Shin-Kokugi-Kan and this is correspond to 40% of total rain water. Shin-Kokugi-Kan means new Kokugi (Japanese Wrestling-SUMO-) building.

Show days such as SUMO, which are about 90 days in 365 days in annual. At that time, due to the great amount of miscellaneous water uses concentrates upon uses rain water collected from the large roof

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of Shin-Kokugi-Kan. It is concentrated to the pattern of rain water uses which rain water uses at one time an occasion demards.

Rain water from the large roof drains sewerage system at one action, it is become to the great load of sewerage system, there are connected to drainage regulation pond. A part of rain water cistern has been combined to regulation pond.

According to Fig. 2, (Takahashi 1988), rain water from the large roof has poured in regulation pond by the two systems of conducting water pipe, and make deposit sands and silts, and rain water through inflow has been filtered the rain water through inflow valve of percolator with mesh of 100 micron.

In case of enough water of rain water cistern, there is a valve which is close in emergency temporarily, and the valve which can be able to check in high water level when torrential rain is falling and the rain water has been reached cistern through this valve.

Rain water storage circulate periodically and it maintain the regular density of clorine, and it hold in check to decomposition of rain water and introduce to it clorine automatically.

Due to the dirty of the rain water on the roof, the beginning the falling rain, and controlling the inflow valve and linkage with rain gauge and timer and then, it trys to not use the rain water at the beginning of rainfall, In such a manner, rain water quality are preserved to pure, and it transported to flash toilet and cooling tower of the rain water.

In the case of long no rain period, rain water cistern bits the bottom, it must be water supply to cistern by the waterworks. It corresponds to one fourth (250 m^3) of total capacity of cistern (1,000 m^3). This water capacity is also used to melt the accumulated snow in the water.

III. Rain Water Use in Tokyo Dome and Others

Tokyo Dome was constructed completely in 1988 which is open immediately before professional baseball games in the end of March 1988. the water use of Tokyo dome is 3,000 m^3 in maximum per day. Within it, water uses 600 m^3 in maximum for toilet, 400 m^3 for kitchen and 200 m^3 in maximum for toilet, 400 m^3 for kitchen and 200 m^3 of rain water. Rain water cistern is 1,000 m^3 in the same capacity of Shin-Kokugi-Kan, and this is collected from the half roof which is 14,000 m^2 of Tokyo dome, and it is planning to use the rain water of 16,000 m^3 of Tokyo dome.

The first building of economization of water to use the rain water was Iikura Enterprise of Japan IBM. The use of the rain water has gradually promoted the spread after the 1980's. there are 77 buildings to use the rain water cistern in the end of 1977 in Tokyo and the building with the largest rain water cistern has 2,000 m^3 in volume in Taisho-Kaijo-Kasai (Company of Taisho Maritime Fire Insurance).

IV. Various Cistern System in Tokyo

Generally speaking, a building with the large roof to collect the rain water may be used to miscellaneous in comparatively cheap. For example. we use rain water to collect the roofs of plat-forms of railway stations and others. In the case of tall buildings, the uses of the rain water are not efficiency due to the small roofs and they are efficiency to use miscellaneous of individual circulation mentioned above. In case of collective houses, it takes as an example of the rain water supply of the infiltration and the storage of the rain water. In the case of individual house, it will difficult to spread the rain water cistern systems without consideration local governments such as countries because of the beginning of the investments to the installation require expenses and by the rain water trough and the rain water introduces to cistern to underground (about 2 m^3) (Fig. 3, Takahashi 1988).

In the case of long no rain period, the water in cistern bits the bottom and lower to water level and then act the electric valves and introduce to cistern by neighboring well water automatically. In the case of torrential rain, its water has been inflowed to neighboring sand and gravel layers from cistern to percolate to the underground due to overflow from the rain water cistern.

In short, it is important to recognize the water resources of the rain water to fall within site of their own houses and has effluented ground-water or be able to use miscellaneous and then it holds not outflow outside the site of the house's garden. The precious water resources become to the surface runoff, and then they will be the origins of the urban damage by floods. So if the indivisual house with rain water cistern and the percolation to underground put into practice, it will be expect to the efficiency such as effective use of rain water, effluenting groundwater and reduction of the damage by floods.

However, the rain water cistern systems are suitable effective in individual house, but the substantial effect has limited due to the small amount of the rain water collected on the roof of individual house, and countermeasures of the water resources and damage by floods in whole urban areas. For example, the rain water cistern of the Shin-Kokugi-Kan has 1,000 m^3 in volume, it is very large cistern in one building, but its volume is only one-two hundred thousandth of Okochi dam-Oku Tama Lake-. In accordance with the many buildings and many collective houses may be needed to provide the rain water cisterns and percolation to the underground.

V. Summary

An establishment of equipments is not simple, but the rain water trough and the simple rain water cistern has prepared in individual house and the rain water do not outflow to the sewerage systems and also the roads and then, the certain number of houses come to a settlement, it will be expect the suitable effects to the effluent of groundwater and reduction of damage by floods in limited small areas.

It will be more important to recognize the meaning of the rain water and to participate in the rain water operation to the common peoples. The common peoples may learn something from the rain water-water resources-, and there is no doubt about the more immaterial effects than the material effects.

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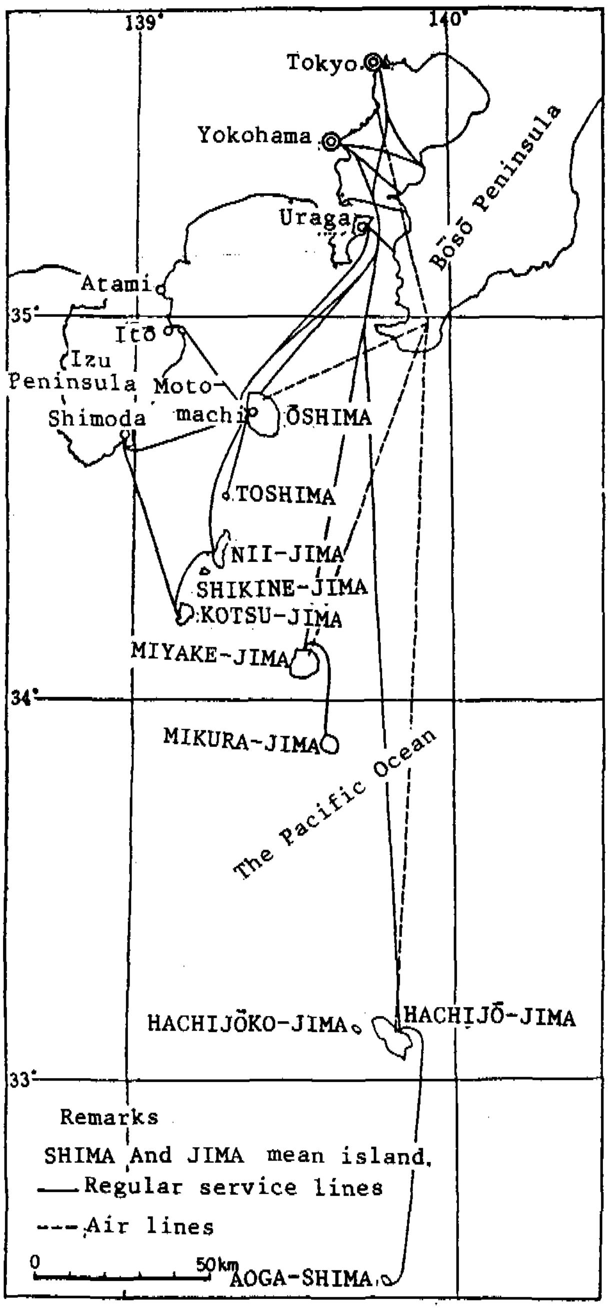

Fig.1 Geographical site of Izu Islands, Tokyo.
(Omura 1960)

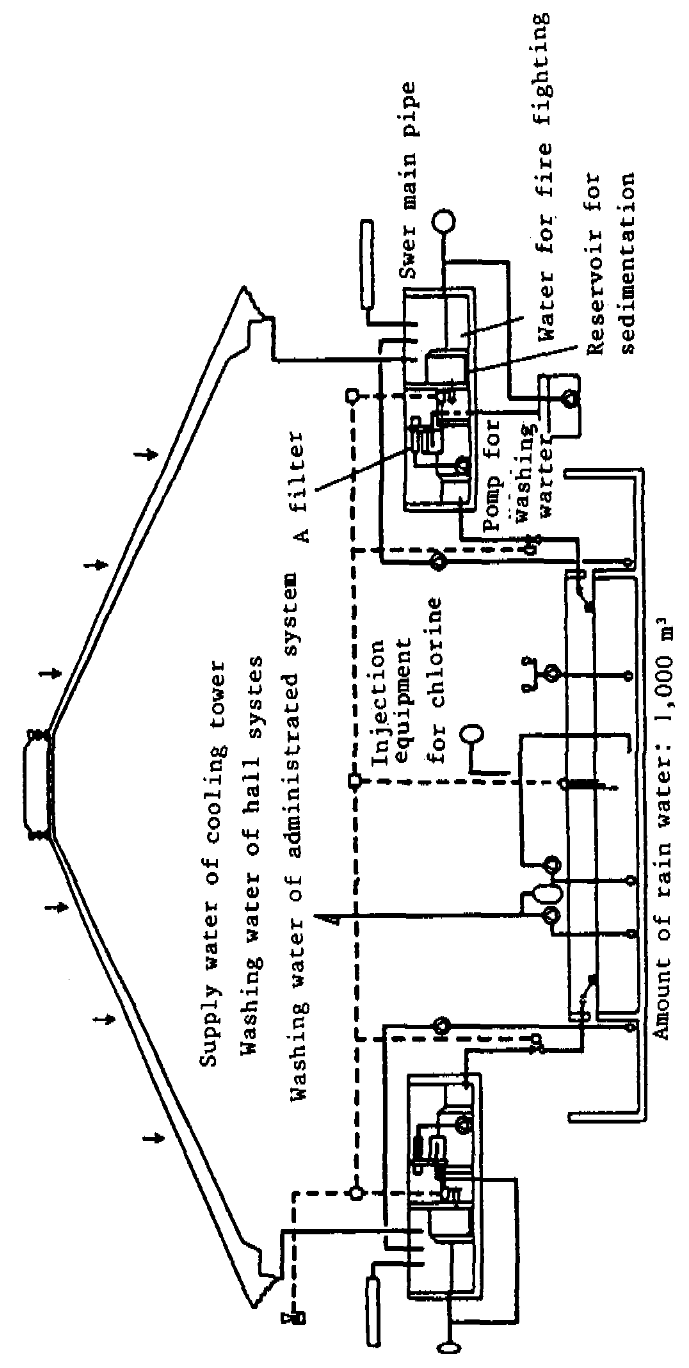

Fig.2 Rain water cistern system in Shin-kokugi-kan. (Takahashi 1988)

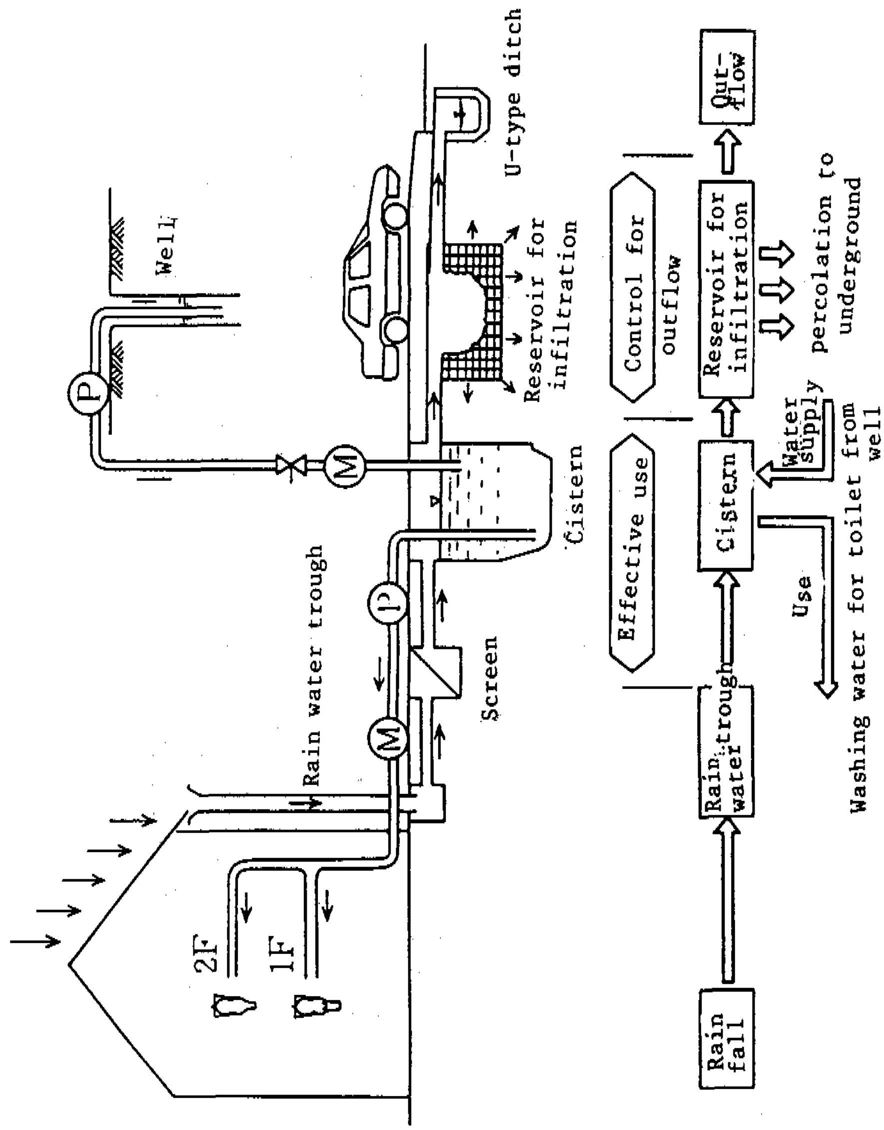

Fig.3 Effective use and control for out-flow in common houses in Tokyo. (Takahashi 1988)

GROUND TANKS IN URBAN OR RURAL SETTINGS; THE ANSWER TO WATER CRISIS

Eluderio S.Salvo*

ABSTRACT

The Philippines is a tropical country situated approximately between latitudes 5° and 20° north of the equator and longitudes 117° and 126°. This island is annually visited by an average of 30 typhoons dumping an average of 2500 mm of rains. This large amount of rainfall, however, is not evenly distributed throughout the year thus causing long periods of wet and dry months.

Analyses of the annual distribution of rainfall shows that during the period from January to June, the rainfall is about 31% of the annual average while from July to December, the rainfall is about 69% of the annual average.

It is to the problem of water crisis brought about by the long dry spell that the use of ground tanks is addressed. It can be concluded that rain water recovery through the use of ground tanks is an economical method which can be utilized in urban as well as rural water supply systems. Furthermore, ground tanks will also help in minimizing the flooding problem accompanying intense rainfall.

INTRODUCTION

The Philippines is an island country composed of more than 7,000 island. Situated in the tropics approximately between 5° and 20° north of the equator and longitudes 117° and 126°, this tropical country is visited annually by an average of 30 typhoons. The annual average rainfall is 2500 mm in which approximately 31% falls from January to June while the remaining 69% fall from July to December.

The country is divided into 12 water resources regions. While the subdivision conforms more or less with the 12 political regions, the boundaries are so chosen such that the areas categorized under

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each region took into account the prevailing climatic patterns (Quimpo, Alejandrino, Mc Nally 1983).

CLIMATE CLASSIFICATION

The Philippine climate is characterized by four types which is shown in Fig. 1. The first type (Type 1) has pronounce wet and dry season, the wet season occurring from May to October while dry from November to April. The second type (Type 2) has no dry season with a very pronounced maximum rainfall occurring from November to January. The third type (Type 3) has no very pronounced maximum rain period with a short dry season lasting from one to three months while the fourth type (Type 4) has no distinct dry season with rainfall more or less evenly distributed throughout the year. Among the four types, it can be dedduced that the areas where the Type 1 climatic pattern is prevalent would be beset by water crisis while the Type 3 climatic pattern will also have the problem to a lessor degree.

ANNUAL RAINFALL ANALYSIS

Two areas, Dagupan City in Luzon and Iloilo City in the Visayas are chosen to be analyze for the purpose of determining the size of storage needed to supply the domestic demand during the period of water crisis. Both areas have Type 1 and Type 3 climatic patterns.

Although the rainfall stations are in the cities, rainfall records are kept only in the cities for long periods of time, it is believed that the study is applicable also to the rural areas considering that the fringes of the cities are rural in character.

Rainfall Records of Dagupan City and Iloilo City

The annual rainfall records of Dagupan City are plotted on Fig. 2. Plotted also in the figure are the mean (Pm) as a horizontal line and two additional horizontal line of one standard deviation (σ) above and below the mean. The period of record was from 1902 to 1989 with a gap of 6 years which was caused by the Second World War. Since no rainfall record exists in any place in the Philippines during this period (no correlation to fill up the vacant records could be made) it is treated in the computation of the mean and standard deviation as if those years did not exist.

On Fig. 3 are shown the plot of the annual rainfall records of

Iloilo City for the same number of years as Dagupan City. Similarly the mean and one standard deviation (σ) above and below the mean are also plotted.

Results of Analyses of the Annual Records

Limiting the analyses to the years after the Second World War, it can be seen that for Dagupan City, from 1951 to 1959 there is a consistent rainfall occurrence below the mean while from 1960 to 1978, the annual rainfall fluctuated almost rythmically about the mean. Starting from 1979 to 1983, there is, again a sustained rainfall occurrence below the mean.

Also from 1947 to 1989, there are five exceedance (Pm + σ) while there are eight exceedance (Pm - σ). From this, we can say that the annual records are skewed to the left and there is a tendency for the occurrence of drought.

On Fig. 3 for Iloilo City the occurrence of sustained rainfall below the mean is more apparent. The years, 1946 to 1971 except for 1949, 1956, 1961 and 1965 can be considered drought years.

Also from 1947 to 1989 there are only two exceedance (Pm + σ) while there are eight exceedance (Pm - σ). We can again say that the annual records are skewed to the left and has a tendency to the occurrence of drought.

MONTHLY RAINFALL RECORDS

Although the annual records give us an idea of the long trend behavior, shorter periods is necessary for water supply purposes and so monthly average rainfall and the standard deviation associated with each average value is analyzed.

In Fig. 4 and 5 are plotted the mean monthly rainfall and the standard deviation as a function of the calendar month for the cities of Dagupan and Iloilo respectively.

From these figures the significant variability of the monthly rainfall is very evident. It can be deduced that there exists the possibility that when the standard deviation is greater than or equal to the mean in any given month, no rainfall occurred in that month.

Referring to Fig. 4 for Dagupan City, it can be seen that the values of the mean minus the standard deviation (Pm - σ) will be negative for the months of December to March. It can therefore be concluded that these are the water crisis months.

Similarly, referring to Fig. 5, for Iloilo City, the months February to April are the water crisis months.

The number of years of record that are analyzed for Dagupan City and Iloilo City month by month has a total of 25 years each.

A diagram showing the years of average, tolerance limit and confidence level was made for Apia, Western Samoa (Lo and Chiang, 1989) which is applicable to all locations. Based on this study, Dagupan City and Iloilo City for a tolerance limit of 10 will have a 97% confidence level.

RAIN WATER CISTERNS SYSTEM

The Rain Water Cisterns System (RWCS) in the province of Capiz in the Philippines has now considerable experience in the building of ferro-cement tanks. In that study the smallest tank size was 6,000 liters and 16,000 liter tanks were sited in schools having 240 pupils and teachers (Appan, Villareal & Wing, 1989).

Storage Volume For Domestic Use

For Dagupan City, a single household of 6 members, using a consumption of 15 liters per capita per day (Dharmabalan, 1989) a minimum storage of 10,800 liters will be needed to take care of four crisis months.

Similarly, for Iloilo City, using the same single household of 6 members and a consumption of 15 lpcd, the minimum storage of 8,100 liters will be needed for the three crisis months.

Effect Of Storage On Flooding Problem

It has been mentioned that a 3-hour storm with a recurrence interval of once in 10 years should be the basis of drainage design (French, 1988). Applying this to Dagupan City and Iloilo City the extreme values of rainfall for these parameters are 107.7 and 92.3 millimeters respectively (PAGASA, 1981).

Assuming that each individual household will have 100 square meters of roof area, and assuming further that the cistern of each household is half empty at the time of occurence of the storm, then only 5,370 and 5,180 liters will be contributary to the flooding problem instead of 10,770 and 9,230 liters for Dagupan City and Iloilo City respectively.

CONCLUSION

This study shows that for every location in the Philippines, depending on the climatic pattern, a certain minimum storage for each individual household will be needed to provide its drinking needs. Through proper management of the RWCS, a family can have access to water during the water crisis months. It has been shown also that RWCS maintained by each individual household will help minimize the flooding problem of a community during the occurrence of a severe storm.

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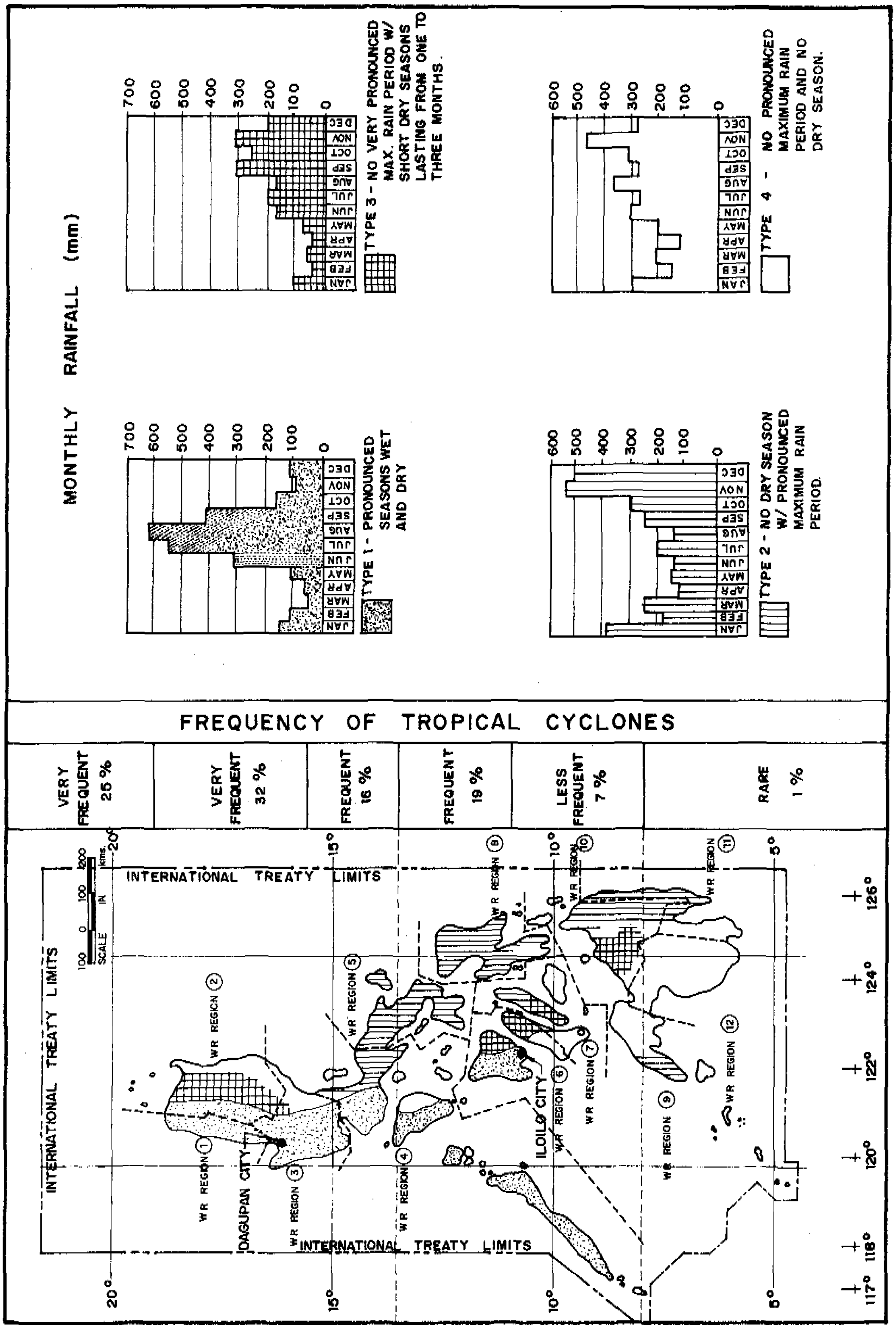

Fig. 1 Climate Map, Republic of The Puilippines

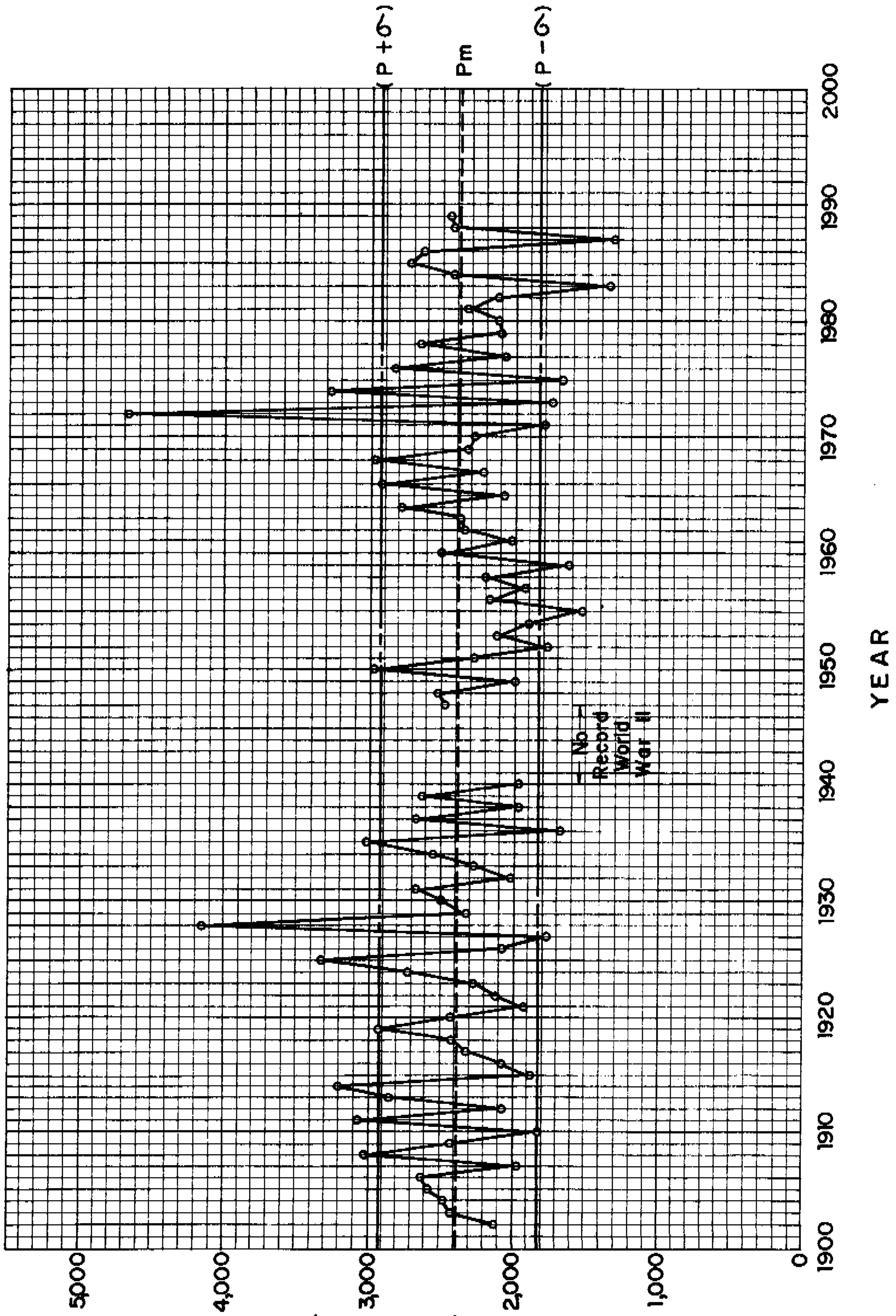

Fig. 2 Annual Record of Rainfall (Dagupan City), 1902-1989

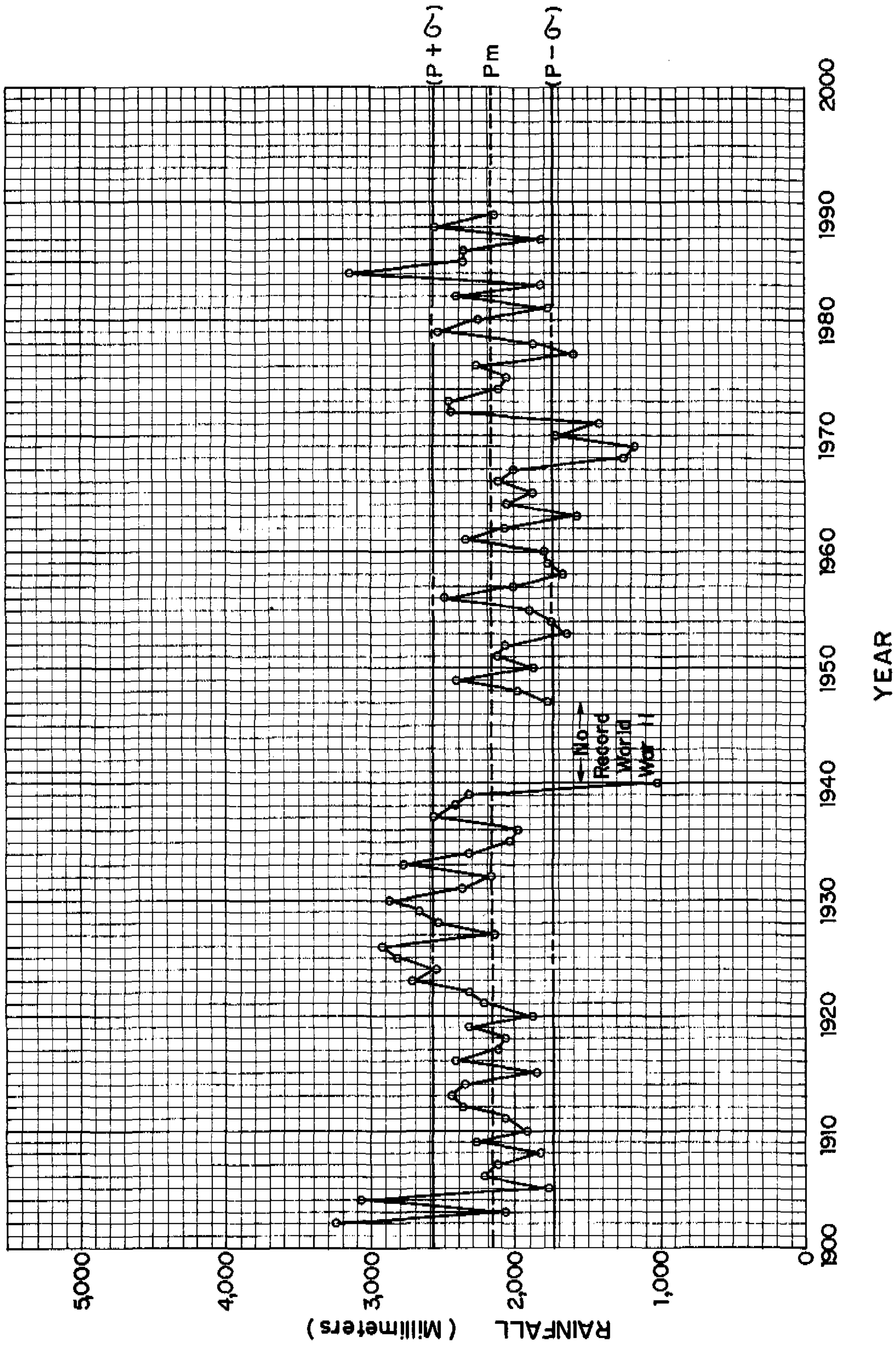

Fig. 3 Annual Record of Rainfall (Iloilo City), 1902-1989

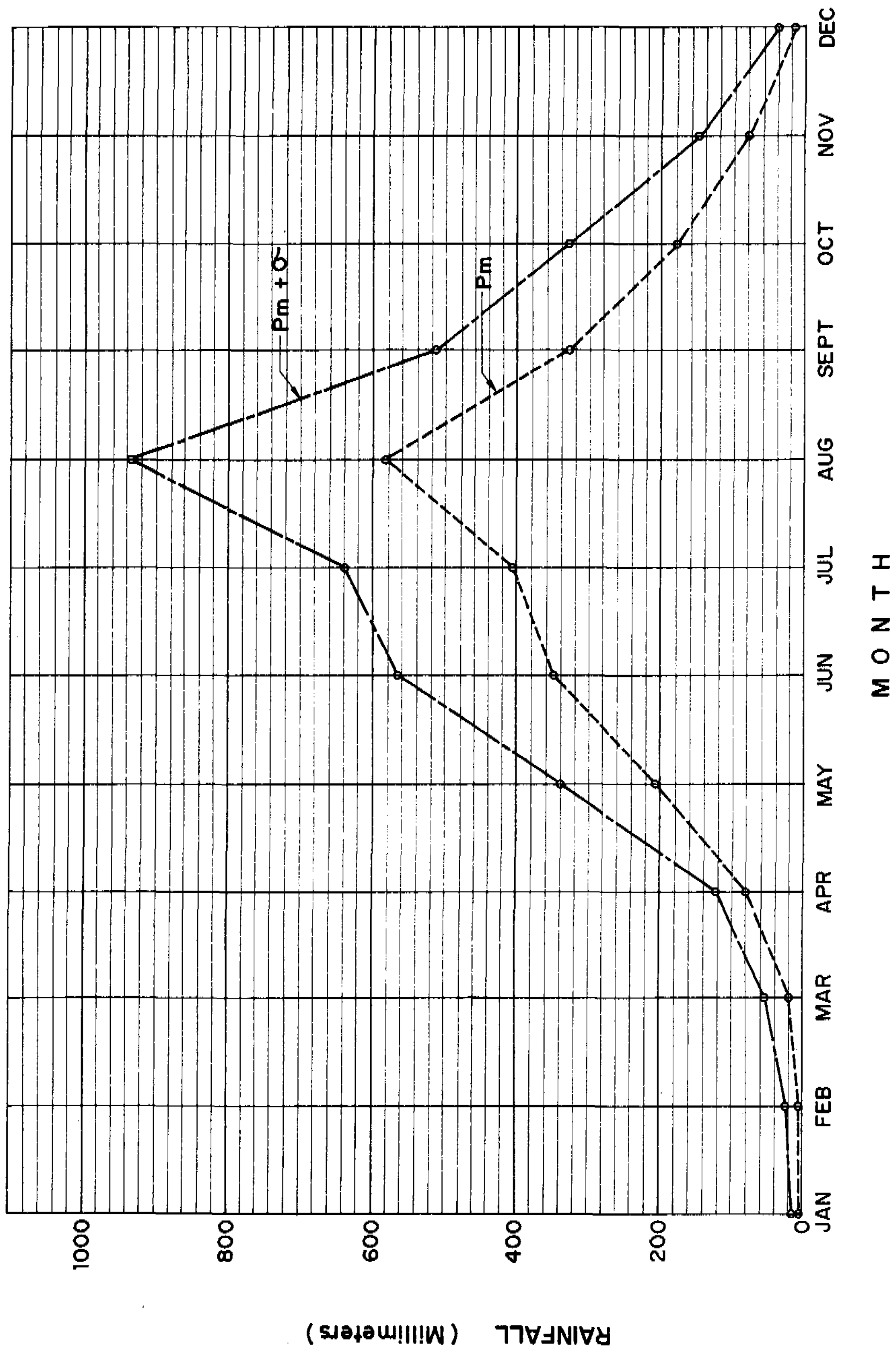

Fig. 4 Monthly Record of Rainfall (Dagupan City), 1951-1975

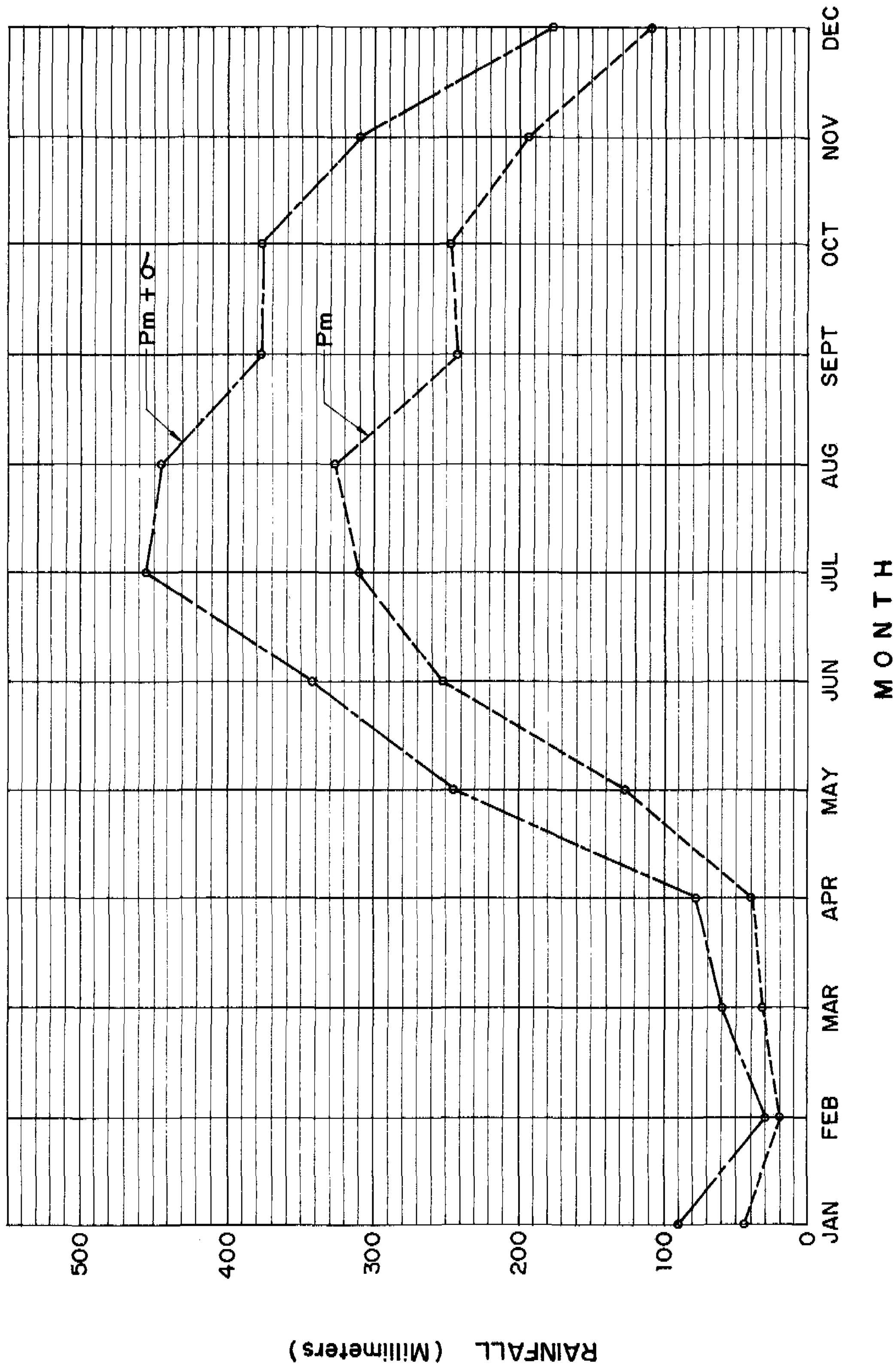

Fig. 5 Monthly Record of Rainfall (Iloilo City), 1949-1974

Store and Utilization of Rainwater with Tameike Cistern System at Rural Areas in Northeast Thailand

Naoki Utsunomiya and Isao Minami

ABSTRACT

In northeast Thailand, 10 tameikes, designed to store rainwater which is catched at paddyfield, were constructed at two villages where they often suffer from drought damage under rainfed condition. Field data on the ability of tameike pond to conserve rainwater and the possibility of the rainwater utilization for agricultural production were collected.

It was shown that rainwater was efficiently catched and stored with tameike system in rainfed farming areas. Every pond was filled with rainwater flowed from paddyfields during wet season and the rainwater could be conserved even under dry season condition. The stored rainwater seems to have the ability not only to alleviate drought damage but also of desalinization.

Rice cultivation has not been affected by dry spell caused by erratic rainfall because the stored rainwater could decrease the damage. In addition, horticultural crops growing and fish raising were promoted owing to the available water all seasons. Although the benefits areas of the rainwater for these crops or fish cultivation were confined, the amount of their productions was enough to meet self-sufficiency. In some cases their products seem to have a potential to increase income.

These suggests that tameike system is an effective measure which developes rural life in small scale with utilization of rainwater in rainfed areas. This system is more adaptable to improve the subsistence agriculture. The avoidance of the drought and increased the agro-aquaculture due to the stored rainwater may increase the standard of living in the village.

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INTRODUCTION

Rainfed cultivation is one of the cultural methods utilizing rainwater directly for agricural productions. In the tropics, especially at subhumid and semi- arid areas, this cultivation is practiced on much more farmlands. Under rainfed farming, since the crops growing exclusively depends on rainwater, rainfall which keeps sufficient soil moisture as long as possible is an important factor for harvest security.

In northeast Thailand the climate is sharply divided into dry and wet season. As most cultivation areas are occupied by rainfed lands, rainfall in the wet season is very important for the life in rural areas. However, they always face the danger of water deficit because the rainfed areas are subject to seasonal and year to year fluctuations in time of onset quantity and distribution of the rainfall. The frequent occurence of dry spell, decreases productivity, is regarded as a reason for the lower standard of living in this region. Therefore, it is necessary to develope the water resources which can get rid of drought damage for improving the rural life.

It is believed that water harvesting can increase the crop production in arid areas. There have been some reports that run-off interception with watershed system was effective to increase crop yields (Vittal et al. 1988. Vijayalakshmi et al. 1989. Grewal et al. 1989). However, it is indicated that the effect of water harvesting technique on crop production has been obtained at research station, but such thequnique has not been adopted significantly by farmers in several countries(Reij 1988). In Japan, tameike (agricultural farm pond), designed to directly harvest rainwater, has been constructed since early times to avoid drought caused by rainfall uncertanity during wet season. The tameike ponds had spread over the rural areas and have played an important role in rural development with increasing the rice production.

In this study, tameike ponds were constructed at paddyfield in northeast Thailand. Field data on the capability of tameike to store rainwater and the practical use of the rainwater by farmers were collected. The possibility of tameike system to develope the tropical rural areas which suffer from drought caused by erratic rainfall was discussed.

MATERIALS AND METHODS

Sites and Rainfall: Field study was conducted at two villages, NonKhwao, KhonKhaen and NonChan, RoiEt in northeast Thailand (Fig.1). They have wet (Apr.-Oct.) and dry(Nov.-Mar.)season (Fig.1). The average ofannual rainfall is about 1000mm, but the amount and pattern vary greatly from year to year. In both villages farmers make their living mainly on rainfed rice cultivation during wet season. However, dry spell often occurs because of sporadic rainfall, which gives drought and salinity damage to rice cultivation and greatly reduces the yield. This is a reason why their living standard is lower. During dry season, little rainfall extremely decreases the agricultural activity and sometimes causes the shortage of domestic water.

The structure, arrangement and owership of tameike: Tameike was designed to store excess rainwater cacthed in the paddy field (Fig.2). The average size of tameike pond was as follows; maximum water storage volume 6400m^3(max. 15000m^3, min. 3700m^3), water surface area 2100m^2(max. 4000m^2, min. 1400m^2), embankment area 2700m^2(max. 4000m^2, min. 1800m^2). The pond was excavated to the point at which ground water exuded out for minimizing the water loss by seapage. The average depth was 4.3m(max. 5.5m, min. 3.5m). Ten tameike ponds were constructed at each village in 1984-1986. These ponds were arranged in the paddyfield. A pond was owned by 3 or 4 households which offered their land for the pond construction. The right to use the water was shared between these farmers in each pond.

Field data collection: After tameike construction, the water depth and the water salinity level has been measured. The way of water use was decided by farmers themselves. We observed how farmers utilize the water for their agricultural practices. The data on productivites were collected with a questionnaire.

RESULTS AND DISCUSSION

Conservation of rainwater: With the beginning of wet season the water depth in tameike pond increased and reached to maxium level at the end of wet season. (Fig.3a). Thereafter, it continued to decrease gradually until the end of dry season, but began to increase again with start of wet season. These indicate that excess rainwater is efficiently stored with tameike system during wet season. Torii and Minami (1985) reported that about 4000m^3 water is enough amount to irrigate continuously to 30a paddy field for 20 days during drought. Each pond was nearly full of rainwater during wet season. It is considered that rainwater which considerably mitigates the drought damage during rice cultivation can be conserved in the tameike pond.

The fluctuation of water level is associated with the balance of rainfall and evaporation in tameike system.' The level decreases because of no rainfall and high pan evaporation rate during dry season. As the evaporation rate in this region is about 2m/year, little water may not be kept in the shallow pond where the depth is less than 2m. However, in every tameike pond, which is designed to be deeper than 3.5m, rainwater can be conserved during dry season although the water level reached to as half as the maxium level.

All tameike ponds have always stored the rainwater throughout the year with varying their water levels since they were constructed. This demonstrates that the tameike system is one of the effective methods to catch and conserve the rainwater under wet-dry season condition.

Water quality: Rainwater remarkably reduced the salinity level in the pond (Fig.3b). Although low or high saline ground water, being 4-30dS/m, sprang out at most tameike ponds, the salinity level decreased rapidly with increase in the volume of conserved rainwater at NonKhwao village. Within about half a year the salinity level decreased by less than 3dS/m at which the water is available for irrigation. Minami et al.(1986)suggested that the downward movement of saline ground water by force of the gravity of conserved rainwater is a reason why salinity level decreases in the pond. By this way rainwater seems to have a potential of desalinization at saline hazard areas. The salinity level has been kept at low level in all ponds even during dry season when the water level decreased.

It took more than one year for the salinity become low level in most ponds at NonChan village. The difference in the rate of salinity reduction between two villages dose not seem to be caused by the difference in the salinity level of ground water or the stored volume of rainwater. Geological features and soil structure may influence the desalinization by rainwater in tameike system. They have been often more adversely affected by salinity damage at NonChan than NonKhwao. Further research on desalinization will be needed when tameike system is introduced to heavily salt-affected areas.

Utilization of conserved rainwater: This study showed that the conserved rainwater can always bring about the sustainable rice production in the rainfed cultivation by reducing the yield loss caused by uncertain rainfall during wet season. When dry spell occurred the rainwater was pumped out to the near paddyfields for irrigating the rice plants. The benefit area of pond water, being restricted, was varied with the stored rainwater volume and the pattern or quantity of rainfall. The results on the use of the conserved water suggest that rice production can be sustained by the supply of $500m^3$/ha rainwater under drought condition lasts for 20 days.

The productivity in the paddyfields was increased due to the the conserved rainwater because some crops can be grown even during dry season. In India the water storaged in tank permits the second crop production in dry season in addition to the first production during wet season(Barrow 1987). The rainwater in tameike also could result in some production of beans, maize, or vegetables in dry season. These crops were cultivated mainly for home consumption since the benefit areas are confined within 1-5a because of limited water volume. However, the cultivation of water melon and tomato for seed production became available, by which farmers could get some cash.

Franco et al.(1986) reported that stored rainwater in small farm ponds can be used effectively to grow vegetables during dry season. In tameike system, horticultural crops could be cultivated thorughout the year by utilization of the conserved rainwater. The embankment of the pond became suitable place for growing the many kinds of vegetables and fruits. These crops could be planted and harvested at any season owing to the rainwater being available all the time. Typical cropping pattern of some vegetables on the embankment is shown in Fig.4. Many species can be grown simultaneously since each crops was grown at small plots (1.5-$40m^2$). Most of the amount of productions was consumed at home, but farmers could get some cash when the surpluses were sold(Table 1). Hopper(1989) suggested that an avilability of nutrient-rich fruits and vegetables would contribute to easing the distress of rural people in developing nations. Clawson(1985) stated that horticultural crops are important for improving the nutritive condition and incomes of local farmers in the tropics. This study indicates that the conserved rainwater in tameike has a great potential to bring farmers sufficient amounts of vegetables and fruits and to increase income through securing the harvest.

The conserved rainwater was utilized for fish raising. At rural areas in this region, fish, one of the main protein sources, is aboundant only during wet season, and farmers trap them in paddyfields or pits (Sirisambhand 1985). Usually fish rasing is impossible without effective water storage system because of little rain during dry season. However, tameike enabled farmers to raise fish continuously with the rainwater conserved all the year round in the deep pond. Fry of chinese carp, common carp, golden rice carp, tawes and tilapia were released in the pond. The first harvest was done partially about one year after releasing, thereafter, farmers could catch the well-grown fish at appropriate time. In this tameike system fish was raised mainly for home consumption, but it also was effective to increase income(Table 2).

It was shown that fish raising is possible at relatively high saline water under which crop cultivation may not be impossible. Although fish weight became less at higher saline water, the yield was sufficient to satisfy the home consumption (Table 2). The introduction of tameike to dry and saline hazard area may increase the fish production.

Hatch and Engle(1987) found that fish raising accompanied with either duck, chicken or hog increased the yield at small pond system. Fertilized pond water by manure of these livestocks seemed to promote the fish growth. In tameike system it is also possible to feed these animals on the embankment. Combination raising of fish and livestock is considered to be a method to increase the utilization efficiency of rainwater stored in the tameike.

In this study the possibility of floating nursery is now being examined on the surface of rainwater in tameike. To date, it was demonstrated that some kinds of crops can be cultivated on floating foam(1x2m^2) loaded with soils 15cm in height. In this cultivation, water is utilized more efficiently for cop production because some amount of water evaporates through crop body. This floating method could decrease the labour power for watering the crops, and prevent the crops from the attacks of animals or insects. At Inlay lake in Myanma vegetables have been produced on the floating bed. Lately this cultivation method also has been researched on some lakes in China(Ling, 1989). With this method, one of the hydroponic cultivation, water resources is fully utilize and cultivation areas is increased. Floating many beds on water surface will conserve water longer through decreasing the evaporation volume fromt he surface. Use efficiency of the conserved rainwater may be increased with floating cultivation.

CONCLUSION

Field data collected at two villages in northeast Thailand indicate that the rainwater conserved in tameike is of great use for improving the subsistence agricultural life in rainfed farming areas under tropical monsoon climate. Since the some volume of rainwater is always available, the damages of drought and salinity can be mitigated to some extent. At benefit areas of tameike system, the water enabled the small scaled agro-aquaculture all the year round(Fig.5). It was shown that this cultural system can produce sustainable yields of rice as staple food, horticultural crops for better nutrition and fish as a protein source and has a potential to increase of cash income. This suggests that tameike system is an effective method to develope the rural life with the utilization of rainwater. The conserved rainwater in tameike can also be used domestically and sometimes as drinking water. If rainwater can be conserved efficiently, farmers can ride out even when they face with heavy drought.

The results on conservation and utilization of rainwater in tameike system obtained in northeast Thailand can be considered applicable and transferable to other areas with similar climatic conditions and futhermore to arid areas. However, at less rainfall areas, design, scale and site of tameike should be taken into account so that rainwater can be captured and stored more effectively. Decreasing the water evaporation will be an important factor for the conservation of rainwater as long as possible. Floating nursery may be more effective to utilize rainwater under dry condition.

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Table 1 Total yeild, % of sold production and income by selling of 4 kinds of vegetables and papaya grown at 3 tameikes from Apr. 1985 to Mar. 1986 At NonKhawo village.

Crop	Toatl yield(kg)	Amount of sold production (kg)	% of sold production	Income (bath)
Chinese cabbage	510	450	88	1600
Shallot	210	145	69	1385
Chili pepper	132	79	60	1075
Eggplant	295	260	88	780
Papaya	360	292	81	1000

ca. 25bath=1US$

Table 2 Fish production and income from fish raising in tameike pond at NonChan village (Mar. 1, 1987)

Pond No. and salinity	Kind of Fish	Fish weight	Total yield	Income
No. 3	Chinese carp	700g	36kg	1124 bath
(11.5dS/m)	Golden rice carp	125	94	50% of total yield
	Tawes	100	32	were sold.
No. 4	Chinese carp	1100	57	2562 bath
(5.5dS/m)	Golden rice carp	162	61	95% of total yield
	Tawes	234	53	were sold.

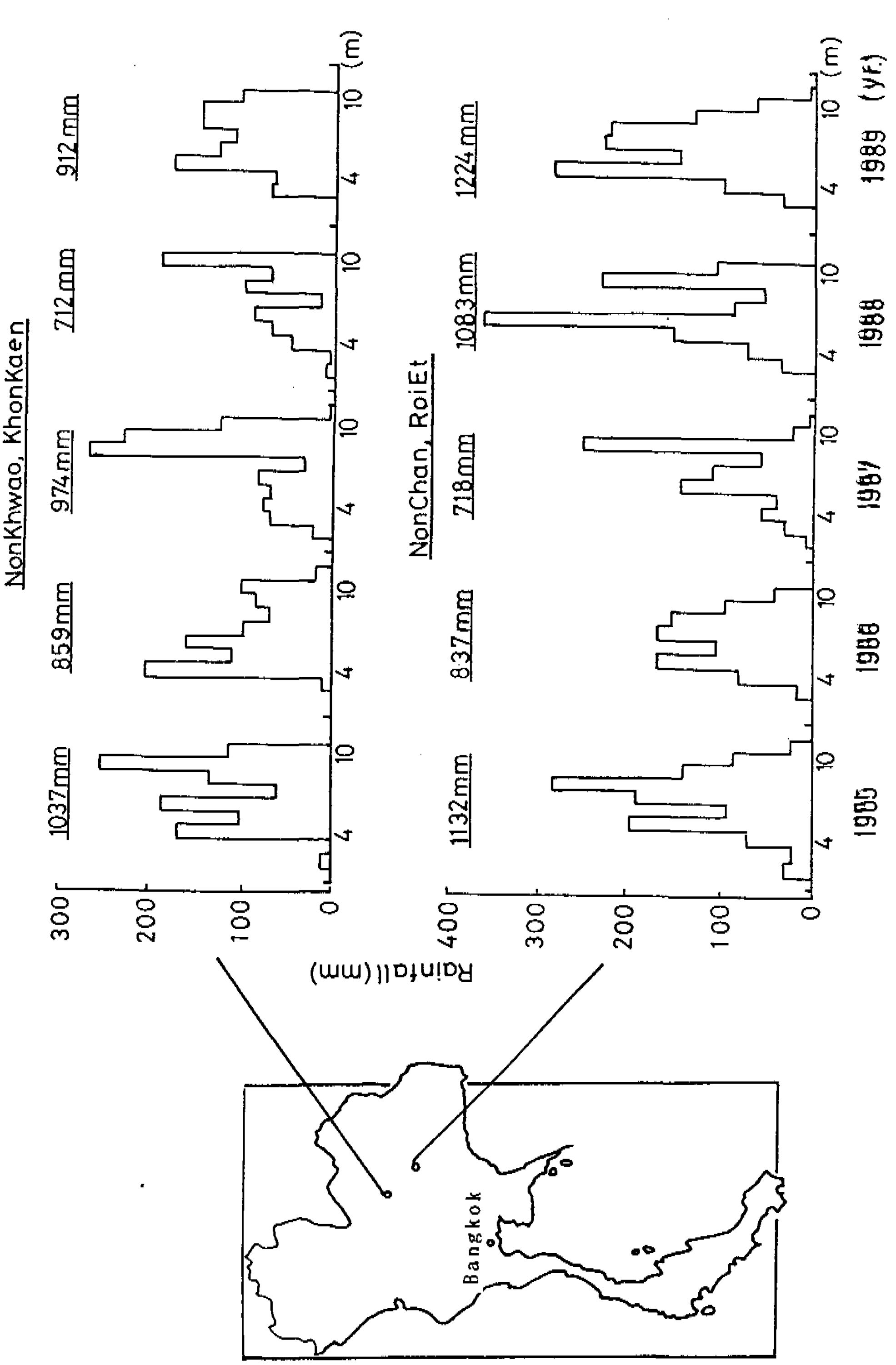

Fig.1 The sites of two villages where study was conducted and the rainfall pattern in recent 5 years.

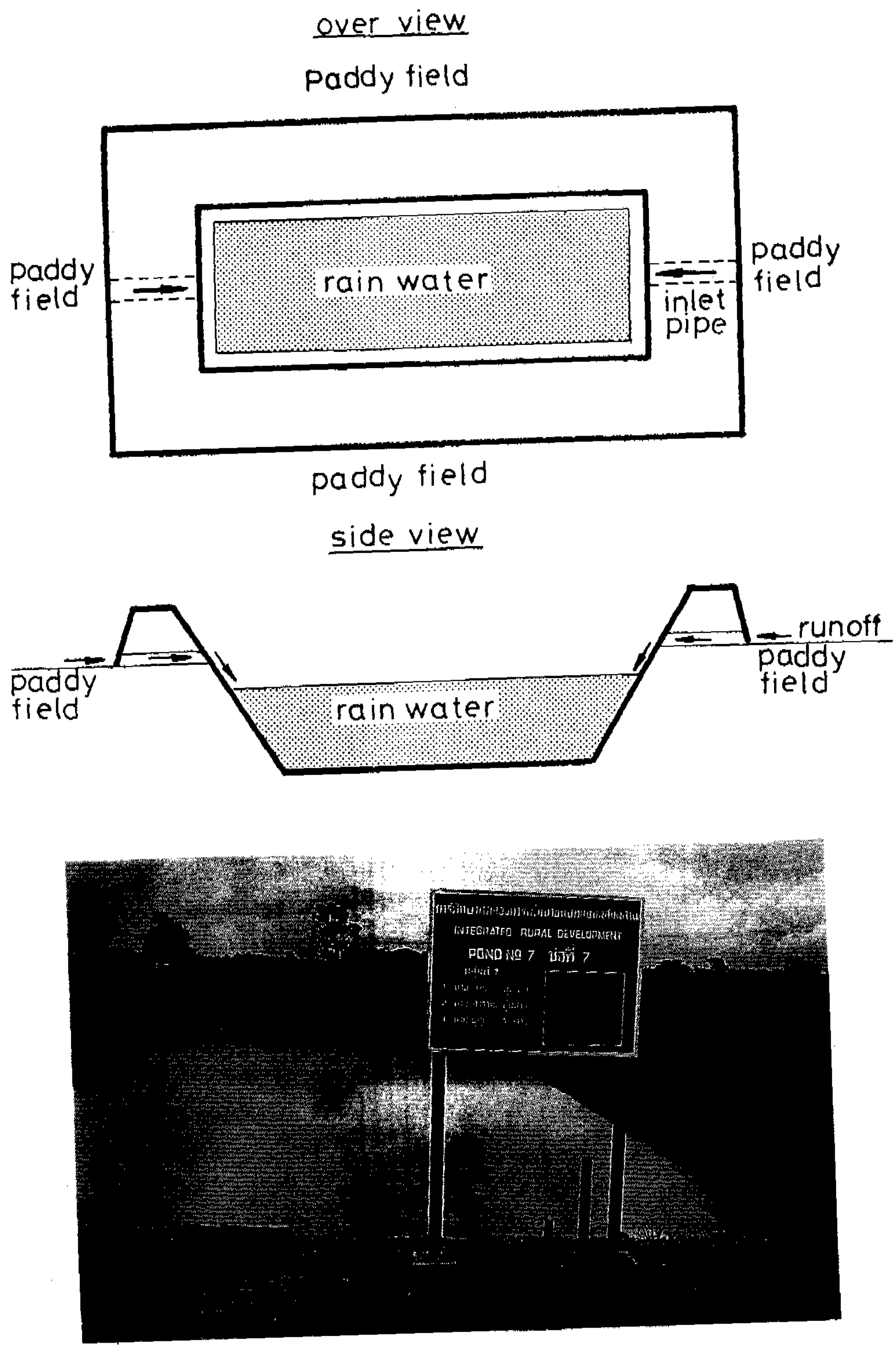

Fig.2 The schema of tameike pond structure and the view of completed tameike.

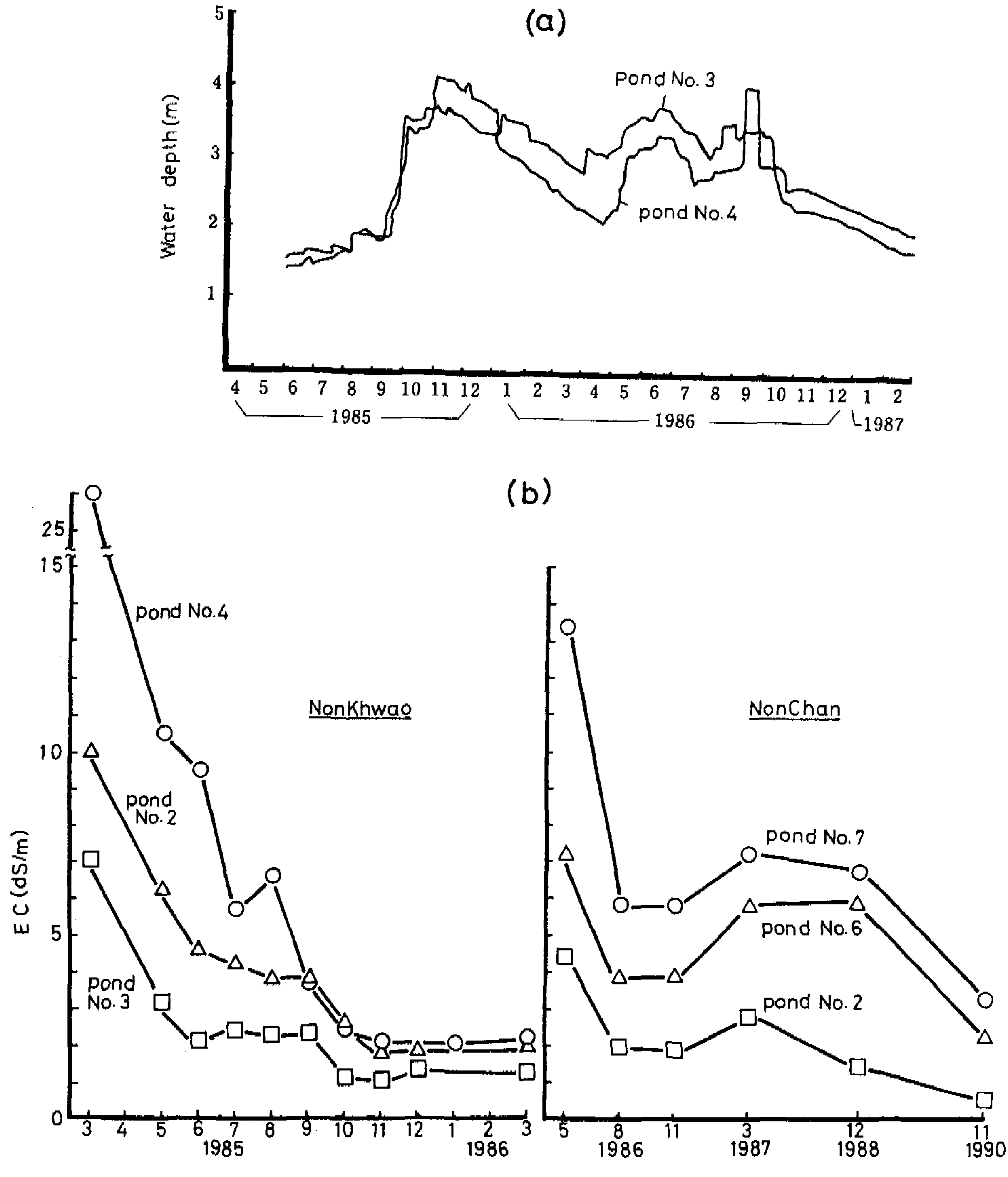

Fig.3 Seasonal changes of water depth in tameike at NonKhawao villagte(a) and change of pond water salinity at NonKhwao and NonChan village(b).

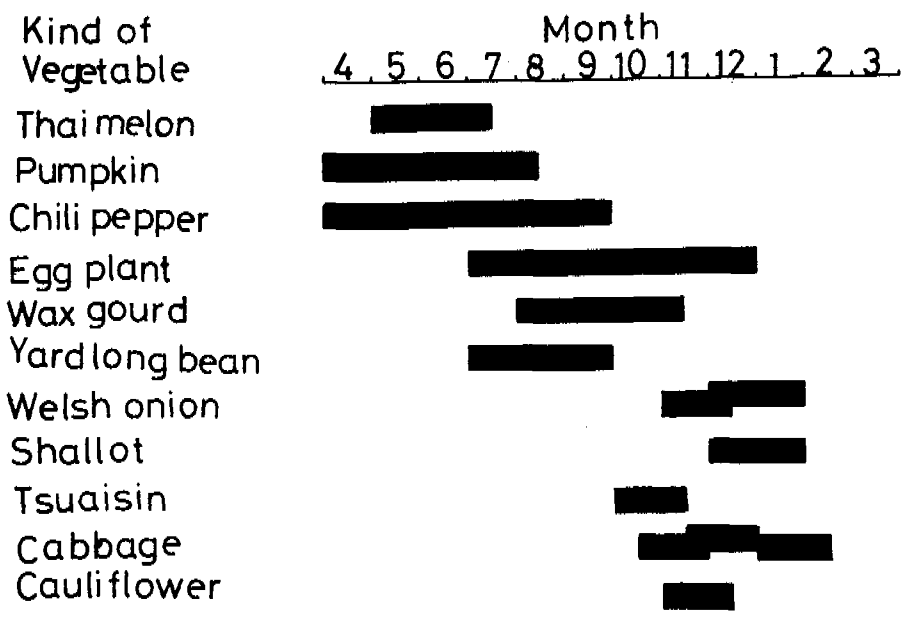

Fig.4 Kinds of vegetables and their cropping pattern on the embankment.

Fig.5 Argo-aquacultural activities at benefit areas of conserved rainwater in tameike system. (a) Floating cultivation. (b)Growing vegetables all season on the embankment. (c)Paddy-field irrigated with tameike water during dry spell. (d)Fish raising in the pond. (e) Crops growing in the paddyfield during dry season.

Extending the Limits of Rubber Dam (Sumigate) Technology

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Haruhiko Matsuoka***, Kazutoyo Yamada****
Katsuya Sakaguchi*****

1. Abstract

Sumigate is a inflatable and deflatable rubberized fabric dam (rubber dam), which consists of a rubberized fabric tube, operation equipments and pipings. It is inflated by air or water and used for various applications, such as, irrigation, water supply, tidal barrier, etc. because of its many features, namely reliable deflation, easy and quick installation, low cost, excellent durability, and easy operation and maintenance. We have installed about 1200 rubber dams (most less than 3 m high) for mainly irrigation since 1966.

We developed materials for higher rubber dam,full automatic operation system actuated by solar battery, and special cushioning technique and have installed the 5 m high experimental rubber dam in 1982 in cooperation with the New Energy Foundation and the Electric Power Development Co..

After ten(10)years observation since the installation, it has no damage and it has become clear that our large Sumigate is operating effectively as an diversion dam even in the upriver.

Moreover as the number of rubber dams increased, their reliability was revaluated through practical demonstration. In 1990 the Japanese Ministry of Construction has installed the first actual use high dam(Inou river: 4.71 m H * 24 m L) for irrigation and tidal barrier, exceeding the construction regulations, that prohibited the use of higher rubber dams than 3 m high dams, and the Electric Power Development Co. starts to install the highest dam (Kurotani river: 6 m H * 34.5 m L) for small hydropower diversion dam this year.

This paper describes the current status and future potential of the inflatable rubber dam in Japan through the development procedure of a higher rubber dam.

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2: Sumigate

2-1. Introduction To Sumigate

The dam, anchored on a concrete slab, consists of a rubber tube which is inflated with either air or water, a control room to accommodate operating equipments and pipes connecting these equipments with the tube as shown Fig 1. It can be deflated automatically in flood conditions.

It is used for various applications such as irrigation, tidal control, water supply, flood control, sewage plant, small hydro power, etc. (see Fig.2)

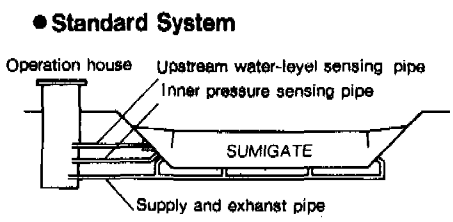


Fig.1 Rubber Dam Structure

Fig.2 Sumigate for Yamakita Power Station(2.5mH*19mL)

The idea of a inflatable dam was originally conceived by Mr. N.M. Imbertson in 1957 who, at that time, was the chief operations engineer for the Los Angeles Department of Water & Power. The first installation in Los Angeles river was completed in 1957 (gate height: 1.52 m. gate length: 39.62 m). Since then, rubber dams have been installed in Japan. Australia. Hong Kong. Canada. Taiwan, Thailand and other countries.

Sumigates have many features and advantages over the conventional movable steel gates, such as easy & reliable deflation, easy & quick installation, low construction cost, excellent durability, and easy operation & maintenance.

Therefore we have installed approx. 1200 Sumigates in Japan & other countries, since the first installation in 1966. They are all operating effectively still now. Among the installations completed by us, the experimental dam on the Ogamigo river, in the Gifu prefecture, is the highest with a crest height of 5.0 m and has the actual proof test. The dam on the Mae Yom river in Thailand is the longest at 350 m. In South Korea, the raising spillway dam installed on the Dofuku concrete dam, is a single span of 80 m.

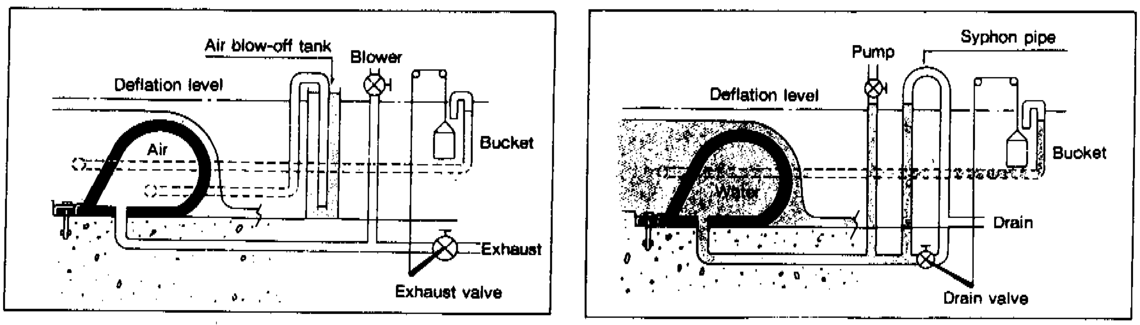
The Sumigate is really best suited to small and medium-sized rivers. It has a wide field application.

With recent increases of dam size, possible applications has become more and more numerous, especially irrigation in the middle reaches of rivers and small hydropower in the upper reaches of rivers, where we have many sites with undeveloped hydropower.

2-2. Basic Technical Description

A Sumigate consists of an inflatable tube of rubberized fabric. It is installed across a river with a control module to accommodate the equipments, which inflates and deflates the tube, and the connecting pipes.

The principles of construction and operation of Sumigates are slightly different, according to the inflation method. These principles are shown below on Fig. 3,. Although a water inflated type is slightly more stable than a air inflated type agaist to the vibration caused by high overflow depth, a air inflated type is less expensive than water inflated one. Therefore recently almost of all Sumigates are air inflated type.



Air Inflation Type　　　　　　Water Inflation Type

Fig. 3. Basic Operation System of Sumigate

As shown on Fig. 3, air or water is supplied to inflate the tube. In the air inflation type, air is forced through the air inlet by a compressor or blower. In the water inflation type a pump is used. The dam is protected against over-pressure during filling as any excess is relieved automatically through the blow-off tank or syphon pipe. Similarly, a fully inflated Sumigate will deflate automatically under flood conditions. When the upstream water level reaches a pre-set level, the dam starts to deflate as the exhaust valve or by-path valve opens automatically by bucket system.

These basic inflating and deflating system have been kept very simple to promote reliability. Therefore these basic systems should be installed as the safety devices even in the full-automatic electric operated Sumigate.

3. Development of Higher Sumigate for Small Hydro Electric Power

Rubber dams have additional advantages for use as diversion dams for small hydroelectric power stations.

1) Preventing debris from impairing their diversion function.
2) Increasing the total hydroelectric energy output by reducing the shutdown period for removal of sand and other debris.

Since diversion dams for small hydro stations are generally located in the upper reaches of rivers, such dams are subject to impact by rapidly flowing rocks. Consequently, in order to utilize rubber dams for such small hydro station diversion dams, it is necessary to develop a higher and larger size dam, and to improve its resistance to impact of many debris.

3-1. The Experimental Dam (5 mH * 10 m L) of Ogamigo River

In 1982, the experimental rubber dam of 5 m height and 10 m length was installed in Gifu prefecture in order to research the dam's performance under the actual, severe conditions. (see Fig.4.)

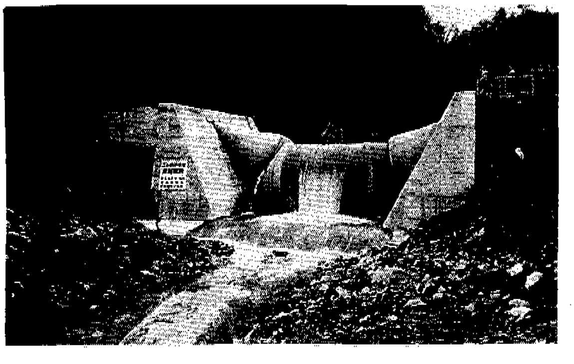


Fig.4. Experimental Dam

Its specifications are shown in the following table (Table 1).

Table 1. Specifications of the experimental rubber dam

dam:	dam height:	5.0 m
	dam length:	10.0 m (at river bed)
	inflation type:	air inflation
location:	river name:	Ogamigo river
	river slope:	1/27
rubberized fabric:	materials:	nylon fabric & chloroprene rubber
	number of ply:	3 plies
	tensile strength:	2130 kg/cm
	breaking elongation:	approx. 30 %
	thickness & weight:	16 mm & 19 kg/m**2

The rubberized fabric which we developed consists of synthetic fiber which provides strength and rubber which provides watertightness. Working strength in a dam develops in proportion to the square of the dam height. Therefore we had to develop high strength rubberized fabric in order to realize production of higher Sumigate. We produced fabrics with tire of basket weaves made of nylon or kevlar as a trial, taking into consideration the strength of the fiber and its adhesiveness to rubber. And we selected above mentioned rubberized fabric.

3-2. Deveropment of Special Cushioning

The main cause of damages to a Sumigateis from large rocks, stones and ice blocks puncturing the deflated dam (usually during flooding). This kind of damage was supposed to be often occured in a Sumigate installed in the upper reaches of rivers, then we have developed the special cushioning as a preventive measure, it adopts ashock-absorbing procedure by providing the resilient cushions to the inside of dam as shown in Fig.5.

In each rubber dam project, we determine the thickness by calculating the minimum energy of flowing rocks on the basis of each site flood conditions. For the experimental rubber dam, we provided 200 mm thick cushion.

We developed materials, such as the special cushioning and a high-tensile strength rubberized fabric for use with high dam. We have installed the 5 m high experimental rubber dam in 1982 under subsidized by the government and observed it since installation.

Initial tests of deflation, flushing and removal of sand and boulder were carried out and the results were excellent.

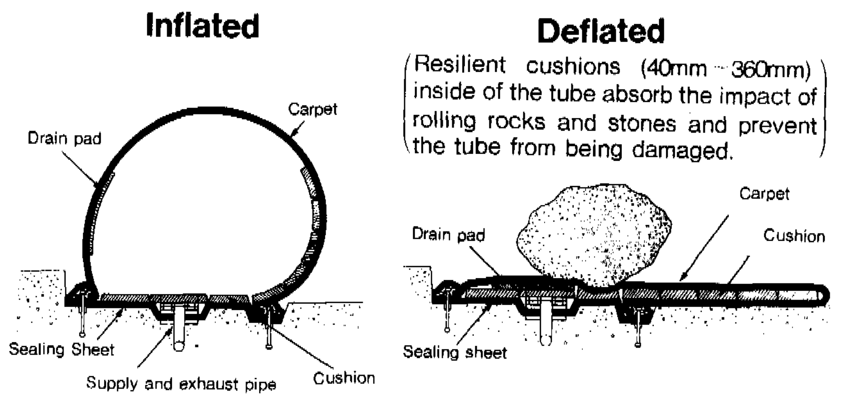


Fig.5. Location of Cushioning

Automatic deflation occured smoothly during rainy seasons and typhoons.

After ten(10) years observation since the installation, the experimental dam has no damage and it has become clear that our large Sumigate is operating effectively as an diversion dam even in the upper reaches of a river for small hydro-electric power stations.

Moreover as the number of rubber dams increased, their reliability was revaluated through practical demonstration. In 1990, the Japanese Ministry of Construction has installed the first actual use high dam (Inou River Gate: 4.71 m H * 24 m L) for irrigation.

4. Inou river Sumigate

We (Sumitomo Electric) received an order from the Shikoku Regional Const-ruction Bureau of the Ministry of Construction for a large sized Sumigate. Installation of the gate body was completed in April 1990. (see Fig.6)

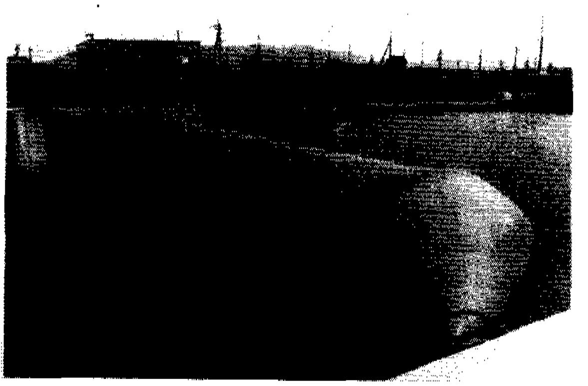


Fig.6. Inou River Sumigate
(4.71 m H * 24 m L)

This Sumigate is the first large sized utility gate to exceed the restriction on the gate height (3 m)set forth in the construction regulation.

4-1. Overview of the Inou River Sumigate

The gate is situated in the diversion channel connecting the Yoshino River and Inou River, both of which flow through Tokushima prefecture in Southern Japan. The gate was installed to control the water level in the Inou River, fromwhich irrigation water is discharged into Yoshino River and provide floodcontrol, thereby preventing damage in the downstream river basin.
Inspite of the fact that the size of this gate surpasses the regal restriction mentioned above, the installation was nonetheless approved. This approval was granted because of 1) operation security. 2) case of maintenance and control and 3) economical advantages of Sumigate when compared to other gates, proven by the more than 1000 Sumigates installed in the past 25 years. In addition, Sumigate underwent a technical evaluation by the Large Scale-Rubberized Fabric Gate Study Committee of the Ministry of Construction and was recommended by the committee.

4-2. Gate Structure

1) High Strength Rubberized Fabric Gate Body

A high strength rubberized fabric is the main material for body. Largesized rubberized fabric inflating deflating gates is composed of rubber material and meets specifications for air and water-tight integrity. Woven fabric adds strength to the rubber, and is formed into a finished rubberized fabric through a plying process. The tension acting on this rubberized fabric increases in proposion to a square of the gate height. Rubberized fabric used in small- and medium-sized gates 3 m and less in height has a tensile strength of 430 kg/cm and a thickness of 5.5 mm. The tensile strength of the rubberized fabric used in the body of Inou River Gate is 1070 kg/cm with a thickness of 10.5 mm.

2) Operating Equipment

In comparison to small- and medium-sized gates, the most important consideration in a large-sized gate is the detrimental effects on the surrounding area that a failure of the gate may cause, including inundation of the area during flooding or destruction of downstream structures as a result of rapid deflation. The Inou Gate uses highly reliable operating equipment with backup system to guarantee safty during inflation-deflation, and operations are carried out based on past operation data.

1) The inflation system is equipped with one motor-driven blower for normal operation, and one engine-driven blower for emergency operation in the event of power failure or trouble with the motor-driven blower during normal operation.
2) The deflation system consists of a water level gauge line installed in the river and a discharge valve which opens according to signals from the gauge. The emergency deflation system permits water to flow through the water level detection pipe, and the level-operated discharge valve opens with the weight of water flowing into the bucket when the water level reaches the deflation level. In addition to these systems, the gate is equipped with emergency air discgarge system, air blow off tank.
3) The gate is equipped with an automatic pressure controller to control internal pressure of the gate, and aremote monitorsystem to monitor each piece of line equipment and the condition of the gate body.

4-3. Maintenance Facility (Inspection Manhole)

The Inou River gate is always in contact with river water and sea water, and is affected by tide flow through the Yoshino River, so it is difficult to externally inspect the gate body. To facilitiate inspection of the gate body, the gate is equipped with an inspection mannole, which enables maintenance personnel to access the gate body internally as it is inflated. (see Fig.7.)

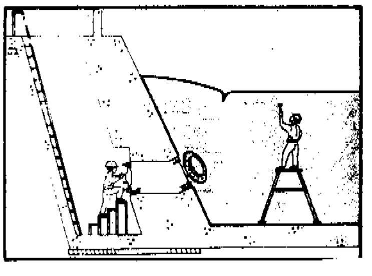


Fig. 7. Inspection Manhole

5. Future Developments

In 1990, installation of a 4.71 m high, 24 m long inflatable dam was completed across the Inou River in Southern Japan and also installation of the Hino river Sumigate (2.5 m height, 35 m length * 5 spans) is continued by the Ministry of Construction, and those are exceeding the construction regulations.
And furthermore, we received an order from the Electric Power Development Co. for installation of the highest dam (Kurotani river: 6 m H * 34.5 m L) for small hydropower diversion dam and we will start to install it in summer 1991.

We expect that many large-sized Sumigates would be any services to irrigation, small hydro and other purposes.

Storage of Rainwater and Snow-water in Southeast Coastal Districts of China and Scattering Purification Treatment of Drinking Water

Zhang Sunwei

Abstract

On the premise that the evaluation is made on the utility value of rainwater and snow-water used as drinking water by residents in the southeast coastal districts of China, this paper illustrates the purification treatment of drinkingwater which the residents there carry on in their scattering households.

I. The background of cashing in on rainwater and snow-water.

Zhejiang Province is situated on the southeast coast of China, between 27 - 31. 12 degrees north latitude and between 118-123 degrees east longitude. Its coastline extends as long as over 3200 kilometers with more than 2100 islands and isles. The total space of the province covers 102,000 square kilometers with its terrain high in southwest and low in northeast, thus showing a slanting feature from southwest to northeast. The mountainous and hilly regions make up 69% of the total area, the plains 24% and the waters of rivers and lakes 7%.

Within the province there are eight major rivers, i.e. the Qiantang River, the Yong River, the Jiao River, the Ou river, the Feiyun River, the Ao River, the Tiaoxi River, and a man-made Great Canal as well. The rivers have the following characteristics: The annual amount of the water discharge is big with heavy rises and falls; the change of seasons is conspicuous; the upper reaches are steep and torrential and the lower reaches are obviously affected by the tides there. Apart from the rivers, the province has built up over 3400 reservoirs in large, medium and small sizes. As the

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climate in the province is mild and rainy, the average annual precipitation amounts to 1200-2200 mm. Therefore the storage of rain-water and snow--water has a close relation with the exploitation of water resources. Moreover, the precipitation of the province varies in seasons and in districts. Every year May and June are a rainy season called Huangmeiyu, yet from December to next March it is dry season, when rain and snow are comparatively little.

So far as the districts are concerned, there is more precipitation in the inner part than on the coast and more in the mountainous areas than on the plains. The distribution of the provincial population of over 41 million is also uneven. The people are as dense as about 700 persons per square kilometer on the plains, yet the people in the mountainous areas are as scarce as a score or so per square kilometer. So the sources of drinking water for the residents are varied and differences are great in the scopes and ways of water provision, treatment of water, water coverage of population, average daily water consumption per capita and hygienic conditions of water sources.

Take for example the drinking water sources. According to the number of people consuming water, they are arranged in the order of shallow wells, rivers and streams, ponds, springs, lakes, reservoirs, deep wells, rain and snow, and tunnel water (See Chart 1).

1. water from shallow wells
2. from rivers and streams
3. from ponds
4. from springs
5. from lakes and reservoirs
6. from deep wells
7. from rain and snow

Chart I

The percentage of drinking water from different sources used by both rural and urban residents.

Generally speaking, pond water and rain water is of poor quality. Where people drink pond water and rainwater, the water sources are usually scarce and the water consumption is limited. But at present in the districts of Hangzhou, Huzhou and Taizhou, 13.27%, 13.06% and 16.57% of the respective residents still drink pond water. In Ningpo district 5.12% of the residents use rain and snow as drinking water source. Speaking of the ways of water provision, as is shown in the statistics of 1985, 23% population of the province enjoy centralized water provision, but the other 77% have to live on scattering water provision.

Ever since the ancient times, part of the residents in Zhejiang Province have formed a habit of directly using rain and snow as drinking water. This habit is especially acquired by the people in the coastal areas like Ningpo, Taizhou and Wenzhou. With the advance of urban life, running water has already taken the place. But in the rural areas, a small number of people still follow this old habit. Besides, in some islands and inner mountainous regions rain and snow are stored in ponds and reservoirs as the source of drinking water. No matter whether they are directly or indirectly used as drinking water, there is the possibility of their being contaminated. Thus an effective treatment to purify them has to be adopted.

II Pollution of rainwater and snow-water

Rainwater and snow-water are polluted in the following ways:

1. Pollutants in the atmosphere absorbed and brought down in the process of rainfalls

In the process of rainfalls, a considerable part of pollutants in the atmosphere are brought down and mixed into the rainwater. At the beginning of rainfalls the density of contamination is particularly high. Because of the rinsing effect of rain and snow, the pollutants in the atmosphere, such as falling dust, floating dust, nitric oxide and sulphor dioxide, are absorbed and brought down in the rain, hence a typical example -- the appearance of acid rain.

With the development of industry and transportation the discharge of waste gases is more and more increasing, the constituents of waste gases are getting complex and their pollution to rain and snow is becoming more serious. All these have aroused the attention of the people.

But the degree of pollution of rain and snow is characterized by its accidental, casual and time-pressing factors. Timely monitor and necessary treatment should be conducted; otherwise rainwater and snow-water are unable to be made use of as a safe drinking water source.

2. Possibility of pollution in the process of collecting rain and snow

In the process of collecting rain and snow, water may be polluted if it keeps in touch with the surface of various building structures or the ground, because this touch may bring in rotten rusts, adjuncts, dirts, plant leaves or branches, wastes of industry, and organic or inorganic pollutants caused by human activities.

3. Possibility of pollution in the process of storing rainwater and snow-water

Lakes and reservoirs that can store rain and snow in large quantities are generally situated in the low-lying land. The passages which bring rainwater into lakes and reservoirs may at the same time carry waste water of various factories or mines and sewage that is discharged from residential living quarters. Pollutants and fertilizers in the surrounding farmfields and nearby woods will also accompany rainwater into lakes and reservoirs. In addition, the water in lakes and reservoirs are generally still and steady. The flow-in waste water is not easy to be mixed up, diluted or spread. As a result, the contaminated lakes always contain various pollutants and are likely to cause serious contamination in some parts. So a special attention must be paid.

III. Scattering purification treatment of rainwater and snow-water as drinking water

When a water source is contaminated, properties of the contained water will undergo some physical, chemical and biological changes. The polluted degree can be illustrated by the indexes of the water pollution. These indexes are as follows:

Colour: Pure and clean water should be transparent and colourless;

Smell: Any appearance of smell means impurity of water quality;

pH value: It is an important quota to reflect the degree of acid and alkali of water quality;

Suspension: It refers to any solid material that cannot be removed by filters. The solid material chiefly comprises three kinds; floating material on the surface, sinking material at the bottom and drifting material amidst water;

Heavy metal ion: It is the major harmful poison in water;

Total organic carbon: It represents the total carbon content of organism in water;

Biochemical Oxygen Demand (BOD): It is used to represent organic contents;

Chemical Oxygen Demand (COD): It is an important index to show the pollution of water quality;

Colon Bacillus Colonies: It refers to the number of colon bacilli in a unit cubic water, the unit being per/litre. Colon bacilli are not bacteria which will cause a disease, but their living conditions are quite similar to those of pathogenetic bacteria in intestines. Therefore they can directly show whether the water body has been polluted by the pathogenetic bacteria or find out whether there are any pathogenetic bacteria in the water body.

In order to purify drinking water for scattering residents and for the people in disaster areas, wars and field operations, we have made out a high-efficient coacervation agent with binary inorganic polymer as a main constituent.

The agent is quite effective when used together with other disinfectants. According to the appraisal of the Science and Technology Committee of Zhejiang Province and through the household use and experimental reports both at home and abroad, this new agent proves to be stable in quality, reliable in property, easy in use and effective in function. The new agent has also won Scientific and Technological Progress Prize of Zhejiang Province for 1980 and a gold medal at the National Patent Fair (held in Xinjiang).

The main functions of the agent are as follows:

1. Decolourize and clear stink;
2. Adjust pH;
3. Purge suspension;
4. Precipitate heavy metal ions;
5. Reduce COD & BOD values;
6. Disinfect.

Below is the test of this agent determined by Zhejiang Environment and Hygeine Supervising and Monitoring Bureau:

	Pond Water (natural)	Water treated with the agent
pH	7. 98	6. 64
colour	40	< 5
turbidity	20	< 3
COD & BOD	10. 4	2. 6
total bacteria	1,400	1
colon bacillus colonies	23,800	< 3

The agent's efficacy in removing heavy metal ions is instanced as follows:

	China GB 5749—85 standards	US pHs drinking water standards	Water treated with the agent
Fe ions	< 0. 3 mg/1	< 0. 05 mg/1	< 0. 05 mg/1
Mn ions	< 0. 1 mg/1	< 0. 05 mg/1	< 0. 05 mg/1
Cu ions	< 1. 0 mg/1	< 0. 2 mg/1	< 0. 05 mg/1

In addition to the above merits, the agent is most economical. Put 45g of this agent into one ton of natural water, stir the water and wait till it settles and you will get wholesome drinking water that meets China's GB 5749 - 85 standards. Water thus treated is fit for drinking directly without any by-effects. This agent has a striking precautionary effect on eradicating pollution of water, preventing infection of disease and promoting health of people.

TEST OF WATERSHED ACIDIFICATION MODELS RESPONSES TO RAINFALL INTENSITY

FI-JOHN CHANG*

ABSTRACT

Mathematical models are useful in improving our understand- ing of various processes and predicting the response in freshwater chemistry to changes in the deposition. A general weakness in models of the effects of acid deposition is that the models have not been tested sufficiently against observation. An alternative way to assess the applicability of models is to perform hypothesis test. Consequently, a hypothsis--increasing rainfall intensity will increase outflow hydrogen concentration--was tested with two well known watershed acidification models, the ILWAS and Birkenes models.

The ILWAS models confirms the hypothesis, while the Birkenes model does not produce the same conclusion. This is probably due to the simplicity of the hydrologic submodel of the Birkenes model and its assumption of constancy of the cation exchange capacity. The result of test the ILWAS model for the hypothsis show that it is a useful tool in the investigation of watershed acidification. This process-oriented model provides the essential insight to make predictive assessment of the effect of surface and subsurface water acidification under different loading.

I. Introduction

The increasingly widespread acid deposition which is associated with forest decline and fish degeneration has become one of the most important environmental issues of the 1980's. Several regions of the United States, Canada, Sweden, and Norway have been reported to have precipitation that is very acidic (pH less than 4.2). Because of the complexity of the interactions of deposited substances moving through ecosystems, the identification of the mechanisms of fresh-water acidification has proven to be difficult. A better knowledge of the paths, movements, and reactions of the acidic pollutants in

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the ground and in surface waters will help in the quantitative characterization of the reaction of the watershed to continued acidic deposition. One method of improving our understanding of the acidification mechanisms is the development of physicochemically based mathematical models of the quantitative linkage between acid deposition and terrestrial ecosystems. Recently, several watershed acidification models have been developed to predict or assess the impact of acidic deposition on terrestrial and aquatic systems (Chen et al., 1983; Cosby et al., 1985; Reuss and Johnson, 1986; Schecher and Driscoll, 1987; Schnoor et al., 1983; and Christophersen et al., 1982).

These models have all shown success in simulating and predicting observed values in particular watersheds for which the model parameters have been specifically calibrated. The models are driven by different hydrochemical processes and the parameters depend on the validity of the assumptions and objectives. A general weakness in several models of the effects of acid deposition is that the models have not been tested sufficiently against observations. An alternative way to assess the applicability of models is to perform hypothesis tests.

The purpose of this paper is to test if the responses of two well known watershed acidification models are consistent with those associated with generally accepted hypotheses. If the models yield approximately the same responses to the formulation of the hypotheses, then the tests not only provide further evidence for the hypotheses but also provide an alternative way to verify the applicability of the models. If the models produce different responses to the formulation of hypotheses, the reliabilities of the models are questionable and the limitations of the models must be clearly stated or the models reformulated. Hypothesis testing with simulation models provides a tool that can be used for the indentification of processes and eventually for the generalization of the results for prediction of watershed responses due to alternative management and abatement strategies.

II. Models and Data Used

ILWAS Model

The ILWAS (Integrated Lake Watershed Acidification Study) model was developed by Chen et al.(1983) for the Electric Power Research Institute (EPRI) to establish a quantitative link between acid deposition and lake acidification and to assess various mitigation strategies for acid rain (Goldstein et al. 1985; Gherini et al., 1985). To simulate the spatial heterogeneity of a watershed system, the ILWAS model conceptualizes the system in drainage subcatchments, stream segments (if any), and lake(s). Each subcatchment contains compartments representing canopy, snowpack, and soil layers. Basically, the model is composed of hydrologic and chemical modules, both split into a number of submodels. The hydrologic module routes precipitation from the vegetative canopy to lake outlet. The chemical module calculates the pH, the concentrations of alkalinity, and the concentrations of the major cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and NH^{+4}) and anions ($SO^{2-}{}_{4}$, $NO^{-}{}_{3}$, Cl^{-}, and F^{-}), monomeric aluminum and its organic and inorganic complexes, organic acid analogues and dissolved inorganic carbon. A schematic and processes summary of the ILWAS model are shown in Figure 1.

Panther watershed is one of three watersheds located in the Adirondack mountains, New York, which were studied as part of the ILWAS project. The input data files of Panther watershed, which were supplied by EPRI, are used in the simulation. The data files include model coefficients, observed meteorologic data and wet and dry deposition chemistry for three years (1978-1981). Panther watershed hydrological basin has an area of 1.24 km^2. The basin is covered predominately by thick glacial till, averaging 24.5 m in depth. The detail description of vegetation and soil geochemistry of the Panther watershed can be found from Cronan (1985).

Birkenes Model

The objective of the Birkenes model is to quantitatively account for the shortterm variations in streamwater chemistry using a simple two-reservoir model incorporating a small number of physically realistic processes (Christophersen and Wright, 1981; Christophersen et al., 1982). The complete model builds on the hydrologic, sulfate, and cation submodels. The hydrologic submodel considers three reservoirs: one snow reservoir added to the two soil layer reservoirs of the original Birkenes model (Figure 2). The sulfate submodel simulates the general trends in sulfate concentrations observed in the stream water. The cation submodel includes H, Al, Ca, and Mg and is based on the mobile anion concept.

The observed data (meteorologic, hydrological, and streamflow chemical data) in a subcatchment known as "Inflow No. 4" of Harp Lake, 8 km northeast of Huntsville, Ontario, Canada, were obtained from the Ontario Ministry of Environment Dorset Research Centre, Canada, and are used for this study. The subcatchment has been described by Seip et al. (1985) and in papers referenced therein. The study area is about 1.19 km^2. The catchment is almost completely covered with deciduous forest. Most of the bedrock (~87%) consists of amphibolite and schist with a small area (~13%) of biotite and hornblende gneiss. The overburden consists of a minor till plain (depth > 1m, 56% of the area), with thin deposits (depth < 1m) and rock ridges covering most of the remainder (33%) of the subcatchment.

III. Hypothesis Tests

One of the important advantages of watershed acidification models is that they provide a compact distillation of watershed response that can be used to focus attention on key hypotheses (Wheater et al., 1986). Here a hypothesis testing procedure which has been provided by Chen et al. (1983) is used and summarized as follows:

1. Provide a clear statement of the hypothesis and anticipated consequences.
2. Develop a testing approach using the model.
3. Conduct the test (set up the model and simulate the process).
4. Evaluate and interpret the results.

Test of the Rainfall Intensity Effect

The interesting hypothesis is: "Increasing the rainfall intensity will increase the outflow hydrogen concentration."

The effects of acid precipitation on the watershed ecosystem are the result of complex hydrological and hydrochemical responses. Transport processes within the catchment are determined by hydrological response; the precipitation intensity is a very important factor, which determines the flow paths in different soil horizons (Whipkey 1965). The soil chemistry of different horizons can vary substantially and hence the quality of stream water outflow will be influenced by precipitation intensity. Winkle et al. (1987) also support this hypothesis, and they state that increasing the rainfall intensity will increase the macropore flow; hence, chemical reactions with soil do not occur, and the outflow hydrogen concentration will increase. Recently, Lynch et al. (1986) also found that storm flow acidity is directly related to the discharge rate, with the peaks nearly coinciding.

For testing the effect of rainfall intensity, several storm events within the test period were chosen and the rainfall intensities multiplied by a factor (e.g. 1,2,4,10). After running the models, the relationships between the rainfall intensity and the outflow hydrogen concentrations of each model were obtained. The simulation results with the ILWAS model for two different periods are shown in Figures 3 and 4. They demonstrate that the outflow hydrogen concentrations do indeed increase as the rainfall intensities increase. The simulation results with the Birkenes model for the period of January 1, 1977 to March 1, 1977, are shown in Figure 5. Unexpectly, the results show that the outflow hydrogen concentrations do not increase as the rainfall intensities increase. Consequently, when the rainfall intensity is changed, proper results are unlikely to be produced.

IV. Conclusions

The results of the hypothesis testing described in this paper are summarized as follows:

The ILWAS model demonstrated that increasing the rainfall intensity will increase the outflow hydrogen concentration while the opposite result was obtained with the Birkenes model. The results of hypotheses test show that the ILWAS model is a useful tool in the investigation of watershed acidification. The model provides the essential insight to make predictive assessments of short-term and long-term effects of surface and subsurface water acidification under different acid loadings. The results emphasize the need of fully understanding the limitations of a model before accepting its results when applied to conditions different from those used in the calibration.

V. Acknowledgement

The author wishes to express his appreciation to professor J.W. Delleur of Purdrue University for his guidance and support throughout this work. Special thanks go to Dr. R. Glodsteinof EPRI for making the ILWAS code and data available and to Dr. D.J. Dillon and Ed de Grosbois of Dorset Research Centre, Canada, for making the Birkenes code and data available.

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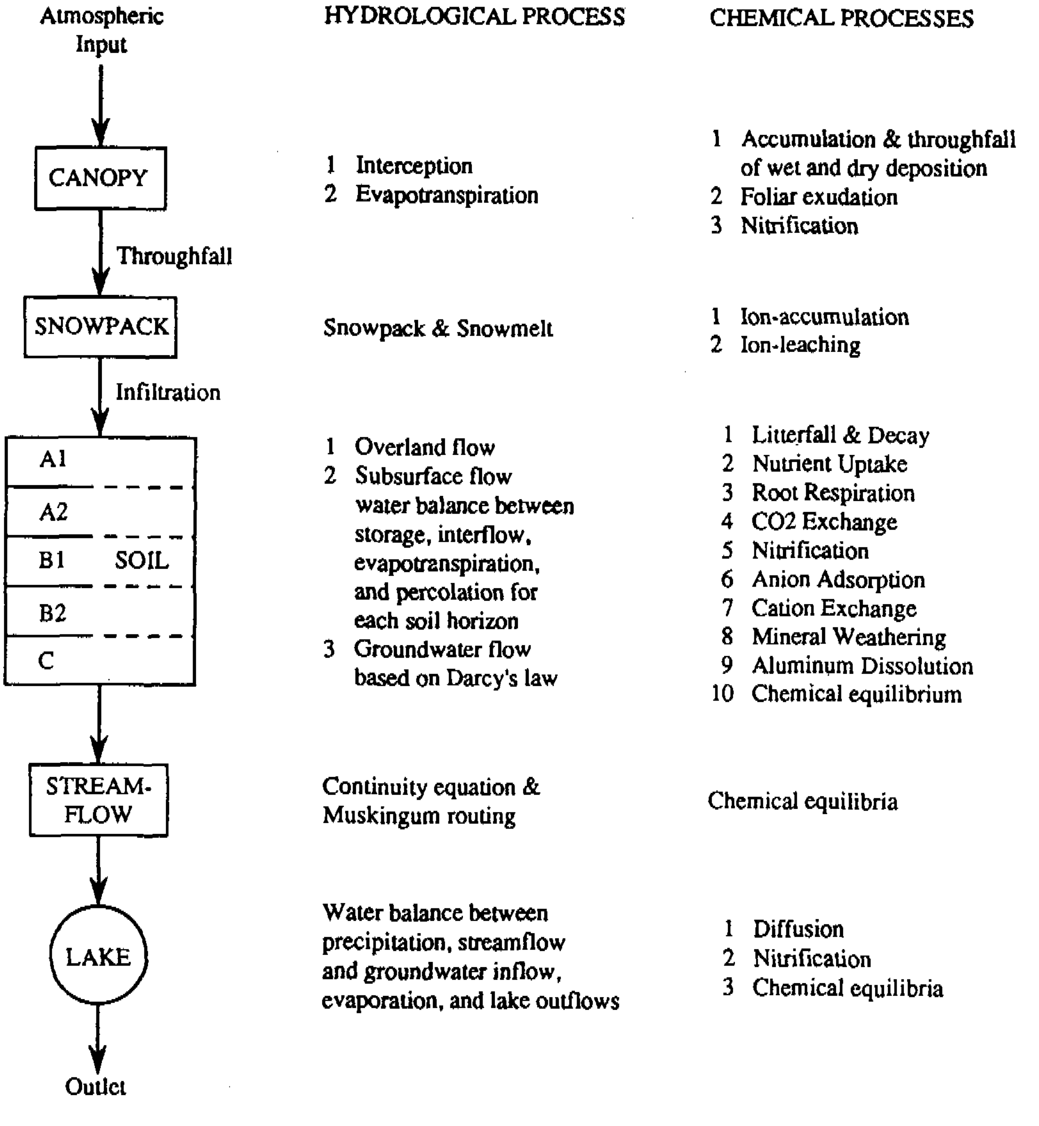

Figure 1 Schematic and major processes of the ILWAS model

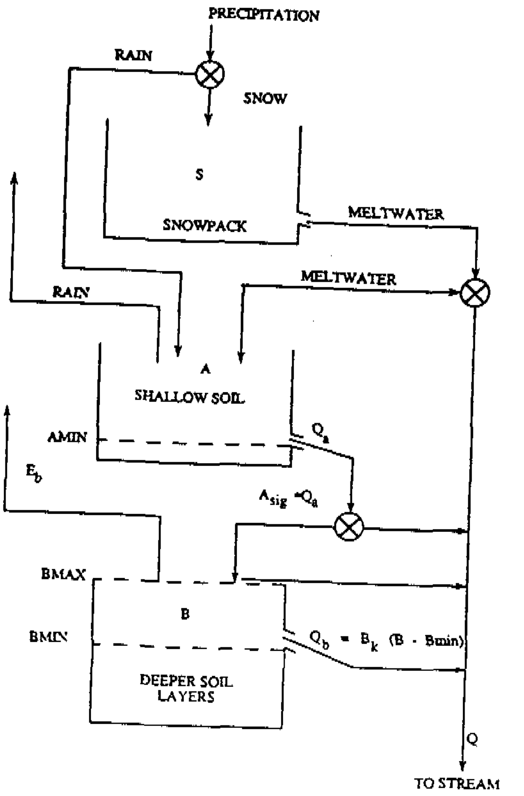

Figure 2 Schematic of the Birkenes hydrologic submodel

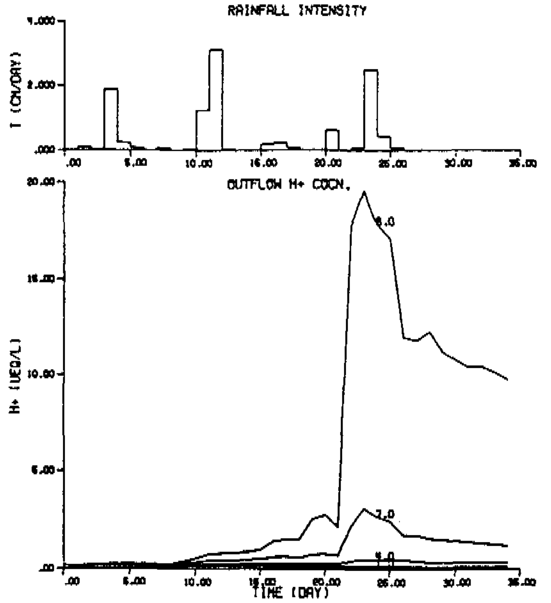

Figure 3. Original rainfall intensity hydrograph and ILWAS model simulated Panther Lake outlet hydrogen concentrations for 4 sets of rainfall intensities (Oct. 3 to No. 7, 1978). Four multiples (1,4,7,8) of the original rainfall intensities were used.

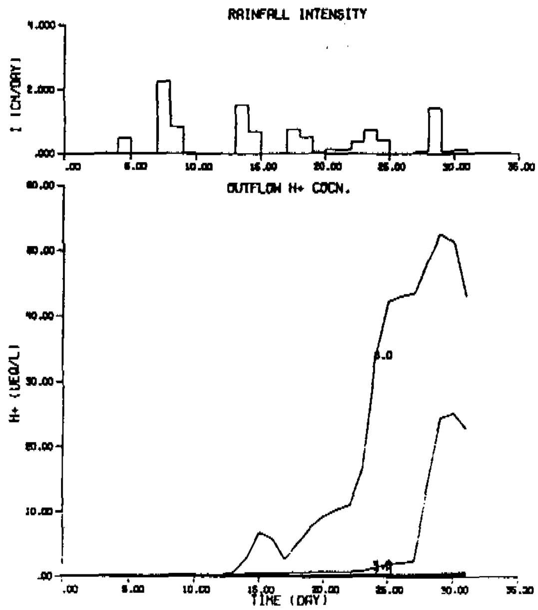

Figure 4. Original rainfall intensity hydrograph (Nov.11 to Dec. 12, 1978) and ILWAS model simulated Panther Lake outlet hydrogen concentrations for 4 sets of rainfall intensities. Four multiples (1,2,4,8) of the original rainfall intensities were used.

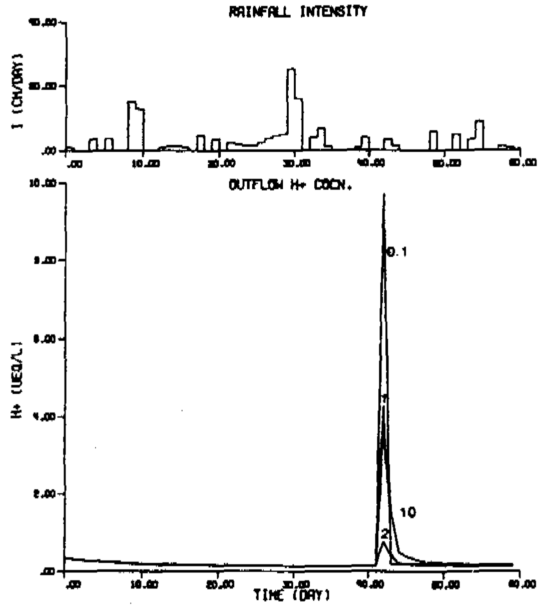

Figure 5. Original rainfall intensity hydrography (Jan. 1 to Mar. 1. 1977) and Birkenes model simulate Harp Lake (Inflow No.4) outlet hydrogen concentration for 4 sets of rainfall intensities. Four multiples (0.1,1,2,10) of the original rainfall intensities were used.

APPLICATION THE BAYESIAN APPROACH TO HYDROLOGIC SAMPLING THEORY FOR THE CHO-SHUI RIVER IN TAIWAN

Ming-Te Liang*

ABSTRACT

The principal aim of this article is to study the Bayesian approach applied to the statistical distribution of the annual maximum flow of the Cho-Shui river in Taiwan. An important result obtained from investigation is the without and with prior information to the Cho-Shui river, the posterior distributions are respectively N(3.721,0.100) and N(3.055,0.081).

INTRODUCTION

On the system planning and design of water resource, usually one has to know the probabilities of occurrence of hydrologic events. This provides the need of assessment to the economic benefits and separated development and estimation for water-resource planning such as flood control engineering, reservoir and dike. Extraordinarily, the inference of hydrologic sample is very important in the study of water-resource control and planning. The hydrologic extreme such as flood or drough is an isolated event of infrequent occurrence. Theoretically, it can be considered as an independent random variable and predicted its occurrence by probability theory and mathematical statistics. In the hydrologic design, the occurrent probability of hydrologic extreme is an important design criteria for choosing the protective level to hydraulic structures.

Once one knows the distribution function of a random variable and the values of its parameters, the probabilities associated with events defined by value of the random variable can be computed. The statistical data provide the information from which the probability

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model and the corresponding parameters required in engineering design may be developed or evaluated. It should be recognized that when population parameters are estimated on the basis of finite samples, errors of estimation are unavoidable. Within the classical methods of estimation, the significance of such errors are not reflected in the (point) estimates of the parameters; they can only be expressed in terms of appropriate confidence intervals. Explicit consideration of these errors is embodied in the Bayesian approach to estimation. The Bayesian approach has special significance to engineering sign, where available information is invariably limited and subjective judgment is often necessary.

The main purpose of this paper is to investigate the statistical distribution of the annual maximum flow of the Cho-Shui river in Taiwan. Assume that the annual maximum flow is an independent random variable. The probabilistic characteristics of a function of random variables may be derived from those of the basic constituent variables. These include, in particular, the probability distribution and the main descriptors (mean and variance) of the function. In the absence of prior information on mean value, a diffuse prior distribution may be assumed. Without any prior information, the posterior distribution of mean value is Gaussian with a mean value equal to the sample mean and standard deviation. In contrast to the classical approach, however, prior information can be included in the estimation of the mean value. If prior information is available, it can be incorporated through the prior distribution. These posterior distribution obtained from Bayesian approach will compare with the results of the classical approach such as standard normal and log-normal distribution. The difference among these results are also discussed and illustrated.

BAYESIAN CONCEPTS IN SAMPLING THEORY

Consider the parameter to be a continuous random variable in the Bayesian method of estimation. Fig.1 shows that θ is the random variable for the parameter of a distribution with a prior density function $f'(\theta)$. If parameter θ between θ_i and $\theta_i+\Delta\theta$, then the prior probability is $f'(\theta_i)\ \theta$. If ϵ is an observed experimental outcome, then the prior distribution $f'(\theta)$ can be revised in terms of ϵ using Baye's theorem. In the limit, Ang and Tang (1975) obtained that the posterior probability is

$$f''(\theta) = \frac{p(\varepsilon \mid \theta) f'(\theta)}{\int_{-\infty}^{\infty} p(\varepsilon \mid \theta) f'(\theta) d\theta} \tag{1}$$

in which $p(\epsilon|\theta)$ is the conditional probability or likelihood of observing the experimental outcome ϵ provided that the value of the parameter is θ. Thus $p(\epsilon|\theta)$ is a function of θ and is commonly called the likelihood function of θ and denoted $L(\theta)$.

The Bayesian estimator of the parameter θ is the expected value of θ; that is

$$\hat{\theta}'' = E(\theta|\epsilon) = \int_{-\infty}^{\infty} \theta f''(\theta)d\theta \quad (2)$$

Eq.(2) indicates that observational data and judgmental information are both used and combined in a systematic way to the point estimator of the underlying parameter.

Assume that the parameter of the distribution is θ. If the experimental outcome ϵ in Eq.(1) is a set of observed values X1,X2,.....,Xn, expressing a random sample from a population X with underlying density function $f_X(x)$, then the probability of observing this parameter set of values is

$$p(\epsilon|\theta) = \prod_{i=1}^{n} f_X(x_i|\theta)dx \quad (3)$$

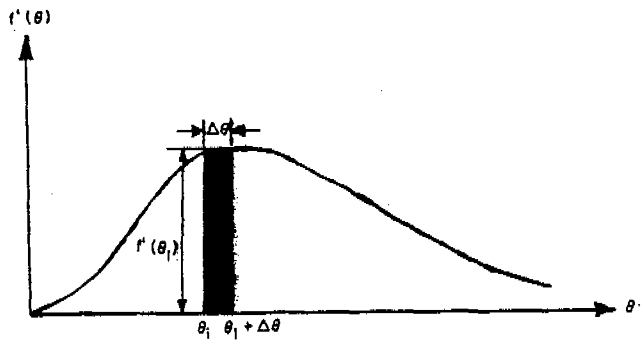

Figure 1. Continuous prior distribution of parameter θ

If the prior density function of θ is $f'(\theta)$, then the corresponding posterior density function becomes, according to Eq.(1),

$$f''(\theta) = \frac{\left[\prod_{i=1}^{n} f_X(x_i|\theta)dx\right] f'(\theta)}{\int_{-\infty}^{\infty}\left[\prod_{i=1}^{n} f_X(x_i|\theta)dx\right] f'(\theta)d\theta} = kL(\theta)f'(\theta) \quad (4)$$

in which the normalizing constant is

$$k = \left[\int_{-\infty}^{\infty} \left(\prod_{i=1}^{n} f_X(x_i \mid \theta) \right) f'(\theta) d\theta \right]^{-1} \quad (5)$$

whereas the likelihood function L(θ) is the product of the density function of X evaluated at X1,X2,....,Xn, or

$$L(\theta) = \prod_{i=1}^{n} f_X(x_i \mid \theta) \quad (6)$$

Making use of the posterior density function for θ of Eq.(4) in Eq.(2), one gets the Bayesian estimator of the parameter θ. In addition, if a diffuse prior distribution is assumed, then the mode of the posterior distribution (that is Eq.(4)) gives the maximum likelihood estimator.

Now make a study of a Gaussian population with known standard deviation σ. Using Eq.(6), the likelihood function for the parameter μ is

$$L(\mu) = \prod_{i=1}^{n} \frac{1}{\sqrt{(2\pi)}\sigma} \exp\left[-\frac{1}{2}\left(\frac{x_i-\mu}{\sigma}\right)^2\right] = \prod_{i=1}^{n} N_\mu(x_i,\sigma) \quad (7)$$

where Mμ(Xi,σ) represents the density function of μ with mean value Xi and standard deviation σ. It can be shown that the product of m normal density functions with respective means μi and standard deviation σi is also a normal density function with mean and variance

$$\mu^* = \frac{\sum_{i=1}^{m} (\mu_i/\sigma_i^2)}{\sum_{i=1}^{m} 1/\sigma_i^2} \quad \text{and} \quad (\sigma^*)^2 = \frac{1}{\sum_{i=1}^{m} 1/\sigma_i^2} \quad (8)$$

If the sample mean is

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \quad (9)$$

then Eq.(7) becomes

$$L(\mu) = N\mu(\mu^*, \sigma^*) = N\mu(\bar{x}, \frac{\sigma}{\sqrt{n}}) \qquad (10)$$

If μ is without prior information, then the prior distribution is assumed a prior diffusion. In such a case one obtains the posterior distribution for μ, as

$$f''(\mu) = kL(\mu) = N\mu(\bar{x}, \frac{\sigma}{\sqrt{n}}) \qquad (11)$$

where k is necessarily equal to 1.0 based upon normalization. Eq.(11) indicates that without prior information, the posterior distribution of μ is Gaussian with a mean value equal to the sample mean $\bar{x}$ and standard variation $\sigma/\sqrt{n}$, using the expected value of μ as the Bayesian estimator, one gets, according to Eq.(2),

$$\hat{\theta}'' = E(\mu \mid \varepsilon) = \bar{x} \qquad (12)$$

Eq.(12) denotes that the sample mean $\bar{x}$ is the point estimate of the population mean.

If μ is with significance of prior information, then, in this case where X is Gaussian with known variance, it is mathematically convenient to assume also a Gaussian prior. If $f'(\mu)$ is $N(\mu', \sigma')$, then, with the likelihood function of Eq.(10), the posterior distribution of μ becomes

$$f''(\mu) = kL(\mu)f'(\mu) = kN\mu(\bar{x}, \frac{\sigma}{\sqrt{n}})N\mu(\mu', \sigma') \qquad (13)$$

which is a product of two normal density functions. Again, it can be shown that $f''(\mu)$ is also Gaussian with mean

$$\mu'' = \frac{\bar{x}(\sigma')^2 + \mu'(\sigma^2/n)}{(\sigma')^2 + (\sigma^2/n)} \qquad (14)$$

and standard deviation

$$\sigma'' = \sqrt{\frac{(\sigma')^2(\sigma^2/n)}{(\sigma')^2 + (\sigma^2/n)}} \qquad (15)$$

In this case the Bayesian estimator of μ, Eq.(2) becomes

$$\hat{\mu}'' = \mu'' \tag{16}$$

That is, the Bayesian estimate of the mean value is an average of the prior mean μ' and the sample mean $\bar{x}$,weighted inversely by the respective variances.

Eq.(14) is an example of how prior information is combined systematically with observed data to estimate the mean value μ. Based on the posterior distribution of μ, that is, $N\mu(\bar{x},\sigma\sqrt{n})$ of Eq.(11) or $N\mu(\mu'',\sigma'')$ with Eqs.(14) and (15), one may also determine the interval for μ corresponding to a specified probability. For instance, the probability that μ is between a and b is given by

$$P(a<\mu\leq b) = \int_a^b f''(\mu)d\mu \tag{17}$$

PRACTICAL APPLICATION

In order to apply the Bayesian approach to practical example, one takes the Cho-Shui river in Taiwan for illustrating it. The annual maximum flow of the Cho-Shui river has been recorded for the last thirty year as shown in Table 1. Based on extensive data from adjacent rivers, the annual maximum river flow may be modeled by a log-normal distribution. Assume that the parameter ξ in the log-normal distribution is equal to the value obtained from the thirty sample values. The problem here is to estimate the parameter λ.

Ang and Tang (1975) pointed out that if a random variable Y is log-normal, then X=ln Y is normal. Hence the logarithm of the river flow will be Gaussian with mean λ and known standard deviation ξ.

The natural logarithm of the thirty sample values are also indicated in Table 1.

Table 1. Computation of wean and variance for the Cho-Shui river

Specimen number	year	max. flow(100 m^3/sec) x_i	x_i^2	$X_i = \ln x_i$	X_i^2
1	1941	43.26	1871.428	2.77	14.213
2	1942	57.50	3306.250	4.05	16.403
3	1943	49.50	2450.250	3.90	15.210
4	1944	32.41	1050.408	3.48	12.110
5	1947	50.72	2572.518	3.93	15.445
6	1949	25.86	668.740	3.25	10.563
7	1950	28.35	803.723	3.34	11.156
8	1951	53.66	2879.296	3.98	15.840
9	1952	41.23	1699.913	3.72	13.838
10	1955	59.00	3481.000	4.08	16.646
11	1956	99.00	9801.000	4.96	24.602
12	1957	53.00	2809.000	3.97	15.682
13	1958	44.70	1998.090	3.80	14.440
14	1959	59.00	3481.000	4.08	16.646
15	1960	105.00	11025.000	4.65	21.623
16	1961	34.00	1156.000	2.53	12.461
17	1962	29.60	876.106	3.39	11.492
18	1963	66.70	4448.890	4.20	17.640
19	1964	5.73	32.833	1.75	3.063
20	1965	26.00	1296.000	3.58	12.816
21	1966	26.80	718.240	3.29	10.824
22	1967	69.00	4761.000	4.23	17.893
23	1968	23.20	583.240	3.14	9.860
24	1969	35.00	1225.000	3.56	12.674
25	1970	61.60	3794.560	4.12	16.974
26	1971	38.40	1474.560	3.65	13.323
27	1972	39.90	1592.010	3.69	13.616
28	1973	40.00	1600.000	3.69	13.616
29	1974	27.20	739.840	3.30	10.890
30	1975	24.50	1190.250	3.54	12.532
		Σ1369.82	Σ75341.299	Σ111.62	Σ424.091

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{1369.82}{30} = 45.661$$

$$s^2 = \frac{1}{n-1}\left(\sum_{i=1}^{n} x_i^2 - n\bar{x}^2\right) = \frac{1}{29}\left[75341.299 - 30(45.661)^2\right] = 441.155$$

$$\lambda = \frac{1}{n}\sum_{i=1}^{n} X_i = \frac{111.62}{30} = 3.721$$

$$\xi^2 = \frac{1}{n-1}\left(\sum_{i=1}^{n} X_i^2 - n\bar{x}^2\right) = \frac{1}{29}\left[424.091 - 30(3.721)^2\right] = 0.301$$

From Table 1 one gets the sample mean $\bar{x}$ = 3.721, and sample standard deviation ξ = 0.548.

Without any prior information, the posterior distribution of λ, according to Eq.(11), is $N(\bar{x}, \xi/\sqrt{30}) = N(3.721, 0.100)$.

If prior information is available, it can be incorporated through the prior distribution of λ. For instance, if $f'(\lambda)$ is assumed to be $N(\mu', \sigma') = N(1.75, 0.140)$; then from Eqs.(14) and (15) the posterior distribution $f''(\lambda)$ will be normal with

$$\mu_\lambda'' = \frac{(3.721)(0.140)^2 + 1.75(0.100)^2}{(0.14)^2 + (0.100)^2} = 3.055$$

and

$$\sigma_\lambda'' = \sqrt{\frac{(0.14)^2(0.100)^2}{(0.14)^2 + (0.100)^2}} = 0.081$$

That is, in this latter case, the posterior distribution of λ is $N(3.055, 0.081)$.

DISCUSSION

It should be recognized that Eq.(12) is the same as the classical methods of estimation. Therefore, in the absence of prior information, the Bayesian and classical methods give the same estimates for the population mean. Conceptually, however, the Bayesian basis for this estimate differs from that of the classical method. In the case of significance of prior information, the Bayesian approach is in contrast to the classical method. The prior information to the Bayesian approach can be included in the estimation of the parameter μ. Table 2 shows the different parameters between the Bayesian and classical methods.

Table 2. Distributions and their parameters of the Cho-Shui river in Taiwan

distribution	parameters
standard normal distribution	$N(\bar{x},\sigma)=(45.661,21.004)$
lognormal distribution	$N(\lambda,\zeta)=(3.721,0.540)$
posterior distribution (without prior information)	$N(\bar{x},\zeta/\sqrt{n})=(3.721,0.100)$
prior distribution (with prior information, assumed value)	$N(\mu',\sigma')=(1.75,0.140)$
posterior distribution (with prior information)	$N(\mu'',\sigma'')=(3.055,0.081)$

CONCLUSIONS

The basic concepts of the Bayesian approach in sampling theory have been introduced here with special reference to sampling and estimation. Application of these concepts in Bayesian approach is also covered in the practical example of the Cho-Shui river is Taiwan.

Philosophically, there are fundamental differences between the Bayesian and classical statistics. This fact can also be seen in practic such as in the Table 2. Within the Bayesian approach, a probability or a probability statement is an expression of the degree-of-belief, while in the classical method, probability is a verifiable measure of relative frequency. Furthermore, in the process of estimation, the Bayesian approach assumes that a parameter is a random variable, whereas in the classical sense it is an unknown constant.

For the engineering planning and design such as water resource, the Bayesian approach provides the following advantages:

1. It offers the formal framework for incorporating engineering judgement (expressed in probability terms) with observational data.

2. It systematically combines the uncertainties of random variable and those arising from errors of estimation and prediction.
3. It provides a formal procedure for systematic updating of information.

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Envelope Curves for Extreme Flood Events in SW Iran

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ABSTRACT

Water shortage in dry areas is the most limiting factor in their growth, even in their existence. Many civilization have vanished because their water resources had exhausted. Preparation of the systems which harness and conserve floodwaters in unusual rainfall events is one way to replenish the badly depleted aquifers, as well as to produce and preserve food, feed, fiber and fuel for the lean years. Prediction of the runoff potential of watersheds in extreme events is a rather conservative method for estimation of the size of floodwater spreading systems and artificial recharge facilities. However, long time, continuous hydrological data required to base the predictions on are lacking for most of the desert watersheds in Iran. Therefore, it is necessary to resort to empiricism for prediction of runoff events. Development of envelope curves for regions with a few gauged watersheds facilitates reasonable estimation of the maximum probable peaks for ungauged basins in the same area.

A total of 36 data points of the deluge of Dec.1986 were used to derive envelope curves for the Mond, Helleh, Zohreh and Shiraz basins. Equation of the form $Q=C+B/A$, in which Q is the peak flow in $ls^{-1}\ km^{-2}$, A is the area of the basin in km^2 and C and B are constants, best describe the overall performance of the basins. However, other equation forms might better match some individual watersheds in the region.

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INTRODUCTION

History of Iran, the land of the flood and the drought, is replete with details of disastrous floods which repeatedly devastated cities and farming communities (Melville 1984). However, collection of hydrological data is very recent and sporadic. The first report of the flood-producing rainfalls in Shiraz has been given by the British consulate in 1908(ibid). The McMahon Mission recorded the flow of the River Hirmand in 1902-05. The gauging of this river has been carried out on a regular basis since 1950, with years of gap thereafter (Anon. 1964).

The difficulties and costs of installing and maintaining gauging stations have limited their allocation to perennial streams of extreme importance. This has deprived the responsible authorities of the vital flow data of the ephemeral streams whose deluge cause tremendous sufferings and financial losses year after year. It is, therefore, imperative to develop a procedure which may be used to estimate peak flows of the ungauged ephemeral streams. Objections of Linsley and Franzini (1972, p.132) not-withstanding, envelope curves provide a readily available means to achieve this purpose, although somewhat subjectively. Apparently, application of this method has some merit even in countries advanced in data acquisition and interpretation. Walters (1966) presented the Binnie-Lapworth formula of 1928 for maximum flood intensity in England : $Q_{max}=750\ M^{1/3}$, where Q_{max} is the flow in cfs mi^{-2}, and M is the area of a certain wathershed in mi^2. Viessman, Jr, et al. (1977), p.607, and Fig.12-20) advocated application of this procedure in obtaining the probable maximum flood in areas of sparse data. Mimikou (1984) developed envelope curves for northwestern and western Greece. Moosavi and Sepaskhah (1989), using statistical procedures, presented predictive equations which may be used to estimate maximum flows of ungauged basins in the Fars Province. The strength of the present paper is that observed data of the largest recorded floods in southwestern Iran are used to derive very simple equations which relate the maximum observed flows to the areas of the basins.

THE FLOOD

As a rule, the western highlands of Iran receive their Oct./Nov. to Apr./May precipitation from clouds originating over the Mediterranean Sea, and carried to them by the westerlies. These rains usually fall on the western Zagros Ranges and deprive the leeward side, the interior of Iran, of the precious water (Ganji

1965). The second type, like the one which has been instrumental in causing the historical deluge of 1986, come from the south. Apparently, the southern system retarded the advancement of the westerlies, piling the clouds and impregnating them with water droplets, thus resulting in a devastating downpour in southwestern Iran which covered an area of about 600000 km^2. Mean annual precipitation (MAP), along with total depth and maximum daily rainfall during this event, is presented in Table 1. Amount and distribution of percipitation in this deluge are better depicted in an isohyetal map (Fig.1). It is observed that for some localities, the amount of rain which fell during this event exceeded the MAP; and for the Estahban-Nayriz area, whose data are not presented here, it was more than twice the MAP; thus, it may be deduced by inspection alone, rather than statistical analyses, that this storm was an exceptional occurrence.

The objective of the study reported here was to derive equations which describe envelope curves for the observed deluge in southwestern Iran, which is believed to have been a rare event.

MATERIALS AND METHODS

The maximum flow of three major and one minor basins [Zohreh, Mond, and Helleh (the Persian Gulf drainage area) and Shiraz (Maharloo Lake Basin)], which were estimated at 36 points, are given in Table 2. Submergence and/or destruction of the gauging stations during the deluge made more accurate measurements impractical. The maximum flow at each station in cubic meters per second was converted to liters (l) per second and divided by the appropriate watershed area in square kilometers. The results, specific yields of the watersheds (S_{yw}, ls^{-1} km^{-2}) are given in Table 2. Regression of S_{yws} on the area of respective watersheds yielded equations of the envelope curves. This was achieved by employing Program 7 of Family Regression (Hewlett and Packard 9825, Statistic Software Vol.I) which "fits, 'simple non-linear' curves by transforming the X and/or Y data to fit the simple linear model, Y=a+bX".

Table 1. Precipitation data for stations in the Zohreh, Mond, Helleh and Shiraz basins during the deluge of Dec.1986, and mean annual precipitation (MAP, 1971-1986).

Station	Duration	Total rain-fall	Maximum daily rain-fall	MAP
			mm	
Zohreh Basin				
Berghan, Sepidan	29Nov.-6 Dec.	197.5	57.0	672.8
Mola-Quaedi, Sheshpir	" "	221.5	106.0	641.7
Tang-e-Brim	" -2 Dec.	216.0	83.5	724.6
Dehdasht	" -3 Dec.	115.0	50.0	538.4
Gachsaran	" -2 Dec.	55.0*	37.0	397.7
Mond Basin				
Fasa	30Nov.-7 Dec.	425.0	181.0	306.2
Nowbandegan	" "	333.0	132.0	298.1
Gareh-Bygone	" "	220.0	93.0	240.4
Bukhan, Baba-Arab	" "	375.0	135.0	240.4
Sarvoo, Jahrom	" "	430.0	171.0	378.2
Qotb-Abad	" "	315.0	104.0	321.3
Bagh-e-Avaz	" "	375.0	135.0	312.4
Mobarak-Abad	" "	293.5	133.0	297.3
Helleh Basin				
Kazerun	30Nov.-7 Dec.	213.0	83.0	576.4
Bushigan	" -3 Dec.	192.5	86.0	571.4
Kamarej	" "	187.0	70.0	491.0
Jareh-Bala	30Nov.-3 Dec.	110.0	50.0	305.9
Saad-Abad	" "	118.0	55.0	278.1
Shur-Jareh	" -7 Dec.	304.0	120.0	350.8
Sar-Qanat	" -2 Dec.	168.5	66.0	386.3
Kolol	" "	165.0*	55.0	244.8
Shiraz Basin				
Kelestan	" -3 Dec.	262.0	100.0	458.1
Tchenar-Sookhteh	" -6 Dec.	324.0	150.0	453.0
Rahdar	" "	216.5*	90.5	341.0
Shiraz	" "	268.0	142.0	325.0
Du Baneh	" "	289.0	114.0	372.1
Post-e-Tchenar	" "	257.0*	157.0	240.1

* Doubtful data.

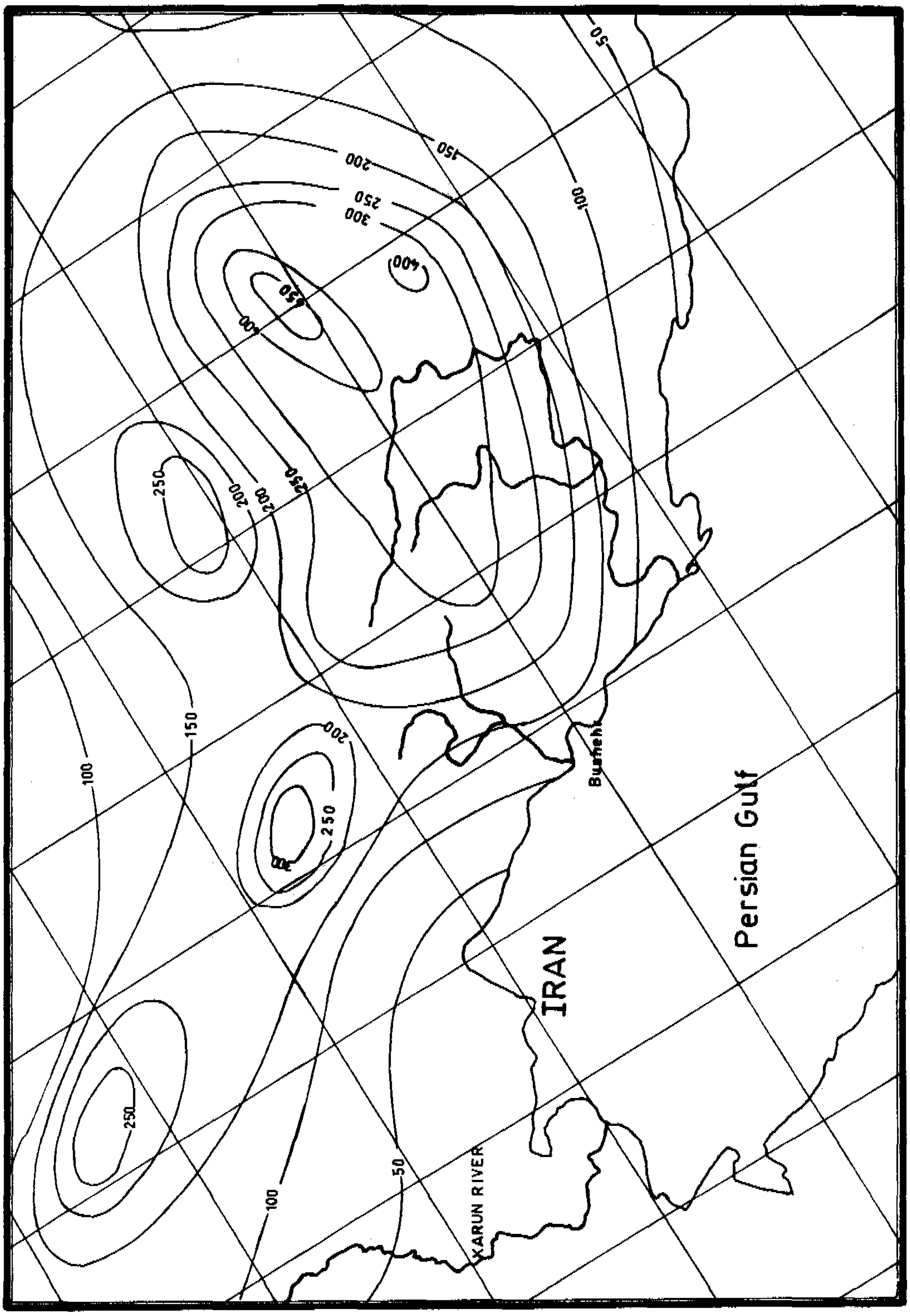

Fig.1. Isohyetal map of southwestern Iran in the deluge of Dec.1986.

Table 2. Maximum flow, area, and specific yield of four major basins in southwestern Iran in the deluge of Dec. 1986.

Station	Date	Max. flow, $m^3 s^{-1}$	Watershed area, km^2	Specific yield, $ls^{-1} km^{-2}$
Zohreh Basin				
Tcham-Chenar, Sheshpir	1Dec.86	143	218	650
Mola-Qaedi, "	3Dec.86	126	490	257
Ab-Shirin, Ger-ab	"	200	510	494
Tang-e-Brim	30Nov.86	657	948	691
Shul, Goosengan	?	900	2100	428
Ab-Shirin, Khair-Abad	"	1698	2838	597
Batun, Zohreh "	?	1100	4120	297
Gachsaran, "		2650	7620	347
Mond Basin				
Tchah-Tiz, Jahrom	3Dec.86	156	56	2780
Khorram-Abad, Jahrom	"	175	62	2800
Bisheh-Zard	"	300	192	1560
Berack, Simakan	"	1085	745	1460
Vasel-Abad	2Dec.86	766	1156	550
Tang-Ab, Firooz-Abad	"	900	1200	750
Zar-Jan, Kooshk-e-Qazi	"	766	1418	540
Qareh-Aghaj, Band-e-Bahman	"	714	1601	446
" ", Ali Abad	3Dec.86	1350	2631	513
Shur, Qotb-Abad	2Dec.86	2280	5181	440
Shur, Bagh-e-Avaz	3Dec.86	2915	6393	456
Mond, Tang-e-Karzin	?	5600	13075	428
Mond, Qantareh		11700	30650	382
Mond, Kangan	?	16000	48400	330
Helleh Basin				
Renjan, Shapur	3Dec.86	580	750	774
Bushigan, "	"	750	1290	581
Pol-e-Shekasteh	"	950	2600	365
Tchiti, Shapur	"	950	2985	318
Sar-Qanat, "	"	1557	3230	482
Saad-Abad, "	"	1530	3600	425
Helleh, Kolol,	"	3000	8100	370

....../cont.

Station	Date	Max. flow, $m^3\ s^{-1}$	Watershed area, km^2	Specific yield, $ls^{-1}\ km^{-2}$
Shiraz Basin				
Khoshk	2Dec.86	141	67	2140
Tchenar-Sookhteh	"	197	304	647
Rahdar	"	254	175	1456
Miscellaneous				
Badamak, Tang-e-Shul; northern area	"	90	185	487
Yasuj, Beshar; northern area	"	414	800	518
Shah-Mokhtar; northern area	"	600	1187	505
Pataveh, Beshar; northern area	30Nov.86	507	4056	124

RESULTS AND DISCUSSION

Peak flow per unit area (Q, $ls^{-1}\ km^{-2}$) for the 36 points, which represented extreme floods in approximately 70000 km^2 of SW Iran is given by:

$Q=393.103+182759.672/A$ $R^2=0.845^{**}$ $F=190.004^{**}$ (1)

where A is the drainage area in km^2, Envelope curves for the other basins are as follows:

Mond:

$Q=8211.369A^{-0.326}$ $R^2=0.839^{**}$ $F=62.328^{**}$ (2)

Helleh:

$Q=295.145+352922.966/A$ $R^2=0.856^{**}$ $F=29.831^{**}$ (3)

Shiraz:

$Q=2560.692-6.299A$ $R^2=1.000^{**}$ $F=126414.065^{**}$ (4)

None of the curves described by the employed models fit the Zohreh Basin better than what is given by (1). It is interesting to note that equation (4) closely estimated peak flow of the 32 km^2 Koran Basin, north of Shiraz, during the same event.

Although Linsley and Franzini (1972, pp.131-132) believe that the exponent in equation (2) is often taken as -0.5, indicating that peak discharge is inversely related to the square root of drainage area, our results conform better to 1/3, the exponent given by Binnie-Lapworth (Walters 1966). This may indicate a closer similarity between the runoff characteristics of the watersheds in SW Iran and those of England, than the basin in the U.S.

CONCLUSIONS

The deluge of Dec. 1986 provided an opportunity to relate the flow data to the area of the respective basin and develop predictive equations which may be used in designing flood mitigation works and artificial recharge facilities. Knowing the extreme discharge of certain wathersheds enables responsible authorities to plan and execute defensive systems in advance and turn a bane into a blessing by wise utilization of floodwaters.

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A COUPLED MODEL OF OVERLAND FLOW, SOIL WATER VARIATION AND GROUNDWATER REGIME IN NORTH-CHINA SEMI-ARID PLAIN

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ABSTRACT

Rain water, soil water and groundwater are interconnected as an intrinsic system. Differential equations of water movement for individual unit of the system have been solved separately but linked together by regarding their common interfaces, namely the surface-water/soil-water and the soil-water/ground-water,as internal boundary conditions. The soil water variation is a controlling factor in transmitting rain water into groundwater, an one-dimensional equation for soil water variation is then solved first using finite analysis method with a prescribed initial soil water content above a variable groundwater level during either precipitation or evaporation. If the precipitation intensity is higher than the soil infiltration rate, a depth-averaged two-dimensional solution for the overland flow is approximated by a power series method to see if both the duration and the depth of ponding water are suitable for crop growth, or otherwise a three-dimensional groundwater regime due to adjusting the pumping scheme for the agricultural and/or the municipal use is calculated by boundary element method in order to make an optimal management of the water circulation. Such a computational process is repeated until minimizing the water-logging, preventing the soil salinity and balancing the water resource are reached to an expected situation.

For the North-China semi-arid plain, model studies show that the optimal groundwater depth for an excess rain season is about 3.5 m at the up-plain, but 5.0 m at the down-plain area, especially, near the shore line, the groundwater level must further be lowered owing to both the slow infiltration rate of the fine soil and the existence of saline water unable for plant growth.

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INTRODUCTION

Precipitation, surface runoff, infiltration, evaporation and groundwater are units of an interconnected hydrocycle. In a semi-arid area, appropriate use of water resources would make an ideal hydro-ecologic system, inadequate use could cause situation worse and worse becoming waterlogging, soil salinity and/or unbalance of water resources.

In the past, the surface water and the groundwater were mostly studied in different fields with little interconnection. Nowadays, attention has been paid to the water circulation and their interchangeable features, but the state of art is more of less in a qualitative analysis. In this paper, a coupled model of overland flow during precipitation, soil water variation due to either infiltration or evaporation and groundwater regime due to either discharging or recharging has been solved numerically, but linked by their internal boundary conditions, such as both the surface-water/soil-water and the soil-water/ground-water interfaces. The aim of this paper is minimizing the waterlogging, preventing the soil salinity and maintaining the water resources in equlibrium in a semi-arid plain area.

Generally, numerical methods, such as finite difference, finite element and boundary element methods are necessary and sufficient tools in solving both surface water and underground water flow problems. However, finite analysis will sometimes give more accurate and stable solutions these problems, especially in soil water variation occurs frequently numerical oscillation with time, which can be overcome by using the finite analysis method. On the other hand, the differential equation for the overland flow is usually non-linear due to involving unknown coefficients, it is rather difficult to solve by finite difference or finite element methods than by localized power series method which will speed up the computation. Therefore, the overland flow problem is solved by the localized power series method, the soil water movement by the finite analysis, but the groundwater regime either by 3-dimensional boundary element method for smaller area or by 2-dimensional finite analysis method for large region. Field measurements both in soil water variation and in groundwater regime are used either to determine inversely the parameters or to be the initial conditions in predicting the optimal management of the water system.

GOVERNING EQUATIONS

1. Boundary element method for groundwater flow (Liggett & Liu, 1983) Continuity equation at a point in a groundwater flow field is

$$\frac{\partial^2\Phi}{\partial x^2}+\frac{\partial^2\Phi}{\partial y^2}+\frac{\partial^2\Phi}{\partial z^2}=0 = \nabla^2\Phi$$

The governing equation with a source or a sink is

$$\nabla^2\Phi=-\sum_{i=1}^{NW}\frac{Q_i}{K}\delta(x-x_i)\delta(y-y_i)\delta(z-z_i) \qquad (1\text{-}1)$$

in which Φ is hydraulic head, NW is number of source (plus sign)or sink (minus sign), Q_i are their intensities, and X_i, Y_i, Z_i are the coordinates of Q_i..

Boundary conditions: $\Phi=\Phi_b$ $\quad \Phi_b$, prescribed head

$$\frac{\partial\Phi}{\partial n}=-q_b/k$$

Where q_b =flux/unit width, K is permeability, $\partial\Phi/\partial n$ is normal derivative. On the free surface,

$$\Phi=\eta \qquad \frac{\partial\eta}{\partial t}=-\frac{K}{\mu}\left[1+\left(\frac{\partial\eta}{\partial x}\right)^2+\left(\frac{\partial\eta}{\partial y}\right)^2\right]^{\frac{1}{2}}\frac{\partial\Phi}{\partial n}+W$$

where η is elevation of water surface, μ is porosity, W is water supply to the surface. The boundary integral equation of Equ. 1-1 is

$$-\alpha\Phi(P)+\sum_{i=1}^{NW}4\pi\frac{Qi}{K}\cdot g=\iint_{\Omega}\left(\Phi\frac{\partial g}{\partial n}-g\frac{\partial\Phi}{\partial n}\right)dA$$

$$g=\left[(x_p-x_i)^2+(y_p-y_i)^2+(z_p-z_i)^2\right]^{-\frac{1}{2}} \qquad (1\text{-}2)$$

the boundary is divided into N points, Pi (i = 1,2,...N), each element made by these points is discreted and then operated by Gauss integration, and finally summed up for solution.

Global coordinated (X,Y,Z) are converted into local coordinates (ξ, η), namely

$$x=\{N(\xi,\eta)\}^T\{x\}_e \qquad y=\{N(\xi,\eta)\}^T\{y\}_e \qquad z=\{N(\xi,\eta)\}^T\{z\}_e$$

in which {N} is shape function. Φ and $\partial\Phi/\partial n$ are also interpolated using the same shape function, then

$$\Phi = \{N\}^T\{\Phi\}_e \qquad \frac{\partial\Phi}{\partial n} = \{N\}^T\left\{\frac{\partial\Phi}{\partial n}\right\}_e$$

By discreting, Equ. 1-2 becomes an algebraic equation as follows:

$$\alpha_i\Phi_i + \sum_{e=1}^{M}\{a\}_e^T\{\Phi\}_e = \sum_{e=1}^{M}\{b\}_e^T\left\{\frac{\partial\Phi}{\partial n}\right\}_e + \sum_{j=1}^{NW}4\pi\frac{Q_j}{K}g \tag{1-3}$$

in which α is a solid angle, M is total number of boundary elements, $\{a\}_e$ and $\{b\}_e$ are vectors related to the local coordinated of each element. Using Equ. 1-3 for all points on the boundary, a set of N dimensional linear equations is obtained as

$$[H]\{u\} = \{r\} + \{h\} \tag{1-4}$$

in which $[H]$ is a known coefficient matrix, $\{u\}$ is a vector of unknown node values, $\{r\}$ is a known vector and $\{h\}$ is the source term. After solving Equa, 1-4 Φ and $\partial\Phi/\partial n$ on the boundary become known values used to calculate the hydraulic head at any point in the flow field.

For un-steady and unconfined groundwater flow problems, the boundary condition on the free surface is rewritten in the from

$$\eta^{k+1} = \eta^k - \frac{k}{\mu}\cdot\Delta t\cdot\gamma^k[\theta(\frac{\partial\Phi}{\partial n})^{k+1} + (1+\theta)(\frac{\partial\Phi}{\partial n})^k] + \Delta t \, [\theta w^{k+1} + (1-\theta)W^k] \tag{1-5}$$

in which $\gamma^k = \left\{1 + [(\frac{\partial\eta}{\partial x})^k]^2 + [(\frac{\partial\eta}{\partial y})^k]^2\right\}^{\frac{1}{2}}$, θ is a weighted factor, k is time step. Using the calculated free surface position at the previous time step as the initial condition for the present time step to calculate new hydaulic heads and the free surface position.

2. Governing equation of soil water movement (Luthin, 1957; Bear,1980)

For a uniformly layered soil system ,the soil water movement for a regional precipitation or evaporation is assumed to be one-dimension flow, then the governing equation can be written as

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left(k\frac{\partial\Phi}{\partial z}\right) \qquad (2\text{-}1)$$

in which θ is soil water content, K is permeability varying with water content. The soil water potetial Φ can be separated into:

$$\Phi=\Phi_m+\Phi_g$$

in which Φ_g is gravitational potential relative to a reference level, if the upward Z coordinate is positive, then $\Phi_g = Z$; Φ_m is the soil suction which is negative. Thus, Equ. 2-1 becomes

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left(k\frac{\partial\Phi_m}{\partial z}+k\right) \qquad (2\text{-}2)$$

There is a functional relationship between θ and Φ_m as

$$\frac{\partial\Phi_m}{\partial z}=\frac{\partial\Phi_m}{\partial\theta}\cdot\frac{\partial\theta}{\partial z}$$

Substituting into Equ. 2-2, gives

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left(k\frac{\partial\Phi_m}{\partial\theta}\cdot\frac{\partial\theta}{\partial z}+k\right)$$

Putting diffusivity $D=k\partial\Phi_m/\partial\theta$ and substituting, yields

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}(D\frac{\partial\theta}{\partial z}+k) \qquad (2\text{-}3)$$

Boundary conditions:

$$\theta(t,z)\Big|_{\Gamma}=\theta_{\Gamma}(t) \qquad\qquad k(\theta)(\frac{\partial\theta}{\partial z}+1)\Big|_{\Gamma}=q_{\Gamma}(t)$$

in which θ_Γ is a known water content and q_Γ is a known unit flux,

Initial condition:

$$\theta(t,z)\Big|_{t=0}=\theta_0(z)$$

Equ. 2-3 is solved by finite analysis method. For a local point P of an element, assuming D is constant at any point in the element, i.e. $D=D_p$, the Equ. 2-3 can be linearized locally as

$$\frac{\partial \theta}{\partial t} = D_p \frac{\partial^2 \theta}{\partial z^2} + \frac{\partial k}{\partial z} \tag{2-4}$$

all derivatives are approximated by finite difference, gives

$$(2 + \frac{L^2}{D_i \Delta t})\theta_i^{k+1} - \theta_{i-1}^{k+1} - \theta_{i+1}^{k+1} = \frac{L^2}{D_i \Delta t}\theta_i^k + \frac{k_i - k_{i+1}}{2D_i} L \tag{2-5}$$

Equ, 2-5 is a finite analysis form for soil water movement for a particular element, in which K is time step, L is the length of a line element and i, i+1, i-1 are its central and end points respectively as shown in Fig.1. Similarly, a set of linear algebraic equation can be obtained for all elements and solved for the water content at any point in the flow field.

3. Governing equation of overland flow (Conner, 1976)

Continuity equation:

$$\frac{\partial(\rho v_i)}{\partial x_i} + \frac{\partial \rho}{\partial t} = 0 \tag{3-1}$$

Momentum equation:

$$\frac{D(\rho v_k)}{Dt} = \frac{\partial(\rho v_k)}{\partial t} + v_i \frac{\partial(\rho v_k)}{\partial x_i} = -\frac{\partial p}{\partial x_k} + \frac{\partial \tau_{ik}}{\partial x_i} + \rho b_k , \quad i, k = 1, 2, 3 \tag{3-2}$$

in which ρ is mass of water, P is pressure, τ is shear stress, and ρb is body force. Because vertical velocity is very small, acceleration and shear stress can be neglected along the Z direction, then the momentum equation is simplified as

$$-\frac{\partial p}{\partial x_3} = \rho g \tag{3-3}$$

where g is gravitational acceleration. Integrating above equation. yields,

$$p = \int_{x_3}^{\eta} \rho g dx_3 = \rho g(\eta - x_3) \tag{3-4}$$

thus, V_x and V_y in the momentum equation are average velocities in X,Y direction along the Z axis. Similarly, integrating Equ. 3-1 with respect to x_3 (see Fig.2), gives

$$\int_{-h}^{\eta}\left(\frac{\partial(\rho v_i)}{\partial x_i}+\frac{\partial \rho}{\partial t}\right)dx_3=0 \qquad (3\text{-}5)$$

Defining unit width flux as

$$q_k=\int_{-h}^{\eta}\rho v_k dx_3=\rho\int_{-h}^{\eta}v_k dx_3\,,\ k=1,2$$

and using Leibniz's rule, Equ, 3-5 becomes

$$\frac{\partial q_i}{\partial x_i}+\frac{\partial(\rho H)}{\partial t}=0 \qquad\qquad \frac{\partial q_i}{\partial x_i}+\frac{\partial(\rho H)}{\partial t}=q^{*} \qquad (3\text{-}6)$$

in which $H=h+\eta$ and q^{*} is intensity of source or sink.

Integrating the momentum equation along the X,Y direction with respect to X_3 , namely,

$$\int_{-h}^{\eta}\left[\frac{\partial(\rho v_k)}{\partial t}+v_1\frac{\partial(\rho v_k)}{\partial x_1}+v_2\frac{\partial(\rho v_k)}{\partial x_2}\right]dx_3$$
$$=\int_{-h}^{\eta}\left(-\frac{\partial p}{\partial x_k}+\frac{\partial \tau_{1k}}{\partial x_1}+\frac{\partial \tau_{2k}}{\partial x_2}+\rho b_k\right)dx_3 \qquad k=1,2 \qquad (3\text{-}7)$$

letting $\quad v_k=\overline{v}_k(x_1,x_2,t)+v'_k(x_1,x_2,x_3,t)$

in which

$$\begin{cases}\overline{v}_k=\dfrac{1}{H}\langle v_k\rangle\\ \langle v_k\rangle=\displaystyle\int_{-h}^{\eta}v_k dx_3=\frac{1}{\rho}q_k\\ \langle v'_k\rangle=0\end{cases}$$

and using Leiniz's rule and the moving boundary condition

$$v_3|_\eta=\frac{D\eta}{Dt}=\frac{\partial\eta}{\partial t}+v_1|_\eta\frac{\partial\eta}{\partial x_1}+v_2|_\eta\frac{\partial\eta}{\partial x_2}$$

also the shear stress along the ground surface is expressed as

$$\tau_1=\frac{g}{c^2}\ \frac{q_1\sqrt{q_1^2+q_2^2}}{\rho H^2} \qquad \tau_2=\frac{g}{c^2}\cdot\frac{q_2\sqrt{q_1^2+q_2^2}}{\rho H^2} \qquad C=\frac{1}{n}H^{\frac{1}{3}}$$

in which C is Chezy coefficient and n is Manning coefficient. Finally, substituting all above equations into Equ. 3-7 with body force is zero in the horizontal direction, yields.

$$\begin{cases} \frac{\partial q_1}{\partial t} + \frac{q_1}{\rho H}\frac{\partial q_1}{\partial x_1} + \frac{q_2}{\rho H}\frac{\partial q_1}{\partial x_2} + \frac{g q_1 \sqrt{q_1^2 + q_2^2}}{c^2 \rho H^2} + \rho g H \frac{\partial}{\partial x_1}(H - h) = 0 \\ \frac{\partial q_2}{\partial t} + \frac{q_1}{\rho H}\frac{\partial q_2}{\partial x_1} + \frac{q_2}{\rho H}\frac{\partial q_2}{\partial x_2} + \frac{g q_2 \sqrt{q_1^2 + q_2^2}}{c^2 \rho H^2} + \rho g H \frac{\partial}{\partial x_2}(H - h) = 0 \end{cases} \quad (3\text{-}8)$$

Then the governing equation for the overland flow can be written as:

$$\begin{cases} \frac{\partial q_x}{\partial t} = -\frac{q_x}{\rho H}\frac{\partial q_x}{\partial x} - \frac{q_y}{\rho H}\frac{\partial q_x}{\partial y} - \frac{g}{c^2}\frac{q_x\sqrt{q_x^2 + q_y^2}}{\rho H^2} - \rho g H \frac{\partial H}{\partial x} + \rho g H i_x \\ \frac{\partial q_y}{\partial t} = -\frac{q_x}{\rho H}\frac{\partial q_y}{\partial x} - \frac{q_y}{\rho H}\frac{\partial q_y}{\partial y} - \frac{g}{c^2}\frac{q_y\sqrt{q_x^2 + q_y^2}}{\rho H^2} - \rho g H \frac{\partial H}{\partial y} + \rho g H i_y \\ \frac{\partial H}{\partial t} = q^* / \rho - \frac{1}{\rho}\frac{\partial q_x}{\partial x} - \frac{1}{\rho}\frac{\partial q_y}{\partial y} \end{cases} \quad (3\text{-}9)$$

Because unknown coefficients are involved in this equation, it is difficult to solve by finite difference method, but can be solved approximately in a easier way by a localized power series method, getting a power series solution at a point and a particular time in small region.

DETERMINATION OF PARAMETERS

Precipitation case:

If the ponding water depth is less than 1 cm, the infiltration rate is assumed to be the saturated permeability of soil, in other words, they are equivalent to the precipitation intensity. For the unsaturated situation, the permeability and the diffusivity are function of soil water content, it is usually determined by empirical equations, such as

$$K(\theta) = A \exp(B\theta)$$

in which θ is soil water content, A and B are experimentally determined constants. The water content can be expressed experimentally as

$$\theta = \theta_s / (1 + \eta h_c^3)$$

in which θ_s is saturated water content, h_c is soil suction and η is empirical constant varying from 10^{-4} to 10^{-9}. Then the diffusivity can be expressed as

$$D(\theta) = K(\theta)\frac{\partial hc}{\partial \theta} = -\frac{1}{3}k(\theta)\eta^{-\frac{1}{3}}(\frac{\theta_s}{\theta} - 1)^{-\frac{2}{3}} \cdot \frac{\theta_s}{\theta^2}$$

For fine sandy soil ,if the groundwater level is 3 m below the ground surface, the measured unsaturated-permeability and diffusivity are

$$K(\theta) = 4.67 \times 10^{-5} e^{35.8\theta} \quad cm / day$$

$$D(\theta) = \begin{cases} 4.42 \times 10^{-4} e^{25.3\theta} & \theta \le 0.35 \\ 8.666 e^{0.5923\theta} & \theta > 0.35 \end{cases} \quad cm^2 / min$$

and the saturated water content is 0.38.

Finally, the soil water variation and the change in groundwater level during infiltration with a negligible depth of water ponding are simulated as shown in Fig.3.

Evaporation Case:

If the soil water content at ground surface, $\theta(0,t)$ is greater than a critical value θ_k, the evaporation rate E can be assumed to be E_o which is the evaporation from water surface. Then, the E can be expressed as

$$-D\frac{\partial \theta}{\partial Z} + K = -\begin{cases} E_0 & , \quad \theta > \theta_k \\ A\theta(0, t) + B & , \quad \theta \le \theta_k \end{cases}$$

in which A and B are empirical constants. If the evaporation is very strong, the water content is assumed to be that at wilting point. For instance, the evaporation rate and the water content at surface for groundwater depth, 0.4 m below the surface ,are determined experimentally as

$$\begin{cases} [-D(\theta)\frac{\partial\theta}{\partial z} + k(\theta)]\Big|_{z=0} = -\begin{cases} 0.8\text{cm/day}, \theta > 0.25 \\ 1.6\theta(0,t) + 0.4\text{cm/day}, 0.05 \le \theta \le 0.25 \end{cases} \\ \theta(0,t) = 0.05 \quad , \quad \theta < 0.05 \end{cases}$$

and the unsaturated permeability and water content are also determined as

$$K(\theta) = 0.032e^{20\theta} \qquad \text{cm / day}$$

$$\theta = 0.4 / (1 - 0.000012h_c^3)$$

Finally, the soil water variation and groundwater regime during soil surface evaporation are simulated as shown in Fig.4.

Water-logging case:

In a small farming field of 2000 acres surrounded by channels and ditches as shown in Fig.5. Only average gradients along X and Y directions are considered, the overland sheet flow is assumed to be laminal, and the average-depth 2-dimensional equation is also assumed to be valid. A stormy rain, 2 cm/hr with a duration of 6 hrs, is taken into account. Based on the groundwater level contours before and after the storm as shown in Fig.5 and the soil water variation, both the unsaturated permeability and the diffusivity are firstly determined as described previously, then the coefficient n is to be varied to match both the measured groundwater levels and the ponding water situation by using Equ. 3-9. The computational procedures are described in detail in Fig.6.

Simulated results show that the surface runoff stared within 0.3 hr as shown in Fig. 7, but the ponding water disappeared within 3.9 hr after the rain stopped as shown in the same figure, and that the quantity of water flowing into channels is 27,634 m^3 (Fig.8), 93.8% of precipitation infiltrated into the underground, of which 25.53% recharged to the groundwater, further that a threshold curve for controlling the waterlogging is shown in Fig.9, which is a function of total precipitation, intensity and groundwater depth, the domain below the curve is considered to be on the safe side. Figs. 7,8,&9 also show these relationships to be associated with the variations of groundwater depth, precipitation intensity and its duration.

MANAGEMENT OF WATER USE OF A COUNTY

A county of 14,000 km^2 in area is a part of the North-China plain, the average precipitation per year for a long term is 576 mm in the eastern part of the county, 530 mm in the western part, and mainly concentrated in a 2-month period of July to August, thus the groundwater is the only available source for both agricultural and industrial use during the dry season. However, the amount of groundwater is limited and should be recharged annually by rain water to balance water resource. Therefore, an optimal management of rain water is a main task of this county.

Based on the relationships between the infiltration and the groundwater depth during raining season as well as the soil surface evaporation and the change in groundwater depth during dry season as shown in Fig.10, it can be suggested that before the raining season, the groundwater level should be lowered to, but not more than, 6 m below the ground surface in order to recharge enough rain water into underground without increasing the pumping cost, and that after the raining season, the level must be controlled at 2 m below the surface so as to minimize the soil surface evaporation and to prevent the soil salinity.

First, making use of the measured groundwater contours of this county before and after a particular rain season, the parameters of the fine sandy stratum are inversely determined, then the optimal groundwater levels for both the normal and excess rain seasons are simulated and compared with the present groundwater contours as shown in Fig.11. One can see from this figure that some areas are unbeneficially overpumped, but that a region near the coast is underpumped due to the saline water unable for planting, the best way to solve the problem is to grow salt-tolerant plants in order to recharge more rain water into the underground to strengthening the water circulation on the one hand and to dilute the saline water in a long term sense on the other.

CONCLUSION

The coupled model of conjunctive use of surface water and groundwater is very useful in optimal management of water resources in a semi-arid plain. The soil water variation which is associated with the groundwater depth is a central part in water system management and in water resources evaluation.

The critical depth of groundwater is a function of time, before the rain season, the depth should be lowered to an ideal condition able to recharge enough water in the coming rain season into underground with little water logging ,and on the other hand, during dry season the groundwater level must be controlled at about 2 m below ground surface in order to prevent the soil salinity problem and to be favorable for plant intake of water. Therefore, the groundwater level has to be lowered gradually from the earlier spring for agricultural use to the harvest time for surface water recharging.

The field conditions used for numerical modelling are oversimplified as an uniform layer of fine sand, the soil water movement is not one-dimensional as pre-assumed and a regional groundwater flow is not two-dimensional either, it seems that a more complex model is needed in dealing with a realistic problem.

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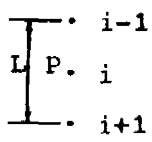


Fig.1 LINE ELEMENT FOR 1-DIMENSIONAL SOIL WATER MOVEMENT

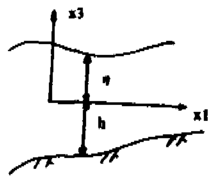


Fig.2 SCHEMATIC OVERLAND FLOW DURING RAINING

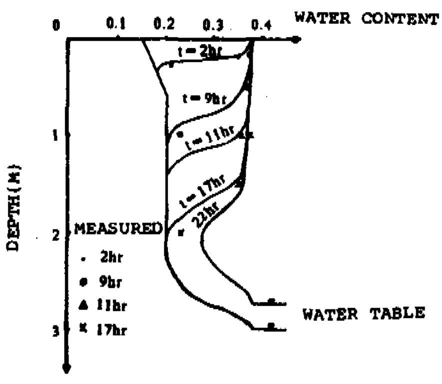


Fig.3 SOIL WATER VARIATION AND GROUNDWATER LEVEL CHANGE DURING INFILTRATION

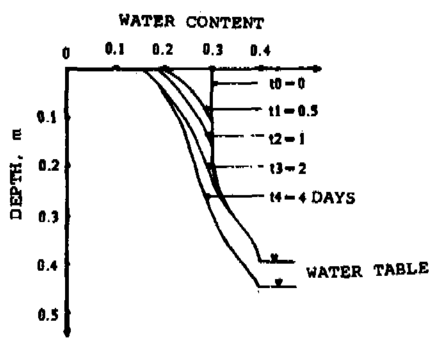
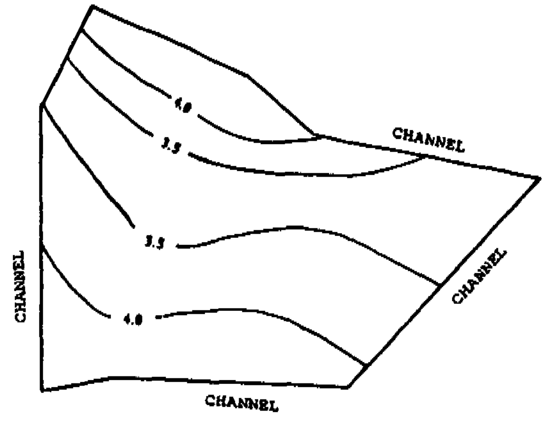
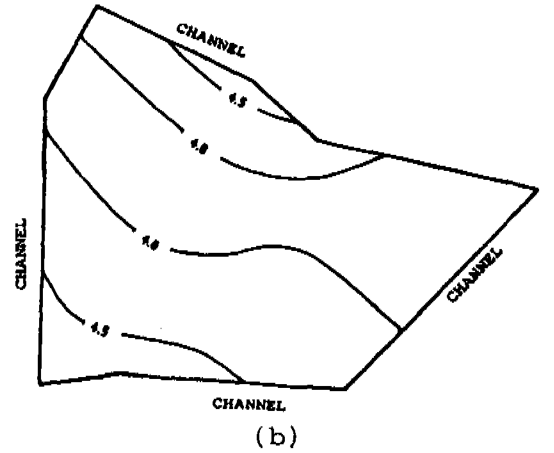


Fig.4 SOIL WATER VARIATION AND GROUNDWATER LEVEL GHANGE DURING EVAPORATION



(a)



(b)

Fig.5 GROUNDWATER LEVEL CONTOURS OF A FARMING FIELD BEFORE(a) AND AFTER (b) A PARTICULAR RAIN

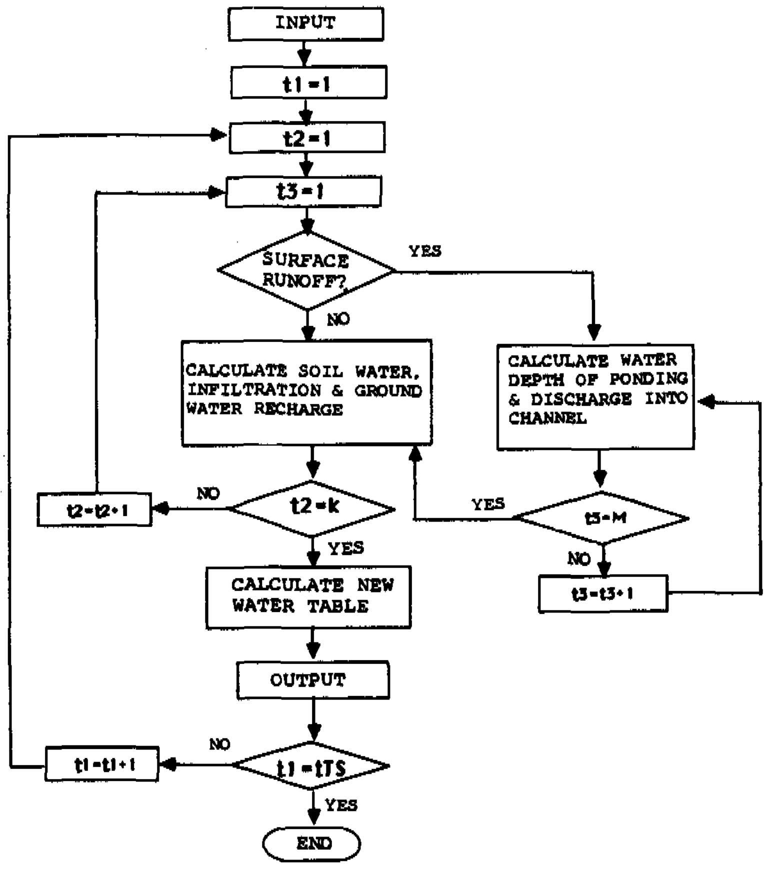
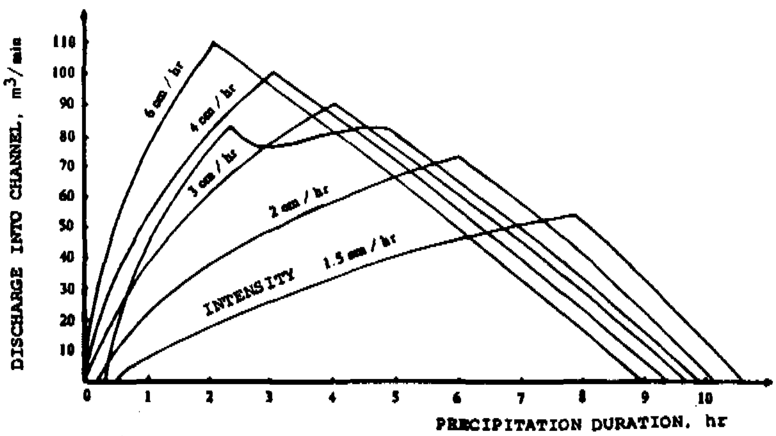


Fig.6 PROGRAMMING FLOW CHART OF INTERACTION BETWEEN SEASONAL PRECIPITATION SOIL WATER VARIATION AND GROUNDWATER REGIME (Time steps: t1<t2<t3: t1 (surface water), t2 (soilwater) t3 (ground water)



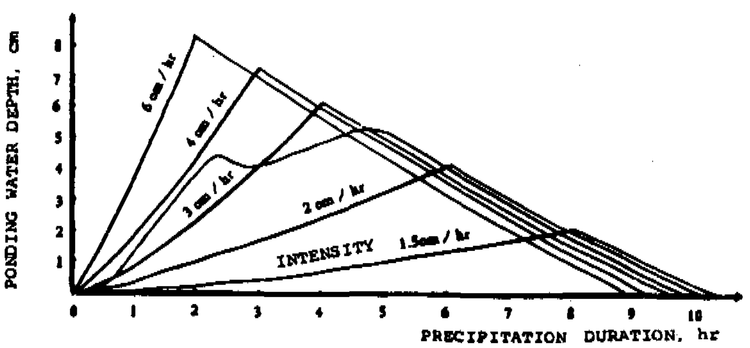


Fig.7 RELATIONSHIP BETWEEN PRECIPITATION INTENSITY, DURATION AND RUNOFF OR PONDING WATER DEPTH

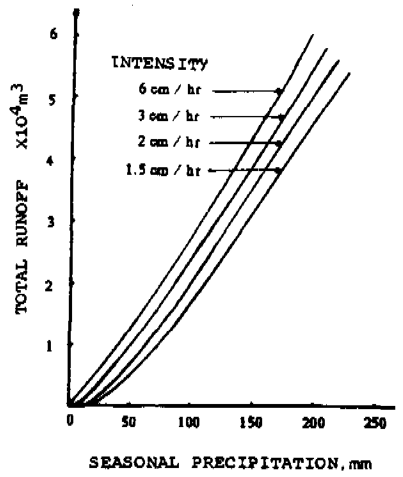


Fig.8 RELATIONSHIP BETWEEN TOTAL RUNOFF, SEASONAL PRECIPITATION AND INTENSITY

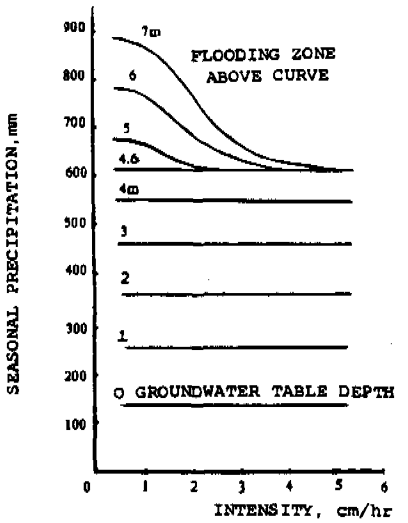


Fig.9 WATERLOGGING CONTROL CURVES DURING RAINING FOR DIFFERENT GROUNDWATER DEPTHS

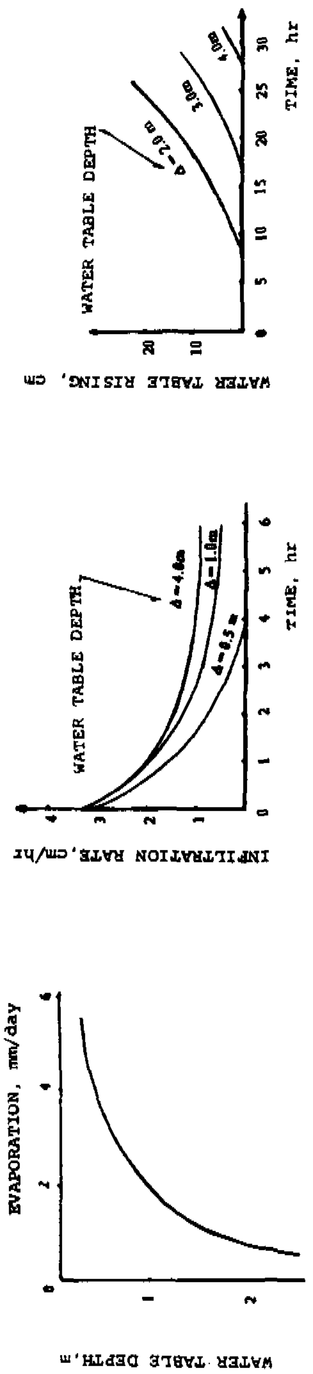


Fig.10 SOIL SURFACE EVAPORATION, INFILTRATION AND WATER LEVEL RISING IN RELATION TO GROUNDWATER DEPTH FOR FINE SANDY SOIL

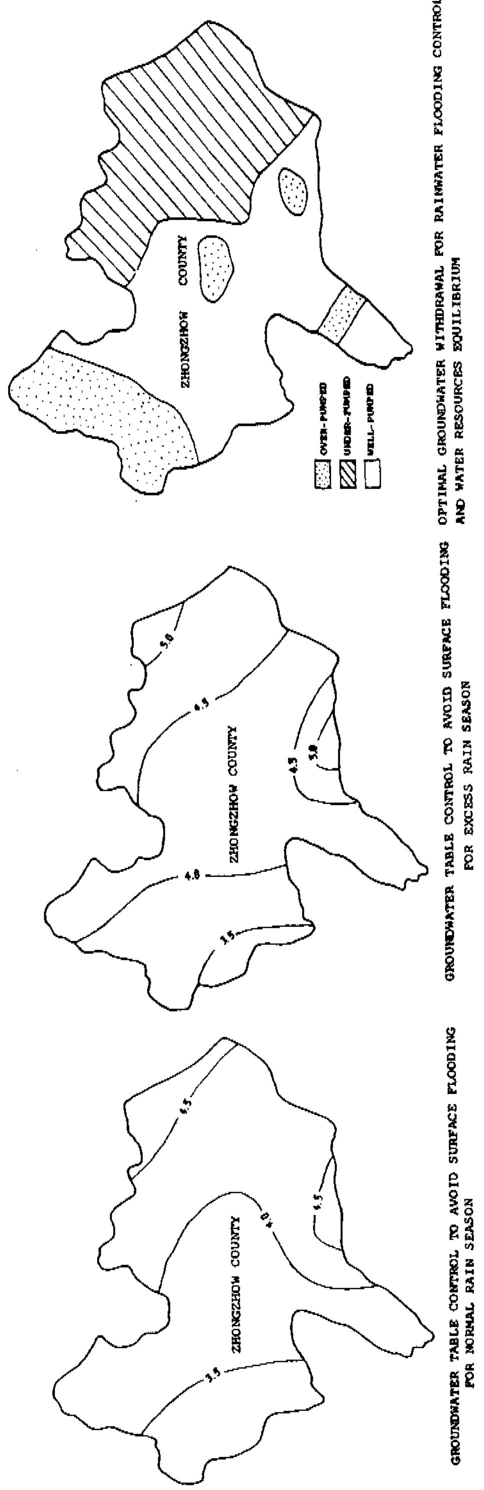


Fig.11 GROUNDWATER MANAGEMENT OF A COUNTY IN NORTH-CHINA SEMI-ARID PLAIN REGION

Characteristics of maximum daily rainfall on vietnam and it's influence on soil erosion

Nguyen Van Tuan*, Le Van Lan**

ABSTRACT

Vietnam is the Tropical country, so its rainfall is high and its periods of sunlight are long. It's rainfall, especially, daily rainfall is the main cause of the flood and soil erosion. Studies of maximum daily rainfall serve as a base estimate flood and soil erosion.

This article expresses the results of the studies undertaken for many years about rainfall and soil erosion all over Vietnam Consisting of more then 1000 rainfall station with tenyears data and data of 40 erosion tanks at Tay Nguyen-central part of Vietnam and at Vinh Phu province. Also this article mentions the following ideas:

1.The causes of flood Rain in Vietnam

2.Characteristics of an annual Rainfall and maximum daily Rainfall, it's spatial-duration variation.

3.Methods for calculating the maximum daily Rainfall.

4.Influence of Rainfall on soil erosion and methods of soil erosion estimation based on maximum daily Rainfall data.

Charteristics of maximum daily rainfall on Vietnam and it's influence on soil erosion

I. The main causes of flood Rain in Vietnam, Vietnam is the Tropical moonson country, so that it's rainfall is very high. Many Researchs (5,6,7,9) show two mainfactors that cause flood Rain in Vietnam. They are:

- The action of world air masses (General circulation of air masses and

-Geography.

The main air masses are moonson winds (South-East and North-East trades tropical cycle, secondary depression, front (cold and

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warm) and low pressure strips in the equter, ect. Many researches express that circulations do not cause Rainfall when they occur isolatedly. For example North-East wind in winter only caused drizzle, but many joining together circulations can produce extremely high rainfall. The key meeting is usually equater-low pressure strip, tropical cycle and moonson winds.

The topography plays an important part in creating the great rainfall. For example Truong son mountains tretch from North to south of Vietnam with elecation of over 1000 metters, serving as a wind great wall to receive the wind from the sea.

The winds with more humidity moving further in land, meeting the high mountains such as Hoanh son, Hai van, ect have created great rainfall in some areas (extreme rainfall regions). In the North of Vietnam, Hoang lien son range with 3000m height is 2 centres of high rainfall. The annual rainfall of their points is about 3600 mm.

Geography is also a factor which causes droughts in some areas such as Thuan hai region with annual rainfall of 700 (mm), Muong xen, and South-west zone with 1200 (mm) per year. With more then 3600 km of seastline stretching in the direction of North-South, inserting somany mountains in it the variation of rainfall in Vietnam is so big along to the latitude.

II. Characteristics of annual rainfall and maximum daily rainfall.

From works (5,6) it reveal that the rainfall extremely varies with time and space.

1. Time variation of rainfall

From the research results ,we have some conclusions as follow:

-Rainy season: There are two seasons in Vietnam: dry and rainny seasons.

The rainny season lasts 6 months from May to Oct and it is rather stable in the North and south . The other months of a year belong to dry season, In the central part, from Thanhhoa to Thuan hai province, the rainny season is only of 3 or 4 months and has tendency to infringe upon. winter slonly-for instance Thanh hoa-Nghe tinh from VI-X; Binh tri thien from VIII -X, and Ouang nam-Da nang province from IX-XI.

The dry season comes earlier from North to South especially, there is a pre-moonson flood in Apr or May -during the dry season.

- The quantity of rainfall (see fig.4Map isobar-rainall and table 1) is about 800 to 4800 (mm) and the rainfall during the rainny season is about 70-80 % of year rainfall.

- Maximum daily rainfall (duration of 24 hours). The rain in 24 hours is always prevailing over the time of rainny season, taking about 60-70% ; resulting in flood water of 60-70%. It can be said that the maximum daily rainfall creates the peak of flood, So that in Vietnam flood is caused by storm and the calenlation of peak flood is based upon maximum daily rainfall.

The maximum flood appeares during the time of Maximum. It is in Aug at Thanh- Nghe provinces and in Sept at Binh trithien and in Oct. from Quangnam-Danang to Thuan hai.

Figure 1 notes the annual rainfall maximum daily rainfall. From 27 rainfall stations in 11 of different climatic zones the maximum daily rainfall varies from 131 (mm) at Bac ha to 731 (mm) at Thanh hoa and Hue city. The provailing value of it is about 200-500 (mm).

-Number of days with rainfall over 50(mm) per day is from 2,8 to 15 days in a year. Commonly 15 days per year.

-In the certain rain (see Fig.1). Rainfall intensity decreases gradually with increasing time (Fig.2). This decreasing is simulated by mathematical function as follows

$$\bar{i}_r = \frac{s}{(r + 1)^n} \qquad (1)$$

in which : S: maximum instant intensity (MII)
r: the duration of calculation
n: constant as coefficient of decreasing rainfall with increasing time

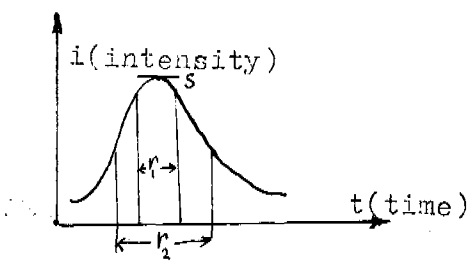

Fig.1: Rainfall hydrograph

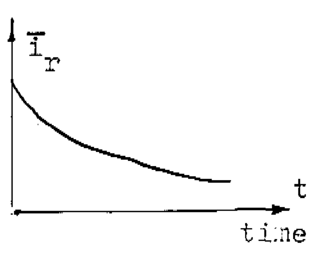

Fig.2: Maximum average rainfall

In Vietnam thi coefficient changes with time as follows
$r \le 10$(min) $n_1 = 0.25$
$r > 10$(min) $n_2 = 0.80$
(see Fig:3)
The MII can be calculated by maximum daily rainfall data.
S= KH in which : H-maximum daily rainfall

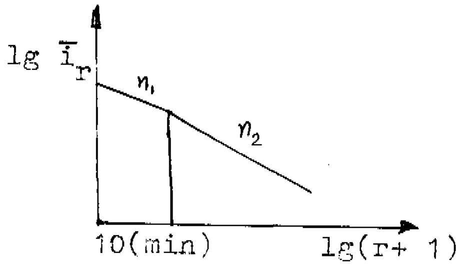

Fig.3: Relation ship between rainfall intensity i_r and time (loga scale)

Replacing into (1) we get

$$\bar{i}_r = \frac{K\ H}{(r + 1)^n} \qquad (2)$$

2. Spatial variation of Rain

From table n° 1 and Fig.4 we can see that annual rainfall varies from 800 to 4800 mm per year. There are 10 of the highest rainfall point. There are:

1.North-west of Lai chau province	Total rainfall p>2800(mm)
2.Sapa (Hoanglienson province)	P > 3600(mm)
3.Bac quang (Ha tuyen)	P > 4800(mm)
4.Mong cai (Quang ninh)	P > 2400(mm)
5.Tam dao (Vinh phu)	P > 2400(mm)
6.Ky anh (Nghe tinh)	P > 3200(mm)
7.The south of thua thien	P > 3200(mm)
8.Le thanh (Binh dinh)	P > 2800(mm)
9.Bao loc (Lam dong)	P > 2800(mm)
10.Phu quoc Island	P > 3200(mm)
and 8 day zones. There are:	
1.song Ma (Thanh hoa)	P < 1200(mm)
2.Yon chan (Son la)	P < 1200(mm)
3.Yaxup (Dac lac)	P < 1400(mm)
4.Phan rang (Thuan hai)	P < 800(mm)
5.The north-West of Lang son	P < 1200(mm)
6.Muong xen (Nghe tinh)	P < 1200(mm)
7.Cheo reo (Gia lai)	P < 1400(mm)
8.Go cong (Bac lieu)	P < 1400(mm)

The decrease of areal rainfall from the highest point to outside is converted as follows :

$$P_{oF} = \frac{P_o}{1 + KF^m} \qquad (3)$$

in which:

Po is areal rainfall and point rainfall respectively

F: Catchment controlled by station number n.

m: speatial coefficient of decreasing of rainfall

K: constant

In Vietnam K= 0.0012 and m = 0.72

- The variation of maximum daily rainfall in space the maximum daily rainfall isobar is drown in the Fig.5 and from that we can define clearly the highest points of rainfall as well as dry areas.

+ The highest rainfall

Location	:Quantity (mm)	:Location	: Quantity (mm)
Mong cai	250	Hagiang	225
Dong trieu	200	Tam dao Ba vi	350
Ha giang	225	Ha son binh	300
Thanh hoa	250	Hue - Hai van	350
Nghe tinh	350	Quang ngai	325
Dong nai	250		

+ Dry areas :

Location	:Total of rainfall (mm)	:Location	:Total of rainfall (mm)
Ca mau	50	Song hieu	100
Thuan hai	75	Moc chau	75
Phu Khanh	75	Lang son	75

In general, the zones of great rainfall is the some places with maximum annual rainfall and the dry zones is watching with draft points. However in the coasal areas we can't find this watching.

- The maximum daily rainfall is not increasing with the elevation This problem combe proved by the following data

Station	elevation (m)	Maximum daily rainfall H (mm)
Son la	676	146
Moc chau	958	146
Bao loc	958	189
Thanh hoa	5	731
Hue	17	741
Ky anh	3	479

So that, we can say that ,the rainfall depends on the meeting of climatic factors.

Table 1 : an annual rainfall and maximum daily rainfall

Sub areas	Station	coodinates latitude •N	coodinates altitude •E	Elevation (m)	Maximum daily rainfall (mm)	Number of days with rainfall 50 (mm)	annual rainfall (mm)
1	Lai chau	22°03	103°09	244	234	9,8	2066,1
	Son la	21°20	103°54	676	146	4,6	1444,3
	Moc chau	20°51	104°38	958	146	5,7	1559,9
2	Lao cai	22°30	103°57	99	174	7,3	1764,4
	Yenbai	21°42	104°52	56	349	10,0	2106,9
	Sa pa	22°20	103°50	1570	350	11,4	2833,0
	Bac ha	22°32	104°17	957	131	10,2	1774,0
3	Lang son	21°50	106°46	258	202	5,1	1391,9
	Mangcai	21°31	107°58	7	385	15,2	2749,0
4	Co to	20°59	107°46	70	344	8,7	1733,3
5	Lang	21°01	105°51	6	569	7,3	1676,2
	Phu lien	20°48	106°38	113	490	8,2	1808,2
6	Thanh hoa	19°49	105°46	5	731	8,5	1744,9
	Vinh	18°40	105°40	6	484	9,7	1944,3
	Ky anh	18°05	106°17	3	479	14,6	2928,9
	Cua rao	19°33	105°07	87	179	5,1	1734,5
7	Đong hơi	17°28	106°37	7	347	12,1	2159,4
	Huế	16°24	107°41	17	741	13,2	2867,7
8	Đa nang	16 02	106 11	6	332	8,2	2044,5
	Qui nhon	13°46	109°12	5	383	7,7	1692,3
	Nha trang	12°15	109°12	5	301	4,1	1358,9
9	Phanthiet	11°57	109°10	2	178	2,8	1372,9
10	Bamethuot	12°41	108°03	490	178	6,8	1773,0
	Bao loc	11°28	107°48	850	179	6,8	2542,4
11	Saigon	10°49	106°40	9	179	10,5	1931,0
	Camau	9°10	105°10	3	151	10,2	2365,7
	Phuquoc	10°13	103°58	2	200	13,8	3067,4

III. Methods for calculation of design rainfall from maximum daily rainfall.

The calculation of rainfall for design purposes is necessary to identify interval and frequency H_{rp}.

$$H_{rp} = \bar{i}_{rp} \times r \qquad (4)$$

From (2) we get $H_{rp} = \frac{KHp}{(r+1)^n} x\ r = (r)H_p$ (5)

in which :
H_{rp} : design rainfall in interval r and frequency P
H_p : Maximum daily rainfall with frequency P

$$\psi(r) = \frac{K \times r}{(r+1)^n} \qquad (6)$$

The value of$\psi(r)$ is rather stable conesponding to Vietnam territory and we can chose from national standard criteria about water resources design n° c -6-77.

From (5) we can estimate the rainfall of any interval.

This problem will be applied to determine soil erosion.

IV. Effects of rain on soil erosion

1. Effects of natural conditions on soil erosion. The effect of rain on soil erosion have been paid much attention by many invitogators over the world. In 1977, the German scientist-volni started his study about this field and about 50 recent years the research had opened by Ellison In 1940 the study got effectively (1). In Vietnam from 1974 we have carried out more than 40 research on erosion fields at Tay nguyen - the high land in the centre of Vietnam and Vinh phu province.

   The research results will be discussed in this report, In general-the erosion consists of two components and is illustrated in the following sketch

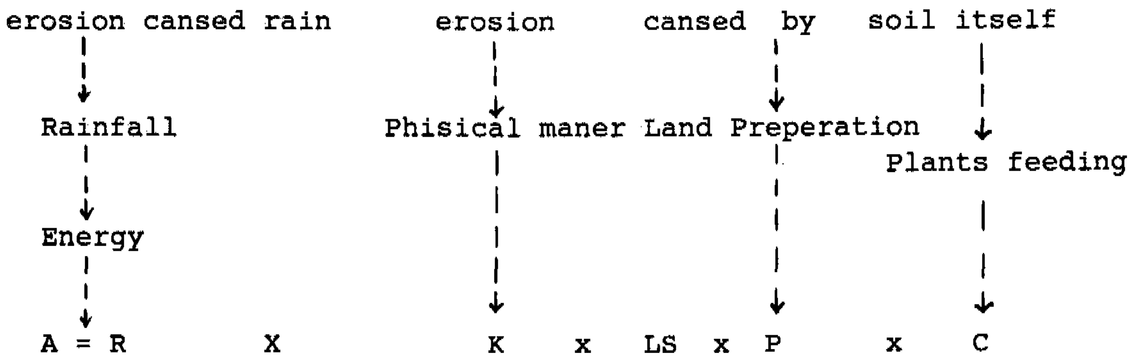

Fig 6. Factors affecting soil erosion

The equation which expressed the loss of soil, will be

$$A = R \times k \times LS \times P \times C \qquad (6)$$

In which
A: quantity of soil loss (T/hectare)
k: Coefficient characterized the type of soils.
Ls: Slope coefficient, the length of the slope
c: Plant coefficient, expressed to plant cover
P: constant, expressed the method for protesting erosion
R: erosion index caused Rain
According to Wischmeler, R can be estimated as follow

$$R = E \quad i_{30}$$

In which
E: Energy's coefficient
i_{30}: Maximum rainfall in 30 (minutes)

The research results on the 19 of erosion fields, having different sizes, but have the constant value of A i.e A is equal to constant. In these cases, we study the relation between A and R.

Let Ah be a eroded soil in the area of 200 square metter in an houre and ih (mon per hour) in maximum rainfall in an hour. The observation data on different experimental fields have been expressed.

Table 2 : Repressive equations on different fields

Field number	Repression Eqt	Field number	Rpression Eqt
1	y = 1,54+ 0,1 (x - 22,85)	11	y =21,94+2,49(x - 22,07)
2	y =11,24+1,39(x - 22,54)	12	y =15,15+1,48(X - 23,07)
3	y = 3,14+0,12(x - 22,07)	13	y =18,7 +2,01(x - 21,7)
4	y = 1,55+0,07(x - 22,56)	14	y =32,25+3,29(x - 22,07)
5	y = 5,56+0,26(x - 22,54)	15	y = 39,17+2,88(x- 22,07)
6	y = 1.60+0,09(x - 22,89)	16	y = 3,43+0,29(x - 22,76)
7	y = 7,61+0,25(x - 22,69)	17	y =14,08+0,88(x -22,63)
8	y =11,11+1,37(x - 22,22)	18	y = 11,32+0,24(x-22,28)
9	y = 2,58+0,18(x - 22,35)	19	y =34,09+4,03(x - 22,46)
10	y =12,93+0,42(x - 22,32)		

That the relation ship between Ah and ih is linear (3,4)
i.e Ah can be written

$$Ah = a\, i_h + b$$

Table 2 are results peported about relation ship between A_h and i_h.

The coefficient for all cases is rather big and greater than 0.7

2. Method for proposed estimation of erosion from maximum daily rainfall's Isobar.
According to wischmeter, Eroded Index caused rains can be determined as follow:

$$R = E\, i_{30}$$

in which i_{30} can be estimate from (5)
with r = 30(minuties) we get

$$H_{30} = \phi(30)H \quad . \quad \text{So } i_{30} = \frac{\phi(30)H}{30}$$

the values of $\phi(30)$, H are taken from maximum daily rainfall Isobar in Fig 7 and national standard criteria. This indirect method is more convenient than making many erosion fields in the whole country dece to constraints finance. In comparisim with the some method applied in USA. We think that the determination of soil erosion from maximum daily rainfall is more accurate than that calculated from annual Rainfall.

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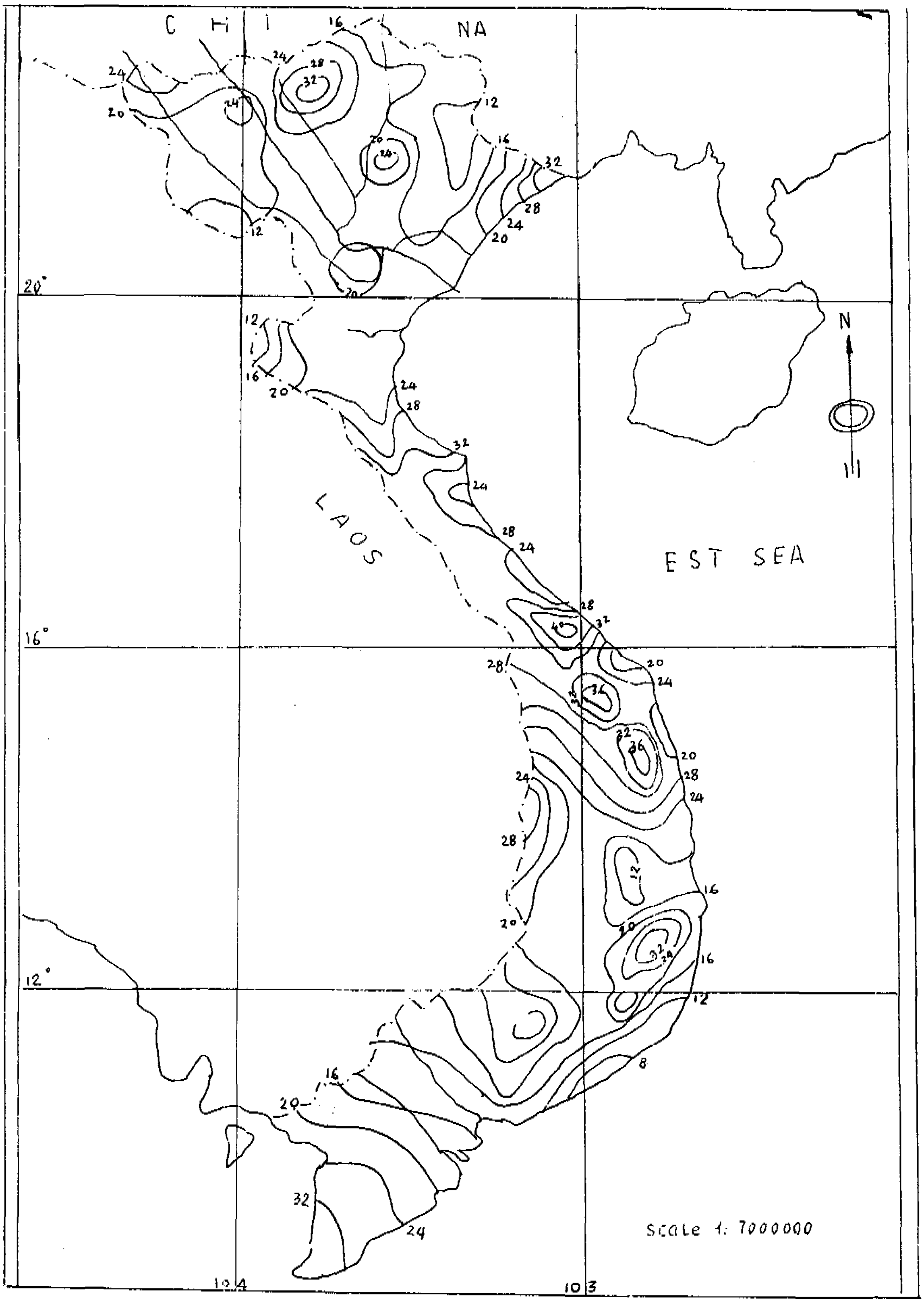

Fig.4. Map of Annual Rain Fall (Unit dm)

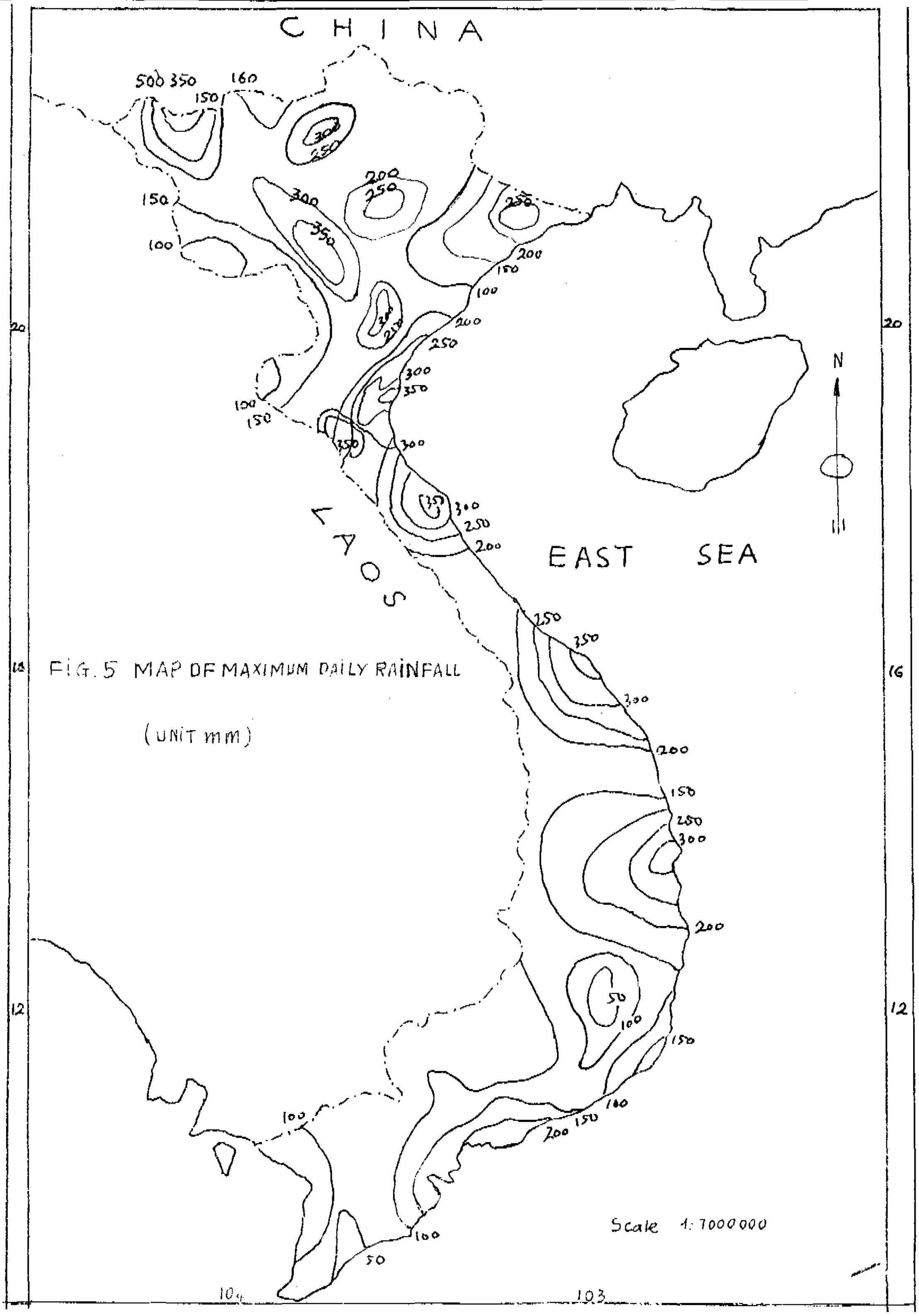

Fig.5 Map of Maximum Daily Rainfall
(unit mm)

Dynamic Programming of Rain Water Catchment

Richard J. Heggen*

Abstract

Rain water catchment has four engineering aspects: design, implementation, construction and operation. Routine design matches capacity with demand. Improvements in financial and educational infrastructure further the regional-scale implementation. Material and technique development make construction more appropriate. The weak link in the engineering process is that of operation, managing the catchment to maximize benefit.

Dynamic programming, a tool long used in reservoir operational studies, reveals how a catchment can be managed (when to draw, when to conserve) to minimize the penalties associated with water shortage. Penalties can be defined in arbitrary terms, relatively or absolutely. Demands can be historic or synthetic, with or without trend, seasonality or random fluctuation. Rainfall can be likewise actual or synthetic. As a deductive tool, dynamic programming reveals the optimal mode of catchment operation for any scenario of supply and demand. As an inductive agent, the analyst may reduce that knowledge to rules for real-time decision making.

A New Mexico catchment system is dynamically evaluated. A seven year rainfall record is employed with logistic, exponential and unit price penalty schedules.

Introduction

Engineered rain water catchment systems, like all engineered projects, should be evaluated in light of design, infrastructural implementation, construction and operation. Failure in any arena jeopardizes the product. Review of the literature indicates some unevenness of engineering effort. Construction has drawn major attention, particularly with respect to the utilization of appropriate building materials and techniques. Such infrastructure issues as finance and social impact are increasingly recognized to be crucial to successful implementation. Design has evolved from

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simplistic assumptions of meeting mean demand with mean supply to more realistic incorporation of probability. The least understood aspect of rain water catchment is that of operation. How should people use a system, particularly in times of short supply? This paper addresses this latter question.

Dynamic programming (DP) is a technique of operations research. DP incorporates within it the sequential nature of complex problem solving. DP takes advantage of the fact that a properly decomposed complex system (i.e. a large system broken into smaller subsystems) can be optimized in stages (rather than as one entity) through the use of recursive computations.

Rain water catchment systems are operated dynamically (Lo and Fok, 1981). Release decisions (how much to use, how much to save) for any time period are based upon what is then in reserve, what is expected to be added in the next time period and what is the consequence of running low or running out of water. An operator with perfect foresight would make the best decisions, knowing when to consume and when to withhold. DP reveals what such a "perfect operator" would do. Once optimal operation is determined, a rule for sound operation can be drawn for a real-world catchment system.

DP allows any sequence of rainfall, historic or synthetic. DP programming allows any physically-definable rain water catchment system, with or without foul flushes, leaks, evaporation, etc. DP allows any pattern of water demand, be it seasonal, random, constant, etc. DP allows any penalty scheme for unsatisfied demand, be it a per-event or per-unit charge, a step or arbitrarily continuous function, etc. In short, DP is appropriate for any rain water catchment system, simplified or complex.

Basic theory

Space precludes any degree of rigorous development of the theory or techniques of DP. The interested reader is directed to a basic text in operations research or systems analysis. The following discussion is intended as brief review for an initiated reader, or as brief introduction for the reader interested more in the overall technique than the details.

Consider a rain water catchment problem of t time periods (stages). Precipitation is p_j for stage j. A cistern contains m possible discrete levels (states) and consumptive withdrawal (the decision variable) in that stage has n possible values. The DP solution increases exponentially with m, so m is typically small. Precipitation, withdrawal and state are measured in the same integer units. One unit can be any arbitrary volume, e.g. 10 liters or 10 gallons. Let $Y_{i,j}$ be the penalty associated with withdrawing i at stage j and $X_{k,j}$ the cumulative penalties associated with being at state k at the end of stage j. The recursive DP equation is.

$$X_{k,j} = \min \{Y_{i,j} + X_{k+pj-i,j-1}\}, \quad i = 0, 1, 2, ..n-1 \qquad (1)$$

The sum $k + p_j$ can be denoted the "resource" at the start of stage j, the storage brought forward plus that period's rainfall, subject to a cistern-volume constraint. Long range optimal operation is choosing the i's to solve Eq. 1 when j = t and k at that final state is some arbitrary value, e.g. m/2.

Case Study

The northern New Mexican rainwater catchment system described by Heggen (1987) is employed for illustration. Analysis is done on a per capita basis. The 1987 study dealt with rationing during periods of short supply; this study places the problem in a DP context. Seven years of recorded daily rainfall are used (t = 2553 days). The basic unit of volume is 10 liters (1 mm of rainfall over a 10 m^2 catchment). Daily demand is 40 liters (4 units). The daily decision variable is to withdraw 0,10,20,30 or 40 liters (0,1,2,3 or 4 units) on a given day (n = 5 possible decisions). Cistern volume is 500 liters (m = 50 units).

The units of penalty are inconsequential; the relative magnitudes are what count. For the case study, a maximum penalty of $9 is assigned for no withdrawal and penalties of $7,$3,$1 and $0 are assigned to 1,2,3 or 4 unit withdrawals. (The dollar signs have no meaning in the problem; cents or pesos would work as well. It is the author's observation, however, that the problem is made more comprehensible if penalties are labeled in monetary terms.) This schedule reflects marginal penalties that are highest at midrange. The first unit of deficit goes relatively unnoticed. The middle units are more costly, as alternative water supply must be arranged. The higher units of deficit are again less costly on a marginal basis, as the last unit of water costs relatively little to draw once an alternative water supply is secured. Mathematically, the penalties illustrate a logistic function.

Fig. 1 shows the DP results. Note that the horizontal resource axis is m+n-1, 54 units long. A day starting with a dry cistern and having no rainfall has 0 units of resource. A day starting with 40 units of storage, for example, and having 8 units of rainfall has

48. Should the sum exceed 54, spill reduces the resource to 54. This example assumes spill after use; limiting the maximum resource to m models a spill-before-use problem.

The other horizontal axis shows the n possible withdrawal decisions. The logarithmic vertical scale indicates the number of times such a withdrawal, given such a resource, was optimal in the long range. The sawtooth nature of the plots are artifacts of the DP algorithm's treatment of ties; realistically, each plot would be smoothed. Note the trend; when resource is large, withdrawal is high; when resource is low, withdrawal is low. The series of withdrawals summarized in Fig.1 generated total penalties of $2745. Were 4 units to have been withdrawn whenever the resource allowed and the cistern to have been emptied when the resource was below 4, the total penalty would have been $3826. DP reduces the penalty by 30 percent.

Note the absence of 1 unit withdrawals. The optimal operator withdraws 2 or more whenever possible, letting the resource fall 0 (the lower spike) on a significant number of occasions. Consider two days of demand for which only two units of water are available. The penalty for withdrawing a single unit of water each day is $7+$7,$14. The penalty for withdrawing both units the first day and no water the second is $3+$9,$12.

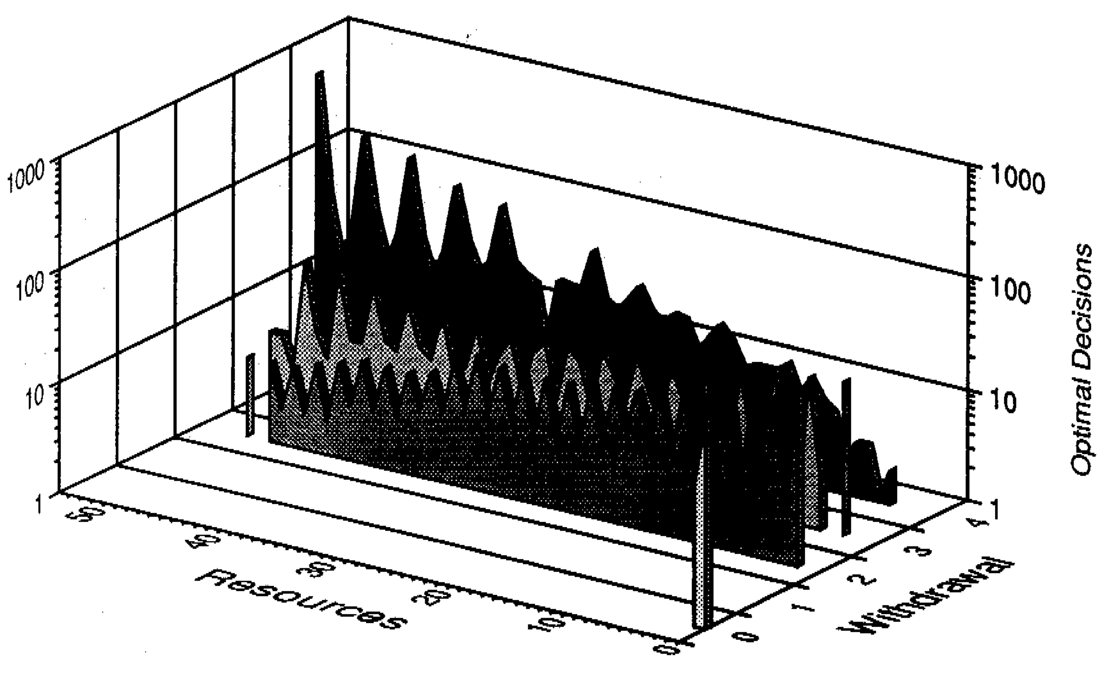

Figure 1. Optimal withdrawals, logistic penalties.

Should no other supply of water be available, the penalties might vary exponentially with deficit, e.g. $16,$9,$4,$1 and $0 for withdrawals of 0 to 4 units. Were water otherwise available at a fixed unit price, the penalties should directly vary deficit, e.g. $8,$6,$4,$2 and $0 for withdrawals of 0 to 4 units. Table 1 summarizes the case study and these penalty schedules.

Table 1. Penalty Schedules

Withdrawal	0	1	2	3	4
Deficit	4	3	2	1	0
Logistic	$9	$7	$3	$1	$0
Exponential	$16	$9	$4	$1	$0
Unit Price	$8	$6	$4	$2	$0

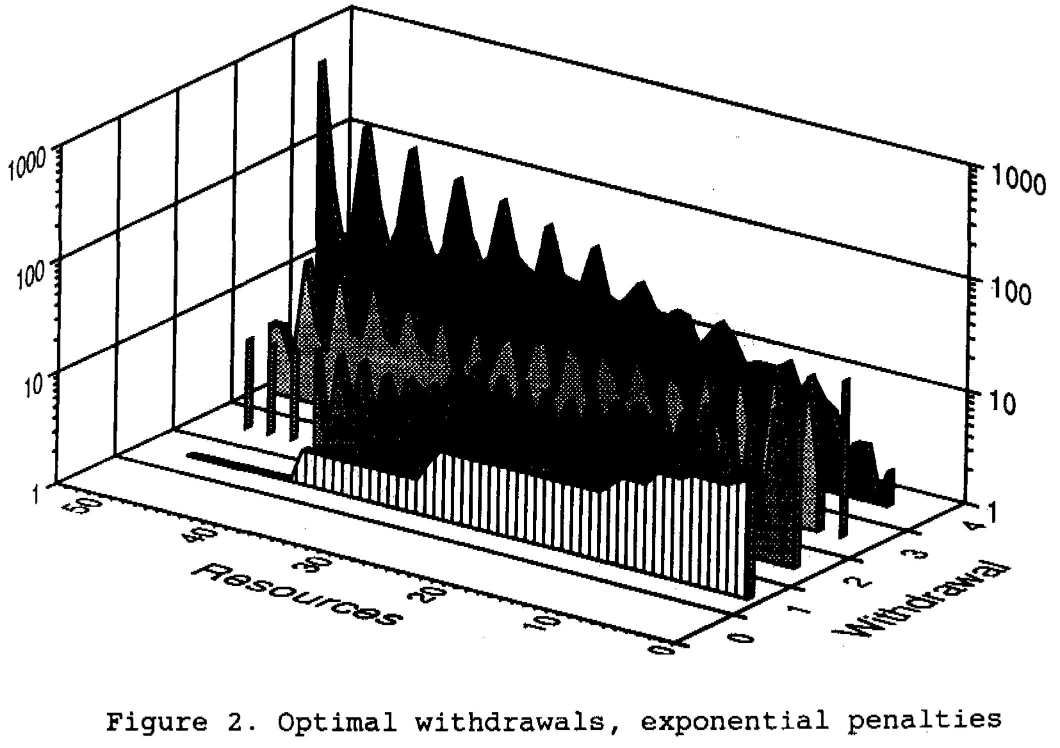

Figure 2. Optimal withdrawals, exponential penalties

Fig.2 illustrates the DP solution for the exponential penalty schedule. It is more costly to run out of water entirely (0 withdrawal) than to make small withdrawals over a period ($20 vs $18 for the two day, two unit example). Note that the spike of Fig.1 shifts in Fig.2 to fill in the row of 1 unit withdrawals. The optimal operator has cut back on 2 unit withdrawals to provide 1 unit in times of need. There is virtually no change regarding withdrawals of 3 and 4 between Figs.1 and 2. The series of withdrawals summarized in Fig.2 generated total penalties of $3713. Were 4 units to have been withdrawn whenever the resource allowed and the cistern to have been emptied when the resource was below 4, the total penalty would have been $6881. DP reduces the penalty in this case by 46 percent.

Running DP for the unit price penalty schedule, Fig.3 shows withdrawals of 4 at all resource levels, save those with resource is below 4 where withdrawal equals resource. When marginal costs for deficit are constant, the optimal operator finds no incentive to conserve when the resource reserve drops. One can always otherwise acquire water at a constant price if it fails to rain. With or without DP, the total penalty is $3546.

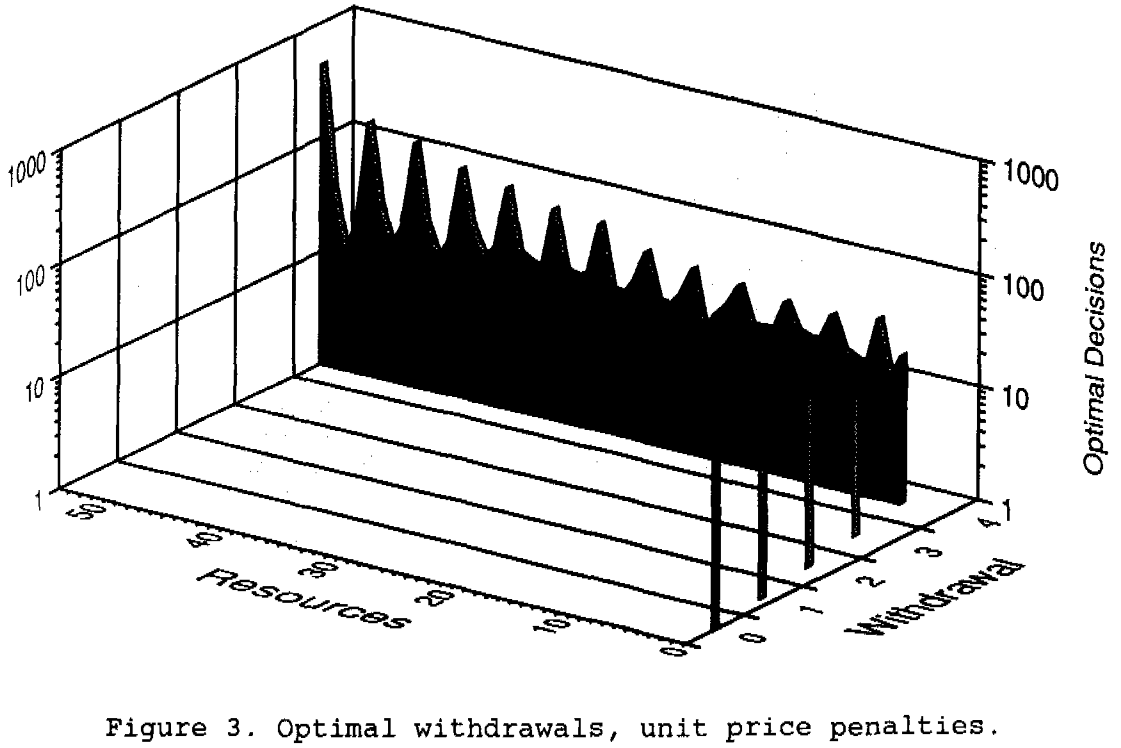

Figure 3. Optimal withdrawals, unit price penalties.

Implementation

The author is well aware that "practical" engineers, those concerned with constructability or user education, may see DP as purely an academic endeavor. This should not be the case. DP and other techniques of operations research have revolutionized the design and operation of large dams. There is no reason why rain water catchment systems cannot likewise benefit. In the New Mexican study, DP reduced penalties (or increased benefits) 30 and 46 percent in two cases. Such savings in sacks of cement or would be appreciated by the most practical of engineers.

Programming Eq.1 in recursive form takes no more than 15 line of computer code, less than that to manage the input and output. The example problems were executed on a 48K machine. The computer aspects are not prohibitive.

DP has the benefit, of course, of hindsight. The algorithm must know in advance the rainfall record. Real-time human operators unfortunately lack such foresight. Thus there is no expectation that actual operation will be optimal. Rather, there is the potential for improved operation based on rules discovered in the DP output. Figs. 1-3 represent graphical renditions of results, a form useful for this paper, but less quantitative than a time-series vector. The tradeoff between visual comprehen- sibility and numerical content depends upon the analyst's objective.

DP should be incorporated into rainfall catchment studies if for no other reason than it expands the analyst's problem solving perspective. The analyst is forced to recognize some penalty schedule. Rain water cistern analysis becomes a more-encompassing engineering problem. The analyst who has explored optimization is likely to discover advances in cistern water supply.

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Development of Guidelines for Rainwater Cistern Systems in Nova Scotia

Richard S. Scott*, Donald H. Waller**

Abstract

Rainwater cistern systems have been in use in Nova Scotia for more than 50 years as an acceptable alternative drinking water source where groundwater supplies are inadequate or are contaminated by gypsum, arsenic, uranium, iron and manganese, road salt, or sea water intrusion. In recognition of its importance, the Nova Scotia Department of Health published guidelines in 1982 for system construction and operation. The source material for this document originated from outside the province and for the most part was not directly applicable to the region. For this reason, research was initiated by the Centre for Water Resources Studies at the Technical University of Nova Scotia and later conducted jointly by the Centre and the Nova Scotia Department of Health on Nova Scotian systems to develop more comprehensive guidelines with the local climate in mind. This paper discusses the various components of a rainwater cistern system and presents recommendations for system design and system operation and maintenance in Nova Scotia.

Introduction

Nova Scotia is a Canadian province of 873,176 persons (1986 census) and an area of 52,840 km^2. Renowned as Canada's Ocean Playground, it is a peninsula surrounded by the Gulf of Saint Lawrence to the north, the Bay of Fundy to the west, and the Atlantic Ocean to the south and east (Figure 1).

Total precipitation ranges between 975 mm for the Northumberland Strait area on the north shore to 1630 mm for the northern areas of Cape Breton Island. The mean annual precipitation for the province is 1325 mm. About 17% of the total annual precipitation in Nova

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Scotia falls as snow. In the northern areas of Cape Breton Island this figure is nearer to 30%. Slightly greater amounts of precipitation are received in the period October to March.

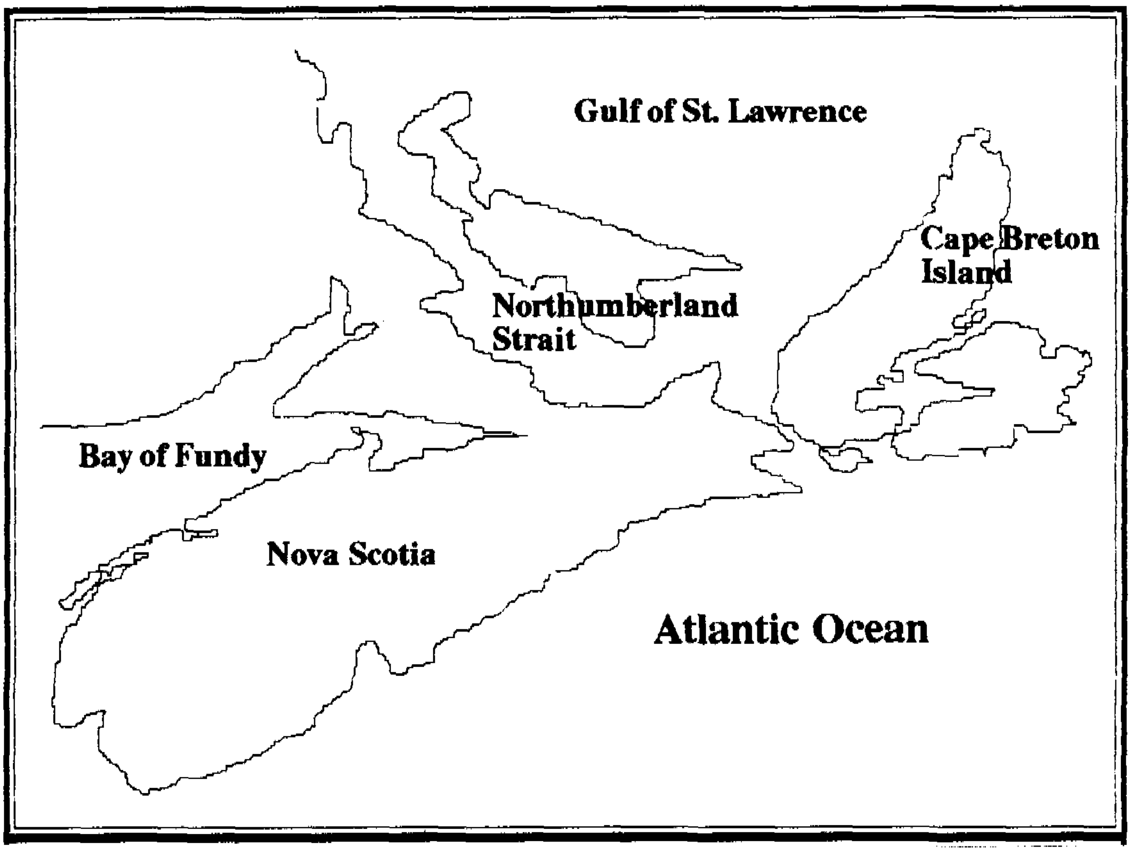

Figure 1. Map of Nova Scotia

About one-half of the population of Nova Scotia receives water from municipally-piped systems. The majority of the remainder is served by private groundwater wells. The quality of groundwater is generally good, and within acceptable limits set forth in the Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1987). There are, however, areas of the province in which groundwater requires some form of treatment. These forms include iron and manganese removal, arsenic removal, softening. pH adjustment, color and taste removal, and disinfection. Salt water intrusion is another problem in some coastal regions. In addition to the restrictive nature of some groundwater sources due to water quality, certain areas of the province have limited groundwater yields. Rainwater cistern systems have been used, or have been proposed as an alternative potable water source.

An estimated total of up to five hundred dwellings in Nova Scotia are now served by rainwater cistern systems. Ages of these systems range up to fifty years (Scott et al. 1986). In recognition of its importance as an alternative water supply, the Nova Scotia Department of Health published guidelines in 1982 for system construction and operation. The source material for this document originated from outside the province and for the most part was not directly applicable to the region. For this reason, research was initiated by the Centre for Water Resources Studies at the Technical University of Nova Scotia, and later conducted jointly by the Centre and the Nova Scotia Department of Health, to develop more comprehensive guidelines with the Nova Scotian climate in mind. The guidelines were intended to aid in the design of rainwater cistern systems to provide water supplies of adequate quality and quantity in Nova Scotia.

System Design

The components of the Nova Scotian rainwater system are typical of most in that they include a collection area, a storage reservoir and a distribution system. The number of materials available for each component is varied and individually unique with respect to effects on water quality. For this reason, the draft Guidelines were divided into component parts, the most commonly used materials evaluated and recommendations made.

Collection System

With few exceptions, roof surfaces in Nova Scotia are covered with asphalt shingles, which are considered acceptable. In addition to asphalt shingles, other suitable materials include polyethylene sheathing and fiberglass panels. The use of metal, including galvanized metal, for any component is not recommended due to its susceptibility to metal leaching by acid precipitation. The average pH of rainwater in Nova Scotia is 4.5. Information gathered from a number of systems using untreated cedar shingles and work by Scott (1987) indicated that collected water acquired a yellow-brown color and cedar taste. The color of the water decreased with the age of the collection surface but was still of objectional quality. In addition, there existed the possibility of the formation of health-threatening chemicals, in particular trihalomethanes, if the water is treated by chlorination. The use of cedar shingles was therefore discouraged.

Other components of the collection system include gutters, downspouts and pipe used to direct collected water to the storage reservoir. Products recommended for this purpose were those made of plastic or enamelled aluminum due to availability, cost ease of installation and limited impact on water quality. To reduce the amount of windborne debris entering the cistern via the gutters, it was recommended that they be equipped with plastic screening commercially manufactured for this purpose. The screening also restricts the frequency of clogged gutters by debris, such as leaves, which results in roof water spillage.

Materials collecting on roof surfaces which are subsequently washed off and pass through the coarse-meshed plastic gutter screening constitutes the majority of sediment which accumulates in the cistern. To reduce the rate of buildup of sediment and its potential effects on water quality, some form of prefiltration can be installed at a point before the cistern. Some forms of prefiltration incorporate the use of a nylon sock, geotextile material or sand. Scott (1987) showed that the bulk of the sediment is organic in nature and is mainly generated during the growing season. It was also recommended that any design incorporating a prefilter include a by-pass to allow for prefilter malfunction due to clogging or freezing (if the filter is operational in the winter months).

Another question asked of this type of water supply system was that dealing with first or foul flush. Is it necessary to waste a portion of initial roof runoff? An investigation of the need for such a device for Nova Scotia systems by Scott (1967) found that the quality of water draining from roofs and gutters of acceptable materials was well within limits set in Guidelines for Canadian Drinking Water Quality. The diversion of any volume of initial roof runoff was not considered necessary to maintain an acceptable level of cistern water quality.

Storage Reservoir (Cistern)

A survey of 72 rainwater systems in the province characterized the type of cistern used to be a single compartment concrete tank, ranging in size from 4.5 to 102 cubic metres; the average size being 22 cubic metres. A few systems used fiberglass tanks and even prefabricated septic tanks.

Recommended design considerations for the Nova Scotia guidelines were limited to the basic features of a cistern (Figure 2). The most important of these was division of the tank into two compartments. This feature ensures a supply of water during cleaning, as each compartment can be cleaned independently. Other features include: an access hatch to both compartments, curbing around the access hatch to prevent contaminants from entering the cistern, a screened overflow through an exterior wall, and a flexible withdrawal pipe to allow its placement in either of the two compartments to within 10 - 15 cm of the bottom. The 10 - 15 cm allowance reduces the possibility of sediment intake. The preferred compartment for household withdrawal (when storage permits) is that opposite the compartment containing the collection surface drain pipe. This allows the compartment receiving the roof runoff to act as a settling tank for any particulates contained in the runoff.

The construction material recommended is concrete, either left untreated or coated on the interior with a cementaceous wash suitable for potable water supplies. The reasons for this are numerous; concrete is readily available; it is relatively inexpensive; the effects of low pH roofwater is buffered by the materials in the concrete, making it considerably less corrosive to the plumbing system; and, a result of increased pH of the stored

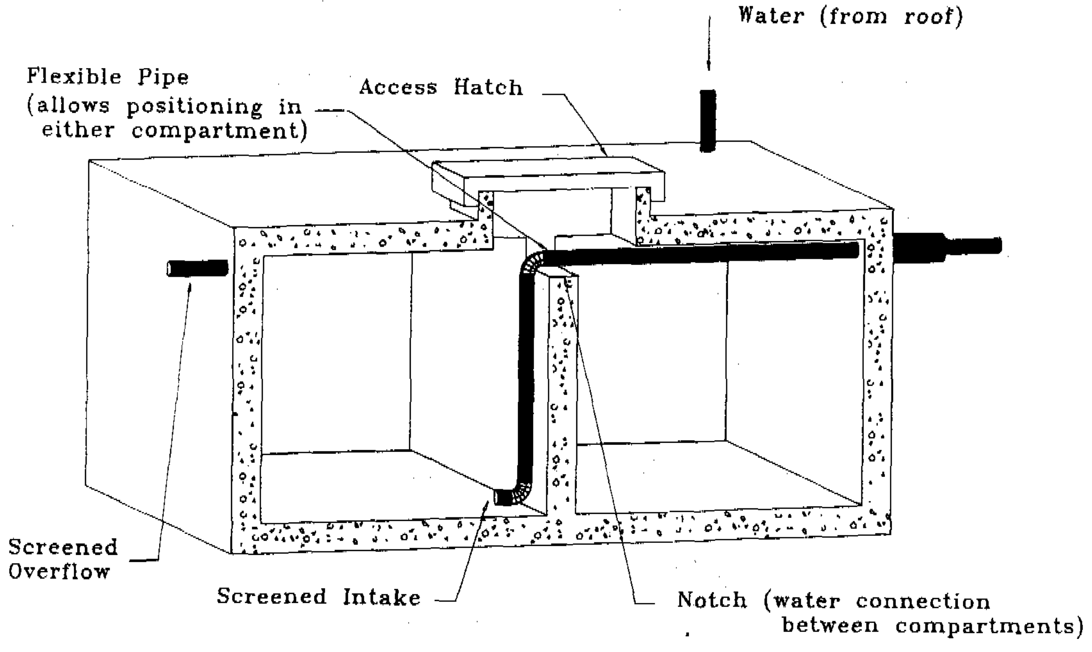

Figure 2. Storage Reservoir

water is the beneficial inhibiting effect on bacteria: Martin et al. (1982) demonstrated that increasing the pH range from 6.8 - 7.2 to 8.5 - 9.0 in the distribution system for the City of Halifax. Nova Scotia, eliminated multiplication of coliform bacteria.
The guidelines for sizing the storage reservoir were based on an average daily per capita demand of 90 liters obtained from the comparison of metered dwellings and Nova Scotia Department of Health records and a 40 year rainfall record from an Atmospheric Environment weather station located at HMCS Shearwater near Halifax. It was first necessary to define a minimum supply for a rainwater user. Therefore, it was felt that a minumum supply would be one that could supply 90 liters per person per day in 90 percent of months. Trucked water is available in most areas of the province to supplement supplies in dry periods. Based on analysis of the longterm record, it was estimated that the collection area needed to adequately supply a household of 2 persons, given a maximum practable storage reservoir of 75 cubic metres, was 58 square metres. Catchment surfaces less than this could not supply an adequate water supply and thus not included in the draft Guidelines (Table 1). To accommodate any increase in household occupancy, the minumum tank size recommended was 30 cubic metres.

For certain areas of the province that receive as much as 30 percent less rainfall than the area of record used in the sizing model, a statement of possible undersizing was included. Consumer awareness of the resource and conservation measures, such as low-flow toilets and shower heads, and wise water use, are promoted in the draft Guidelines as methods to reduce the possibility of water shortages.

Table 1. Storage Reservoir Sizing Chart

Effective Volume: Cubic Metres/ Imperial Gallons

Collection Area m^2 (sq ft)	Number of Occupants				
	2	3	4	5	6
58 (624)	30/6600				
75 (807)	6/1320 *				
100 (1076)	*	15/3300 *			
125 (1345)	*	*	30/6600		
150 (1614)	*	*	*	40/8800	
175 (1884)	*	*	*	*	75/16500
200 (2153)	*	*	*	*	*

Shaded area indicates impractical cistern volumes

* NSDOH recommends a minimum effective tank volume of 30 cubic metres (6600 imp. gal.)

Treatment

Although it is was found by Waller and Scott (1988) that chemical and bacteriological quality is satisfactory if design and maintenance of a rainwater cistern system are adequate, some form of disinfection is recommended to guard against chance contamination. The two forms considered for the draft Guidelines are disinfection by chlorine and disinfection by ultraviolet light. The most widely used method in Nova Scotia is disinfection by ultraviolet light. The Nova Scotia Department of Health requires that any public building. Such as tourist establishments and restaurants, chlorinate the water supply.

Water from any system that has acquired tastes from materials used in the system can install an activated carbon filter. The draft Guidelines emphasize, in the case of a system using ultraviolet light for disinfection, the carbon filter be located before the disinfection unit because the carbon media in activated carbon filters is an ideal environment for bacterial growth and a potential source of bacteria in tap water. The location of the carbon filter with respect to the disinfection unit is not critical if chlorination is used.

System Maintenance and Operation

To ensure adequate supply and satistactory water quality, the draft Guidelines include recommendations about operation and maintenance of the system. All components of the system should to be periodically inspected for failure (cracked or leaking gutters and downspouts; misaligned gutter screening) and debris buildup (gutters and cistern). It is recommended that the cistern be cleaned once every 5 years, or sooner if the sludge buildup exceeds 1 - 2 cm depth. Waller and Scott (1988) found that materials that accumulate as sludge on the bottom of cisterns can have significant impact on cistern water quality.

The cleaning procedures recommended involved the lowering of the water level in the compartment to be cleaned to approximately 30 cm, agitating the sludge in the remaining water, then pumping the water to waste. This action is assumed to remove the majority of the sediment. The interior of the tank would then be swabbed with a 3 mL/liter solution of household chlorine bleach, allowing at least 3 hours of contact time before a final rinse and removal of wastewater. Surfaces should be kept wet with the chlorine solution during this time.

The maintenance requirements of water treatment devices varies with the particular unit. For example, the reader of the guidelines is made aware of: the need to replace the ultraviolet lamp in an ultraviolet disinfection unit on an average of once per year; that chlorination units require preparation of a hypochlorite solution at least once a month; and that carbon filters require replacement periodically.

Summary

In recognition of the importance of rainwater as an alternative drinking water source in Nova Scotia, the Nova Scotia Department of Health published guidelines in 1982 for rainwater cistern system construction and operation. Until that time, local research was limited and the guidelines relied on experiences from outside the province. As a result, research on Nova Scotian systems was initiated and has since led to the development of more comprehensive draft guidelines suitable for Nova Scotia, an area with a northern temperature Maritime climate.

Questions on quantity and quality on which effective designs and operation and maintenance of such systems can be based, were systematically addressed.

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WATER OPERATION ON TAMEIKE IN TOBAN REGION IN JAPAN
- - - - a rain water catchment system - - -

Kunihiko KITAMURA* Isao MINAMI**

ABSTRACT

Toban region has been irrigated mainly by tameikes which are operated mostly intensively. The rules of operation have been formed by farmers experience for hundreds of year. They are reasonable and instructive. So the author had investigated about the tameike operation in the Toban irrigation area for several years and got the following results.

1) Tameikes are classified into four types by their function,mother-ike, daughter-ike, independent-ike and collecting-ike. They compose a water system combining the function of each type of ike. Features of the system are much related to the topography. For example, in the flat belt, a close combination between mother-ike and daughter-ike is obviously seen. In the mountainous belt, each independent-ike irrigates its own area independently. And each collecting-ike exclusively supplies its daughter-ikes. In the middle belt, the characteristics of both flat and mountainous belt are seen.
2) A standard storage level is set at each tameike. Usually, it is decided at a level of half to one-third of its full depth. When the storage of daughter-ike decreases to this level before the middle of September, the mother-ike supplies her during the night, from 20 to 6 o'clock in the next morning.
3) A ditch-tender selected among farmers exclusively operates the tameike and distributes the water to each plot of field systematically. His standard working time is usually 12 hours a day, from 6 to 18 o'clock. When it rains, he stops release of tameike to conserve its storage.

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1. Introduction

Tameike has been the most important water source of irrigation area which suffers from lack of water. Nearly three hundred thousand of tameike have been constructed since the historical age in Japan. They are mainly distributed in the areas where the precipitation is little and the catchment basin is narrow.

A number of modern irrigation project have been carried out to improve the water balance for irrigation recently. However, tameikes still continue to play their roles actively.

The Toban Irrigation Project was set in a typical tameike region suffering from water shortage. It is important to know about the features and aspects of the tameikes for planning of the new project. That is why the investigation was carried out and the results are here by reported.

11. The outline of Toban region

The Toban irrigation area is situated in the middle part of Japan facing the sea of Setonaikai (refer to Fig-1). The whole area can be divided into three belts, flat, middle and mountainous, according to the topography. It has been irrigated by several

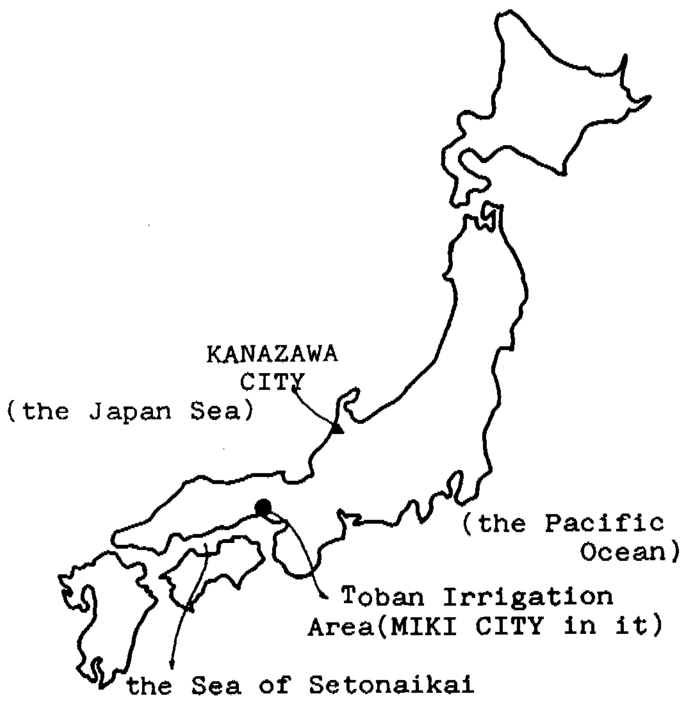

Fig.1 The position of the Toban Irrigation Area

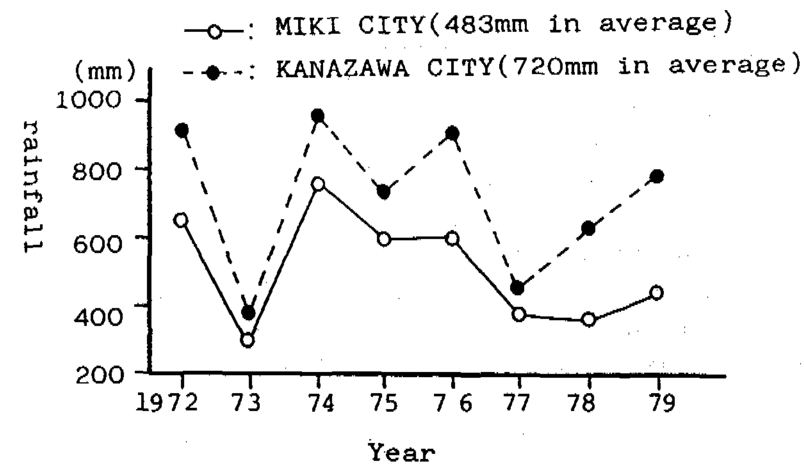

Fig.2 The amount of rainfall during the irrigation season

thousands of tameikes which surface covers about one-fifth of the total arable land.

Annual rainfall in this area is around 1200 mm, which is only two-third of the average rainfall in Japan. As shown in Fig-2, the amount of rainfall during the irrigation season, from the middle of June to the end of September, is about 500mm.

111. The method of investigation

Since it was too wide to investigate the whole area in detail, the Kako-Land Improvement District was taken as a pilot area for a intensive survey first. The items of investigation in this area were as follows;

1) storage fluctuation of the tameikes during the irrigation season,
2) distribution operation of the released water from the tameikes,
3) hearing from farmers on the tameike operation.

Next, a broad investigation for the whole area was carried out by means of questionnaire based on the operation in the pilot area. The period spent for these investigation was 4 years from 1979 to 1982.

1v. Outline of the Pilot area

The pilot area is situated in the flat belt. Its general features are shown in Fig-3 and Table-1. At the upper part of the area, there is the Kako-oike (refer to Photo-1), the largest tameike with full capacity of 1,419 thousand cubic meter consists of five blocks. While, small or middle sized tameikes with 2 to 89 thousand cubic meter of storage are distributed in the lower part. The total number of tameikes is 20 and the total storage is 1,838 thousand cubic meter.

Photo-1 Kako-sike

Irrigation area of each tameike is 4.1 to 70.1 ha. The water is managed by 15 dich-tenders selected among farmers of each tameike group. Total irrigation area is 320.1 ha and average storage of all tameikes is 560 mm converted in depth for the irrigated area.

V. The Results of Investigation and Discussion

A) In the pilot area

1. The function of tameike

Releasing from tameike is carried out only daytime during the irrigation season, and is stopped at night or rainy day to collect the water running down from the upper part of tameike.

A simplified model for operation of tameike is shown in Fig-4. As is obvious from this figure, tameike has its own function as follows:

a) release water for her own area,
b) receive supplemental water from other tameike of upper reach,
c) supply other tameike of down reach,
d) receive some quantity of water from outside basin.

They compose a water system combining these functions. Accordingly tameikes are classified into three types, daughter-ike, mother-ike and collecting-ike. The functions of daughter-ike are a) and b) of above mentioned, that of mother-ike are a) b) and c), and that of collecting-ike are b) and d).

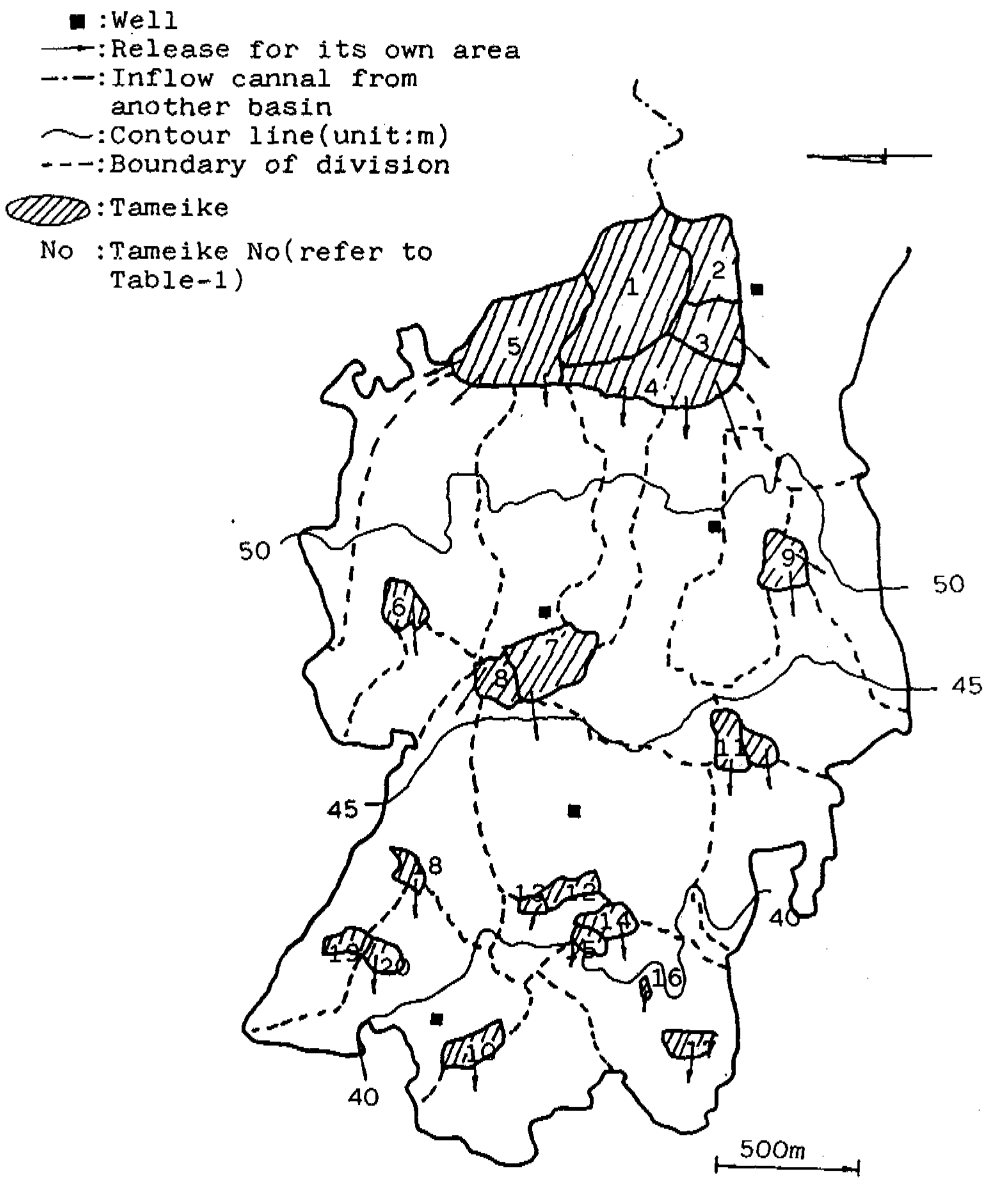

Fig.3 Plan of the pilot area

Table 1 Outline of the pilot area

No	Tameike name	Full capacity ($\times 10^3 m^3$)	Irrigation area (ha)	Dich-tender the number	Dich-tender operated average area (ha)	Average storage (mm)
1	O-ike ***	360				
2	Gokenya-ike ***	82				
3	Naka-ike **	34	15.2	1	15.2	625
4	Ato-ike **	512	70.2	3	23.4	
5	Kita-ike **	431	70.9	2	35.5	
(No 1-5) Mean or total		1.419	156.3	6	26.1	907
6	Oosawa-ike *	45	7.6	1	7.6	592
7	Ibara-ike *	87	39.8	1	39.8	219
8	Shin-ike *	49	27.8	1	27.8	175
9	Rokenya-ike *	27	14.1	1	14.1	189
10	Shichikenya-ike*	26	17.1	1	17.1	152
11	Hachikenya-ike *	39	17.0	1	17.0	228
12	Shikenya-ike *	13	4.1	1	4.1	400
13	Shimo-ike *	4				
14	Kendani-ike *	38				
15	Ko-ike *	2				
16	Shimo-ike *	17	20.9	1	20.9	383
17	Nishishin-ike *	23				
18	Magodau-ike *	17				
19	Zenpei-ike *	11	15.9	1	15.9	286
20	Sangenya-ike *	18				
(No 6-20) Mean or total		416	164.3	9	18.3	253
(No 1-20) Mean or total		1,836	320.6	15	21.4	572

Function of tameike(*:daughter,**:mother,***:collecting) ,****:In 1969

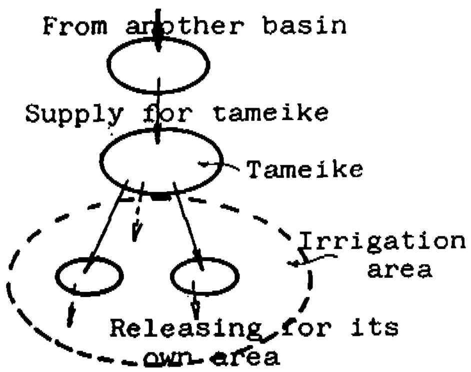

Fig.4 Model of tameike operation in the pilot area

2. Tameike operation

Fig-5 shows the storage fluctuations in some daughter-ikes during the irrigation season in 1979. As is obvious from this figure, the fluctuations are classified into two types as follows:

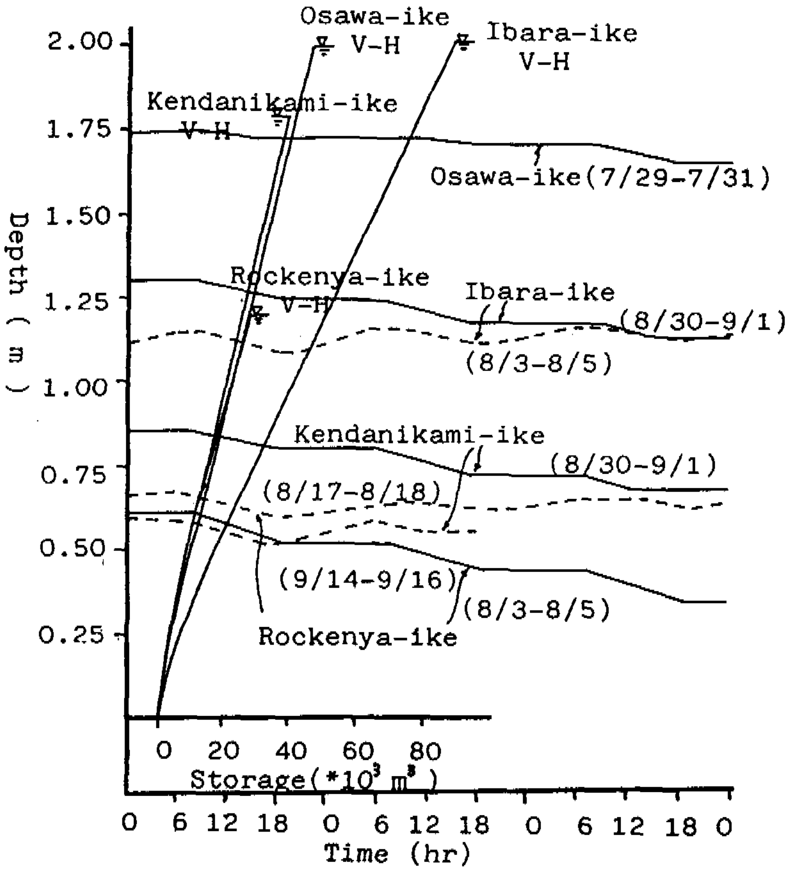

Fig. 5 Storage fluctuation in each daughter-ike

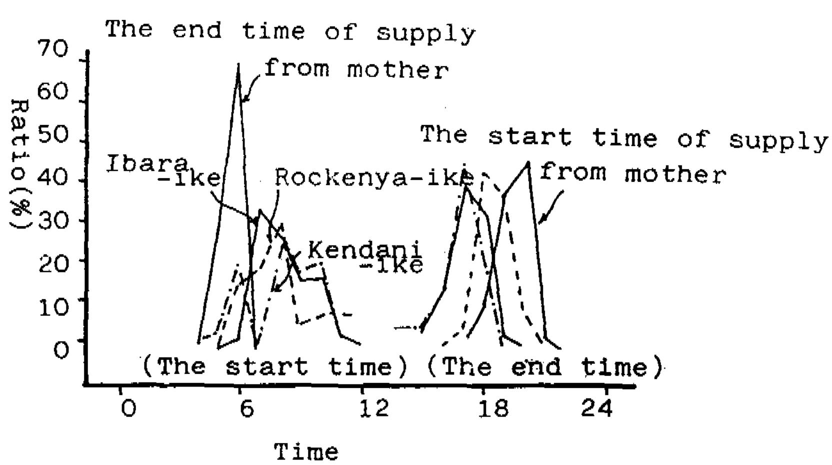

Fig.6 The start time and end time of release to each daughter-ike

a) water level recovers up at night every day,
b) water level goes down one way step by step. The former fluctuation shows that the tameike received water supply from their mother, whereas no supply in the latter case. Since there was no rain during the observation period, each turning point of the curves shows the operation practice of a ditch-tender or a water master.

Fig-6 shows the starting time and the ending time of release to each daughter-ike. The starting time of release is variable from 6 to 12 o'clock, which peak appears at 8 o'clock. The ending time is concentrated at 17 o'clock. The average releasing period is 9 hours a day. On the other hand, a mother feeds her daughter from 20 o'clock to 6 o'clock next morning. These times seems to be determined by the working schedule of ditch-tenders.

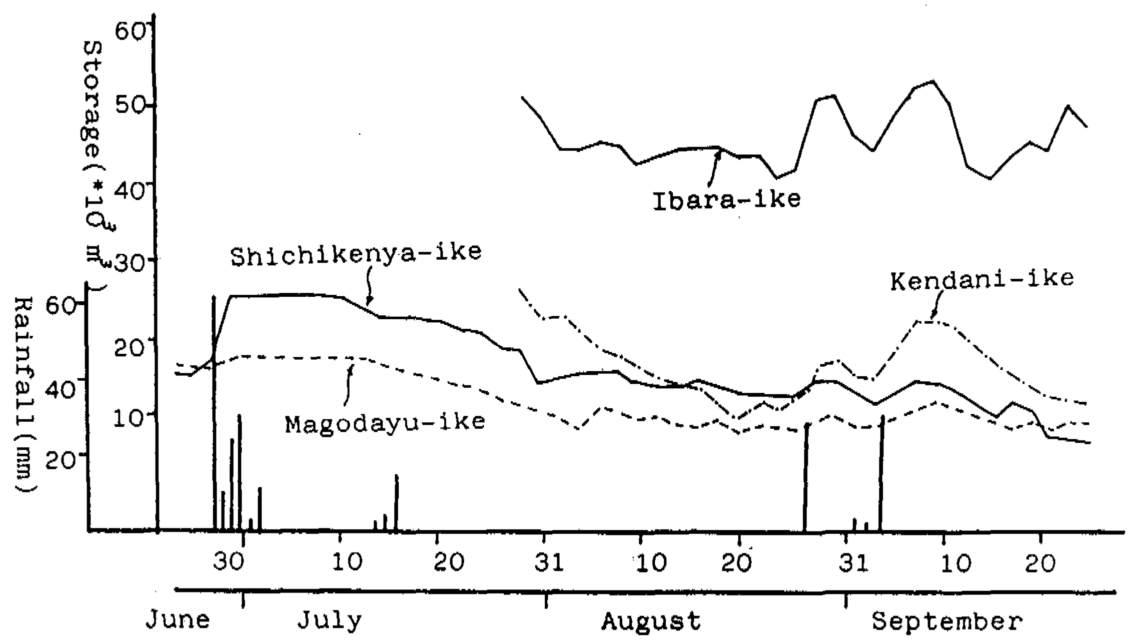

Fig.7 Storage fluctuation

Fig-7 shows the storage fluctuation of each tameike in the irrigation season. The storage of each tameike increases at the end of June, the end of August and the beginning of September caused by heavy rainfalls over 30 mm a day. The storage decreases along a straight line by constant release in July. Whereas in August, it waves up and down because the release and the receipt of each daughter alternate. The storage fluctuation pattern can be shown in Fig-8. There is a line to secure the minimum storage in August which is called standard storage. The standard storage guarantees an emergency treatment and gives a room for inflow.

Table-2 shows the standard storage in August in each division and the average storage in June and September. The Standard storage in August and that in the other period are very similar and it is canceled in the middle of September. This means that the standard storage can feed the area for two weeks until the end of irrigation.

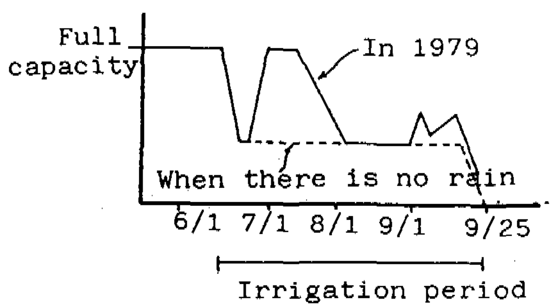

Fig.8 Model of the storage fluctuation

Table 2 Standard storage of each tamike is the pilot area

unit: $\cdot 10^3 m^3$

Items / Name of tameike	Standard storage in August	Average storage after supplied during June and September			Average release per day	Possible days for releasing (day)
		6/23 -6/26	9/3	9/15 -9/18		
Ibara-ike	41.4	*		43.0	2.7	15
Rokenya-ike	13.0	*			1.5	9
Shichikenya-ike	14.2	15.0		10.7	1.1	13
Hachikenya-ike	13.8				1.6	9
Kendani,Ko,Shimo Nishishin-ike	27.0				1.9	14
Magodau,Zenpei Sangenya-ike	23.9				1.3	18
Nishishin-ike	5.6	6.3				
Magodau-ike	9.8			8.2		

*: lack of data empty colume: no supply

3. Distribution operation

Fig-9 shows the distribution operation in the kendani-ike area as a typical example. The observation was carried out every two hours from ten oclock in the morning untill the time of the gate closed. The released water of the tameike (strong line in this figure) runs down along the ditch system controlled by check boards. It feeds a few lots at a time from the upper part to the down part in turn. The leaked water from checks and the seepage from soil layers creeps down the ditch. Then, it is stored in the ditch space and reaches some field lots for preparatory irrigation. These facts shows that released water is operated systemtically, and there is almost no water wasted except evaporation.

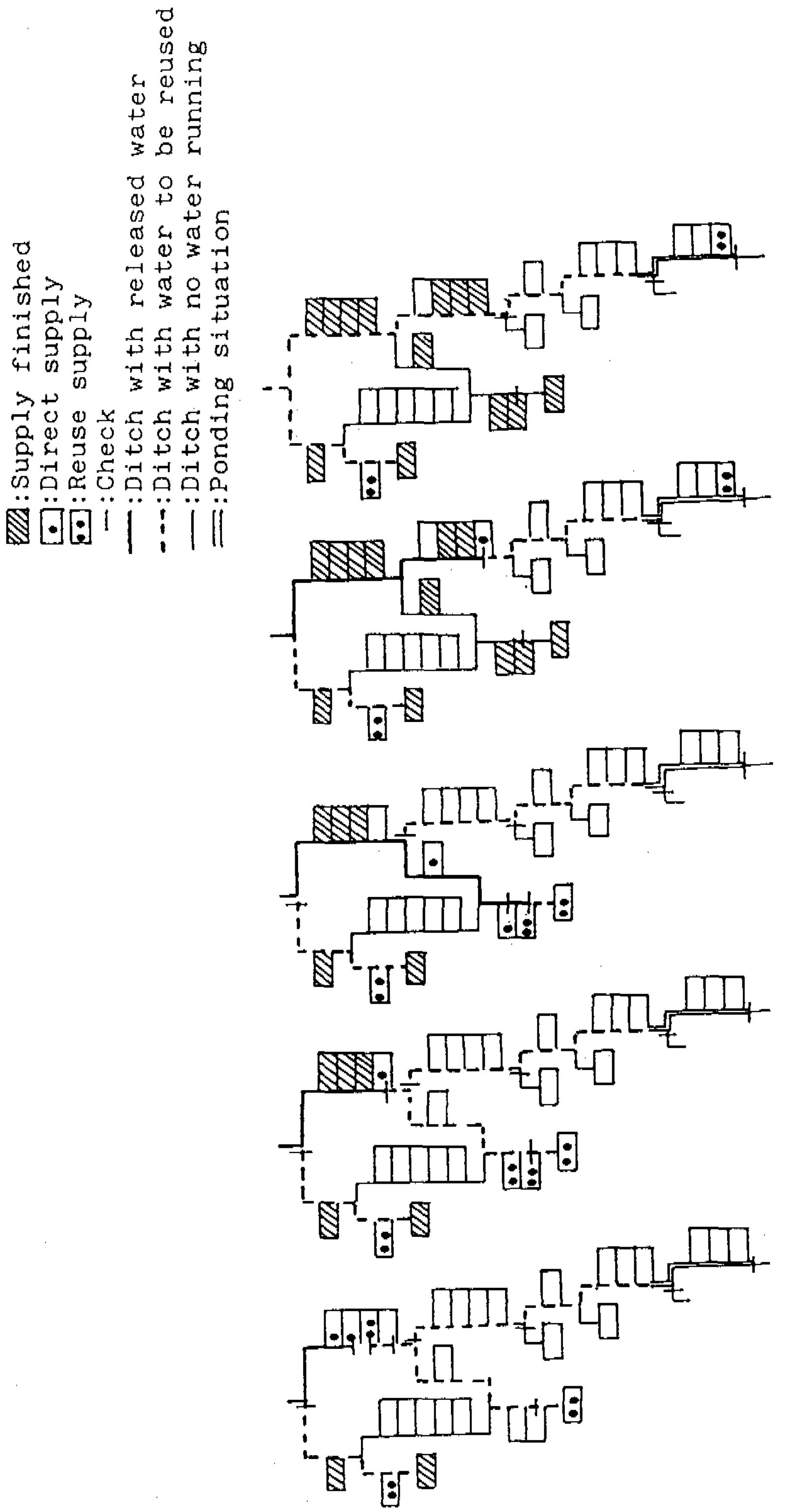

Fig.-9 Distribution operation in the area fed by Kendani-ike

B. Characteristics of the tameike operation in the whole area

A survey by questionnaire was carried out for 30 divisions (refer to Table-4) in the whole area. Fig-10 shows the typical location of each type of tameikes. In the flat belt, the division is irrigated by a group of tameikes with a help of wells, and all tameikes are operated in combination. On the other hand, in the middle and the mountainous belts, there are many types of tameikes, some of them are operated independently (independent-ike), and the others without own areas exclusively supply neighboring tameike down reach (collecting-ike). The difference of operation among the belts depends mainly on the usage type of tameikes in a division.

Table-3 shows the function and ability of each type of tameikes. In the flat belt, almost all tameikes are mothers or daughters. The number and irrigation area of mothers are nearly the same as daughters but mothers storage is twice as large as daughters. This shows that the mothers have some surplus water to feed daughters and irrigate whole area evenly.

In the middle belt, the storage of daughters is particularly large (43.4 percent), while that of mothers is the least (8.2 percent). That is, daughters are mainly self-supporting, and they only depend on their mothers or collecting-ikes in emergency cases.

On the other hand, in the mountainous belt, daughter and independent-ikes irrigate the area half and half, whereas independent-ikes have only one third of total storage (37.9 percent). It is obvious that independent-ikes have larger amount of inflow than daughter-ikes from their wide basin.

Table 3 Function and ability of each type of tameike

Items	Number of tameike			Storage capacity and ratio						Irrigation area and ratio					
Belt / Function	Flat	Middle	Mountaineous	Flat		Middle		Mountaineous		Flat		Middle		Mountaineous	
				($\times 10^3 m^3$)	(%)	($\times 10^3 m^3$)	(%)	($\times 10^3 m^3$)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Daughter-ike	13	14	5	616	33.5	379	43.4	56	22.6	1,418	46.0	1,340	60.6	275	49.7
Mother-ike	11	4	0	1,103	59.8	72	8.2	0	0.0	1,659	54.0	210	9.5	0	0.0
Collecting-ike	2	20	7	124	6.7	201	23.0	96	39.5	—	—	—	—	—	—
Independent-ike	0	12	8	0	0.0	221	25.4	92	37.9	0	0.0	662	29.9	278	50.3
Total	26	50	20	1,843	100.0	873	100.0	243	100.0	3,077	100.0	2,212	100.0	553	100.0

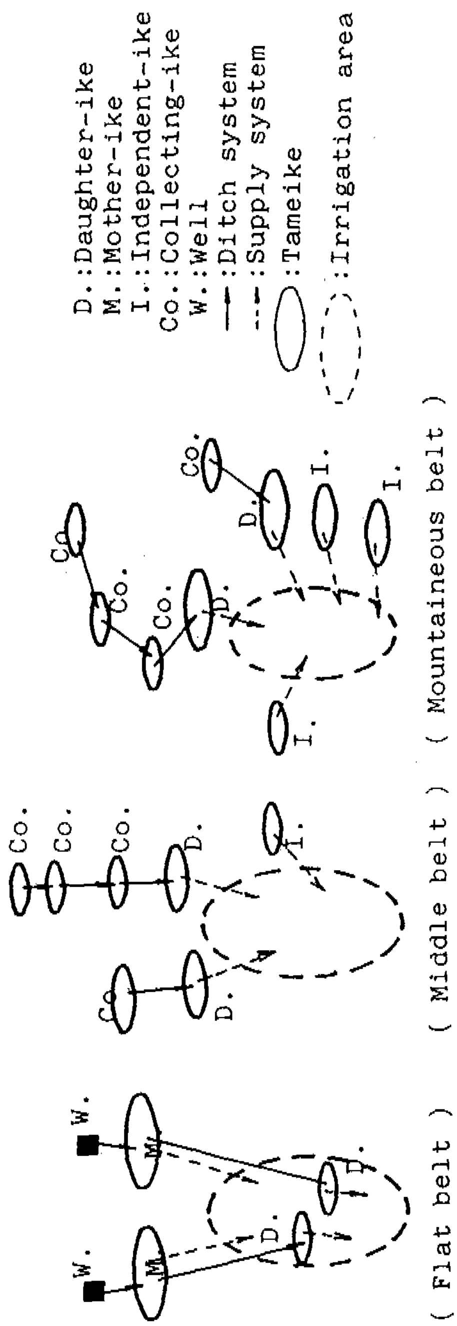

Fig.10 Model of tameike operation is each belt

Table-4 shows particular features of tameike operation in each division. In the flat belt and the middle belt, the standard storage level is mostly one-third of full depth, and the standard releasing period is 12 hours a day, from 6 to 18 o'clock. Only No.p-3 and No.P-6 in the flat belt are irrigated in the morning. They are still operated intensively so as to stop release at rains. While, all divisions in the mountainous belt have neither any time restriction for releasing nor standard storage level . The existence or the number of dich-tenders indicates the intensity of tameike operation.

Table 4 Particular features of tameike operation in each division

Belt	Items / Division No	Period of releasing time (hr)	Stop the releasing at rainfal	Water level at standard storage	Number of dich-tender
Flat	P-1	6-18	•	1/3	2
	P-2	6-20	---	---	0
	P-3	7-12	•	1/3	1
	P-4	7-16	•	1/4	3
	P-5	6-14	•	1/2	1
	P-6	8-12	•	1/4	0
	P-7	5-18	•	1/3	1
	P-8	5-19	•	1/4	2
	P-9	6-18	•	1/4	1
	P-10	6-18	•	1/4	0
	P-11	6-18	•	1/3	1
	P-12	6-17	---	1/2	1
Mean or total		6-17	10	1/3	13
Middle	P-13	---	---	1/3	0
	P-14	6-18	•	1/4	3
	P-15	6-19	---	---	1
	P-16	6-18	---	---	1
	P-17	6-18	•	1/3	2
	P-18	7-18	•	1/3	1
	P-19	6-18	•	1/3	0
	P-20	6-18	•	1/2	1
	P-21	6-17	•	1/2	2
	P-22	6-19	---	1/2	0
	P-23	6-19	---	---	0
Mean or total		6-18	6	1/3	11
Mountainous	P-24				
	P-25				0
	P-26				0
	P-27	(not established)			0
	P-28				0
	P-29				0
	P-30				0
Mean or total		---	---	---	0

---:not established

vl. Conclusion

Toban region has been irrigated mainly by tameikes which are operated mostly intensively. The rules of operation have been formed by farmers experience for hundreds of year. They are reasonable and instructive. So the author had investigated about the tameike operation in the Toban irrigation area for several years and got the following results.

1) Tameikes are classified into four types by their function, mother-ike, daughter-ike, independent-ike and collecting-ike. They compose a water system combining the function of each type of ike. Features of the system are much related to the topography. For example, in the flat belt, a close combination between mother-ike and daughter-ike is obviously seen. In the mountainous belt, each independent-ike irrigates its own area independently. And each collecting-ike exclusively supplies its daughter-ikes. In the middle belt, the characteristics of both flat and mountaineous belt are seen.

2) A standard storage level is set at each tameike. Usually, it is decided at a level of half to one-third of its full depth. When the storage of daughter-ike decreases to this level before the middle of September , the mother-ike supplies her during the night, from 20 to 6 o'clock in the next morning.
3) A ditch-tender selected among farmers exclusively operates the tameike and distributes the water to each plot of field systematically. His standard working time is usually 12 hours a day, from 6 to 18 o'clock. When it rains, he stops release of tameike to conserve its storage.

From these results mentioned above, it is clear that the water stored in tameike is operated as a common property in each division, and is used very effectively.

OPTIMIZATION OF GROUND CATCHMENTS TO MAXIMIZE RAIN WATER COLLECTION IN SOUTH AFRICA

CECIL CHIBI

ABSTRACT

About 40% of South Africa suffers semi-arid to arid conditions with annual rain varying up to 200 mm. People staying in these areas are largely served by ground water through boreholes for their water needs. Typically the water is rich in dissolved iron or has an unacceptably high content of salt. The settlements in these areas, as is often the case, are sparsely distributed making it costly to import water. This means that the next practical and appropriate source to develop is rain water which is at the moment only exploited limitedly.

The importance of rain water as an alternative source have already been well documented elsewhere (e.g. Waller 1989) and will hence been assumed in this paper.

In the past the development of rain water catchment systems in South Africa has centred largely in the optimization of roof catchment Systems. Significant breakthroughs have been realized in work on water storage tanks. However, little has been done to explore the potential for ground catchment systems.

This paper reports on work done by the Division of Water Technology (CSIR) to evaluate ground catchments that have been treated with four locally available materials viz a tar product, paraffin wax graded sand and gravel and gravel-covered sheeting. To date the gravel-covered sheeting method has shown the greatest promise for use because the catchment plots are easy to prepare, the media affordable and most importantly deliver a reasonably good quality water.

1. INTRODUCTION

1.1 Water supplies in South Africa

Major water supplies in South Africa, whether for farming or urban development, are derived from surface sources. Underground water resources are relatively meagre but nevertheless extremely valuable to meet diffuse needs.

The scarcity of water is attributed firstly to the very low annual rainfall over most of the country - the average mean annual rainfall is only about 450 mm compared to a world average of around 850 mm. Secondly, because most of the country consists of an elevated plateau, the rate of evaporation is very high (Reader's Digest, 1989). The result is that 91 percent of the rain that falls never reaches the rivers; it either infiltrates the ground or is lost back to the atmosphere as evaporation. Thirdly, the distribution of exploitable water supplies, as is frequently the case, does not conform favourably to the distribution of demands. The result is that increasing quantities of water will have to be imported over longer and longer distances (a very costly option for diffusely distributed settlements in outlying areas).

The unevenness of the rainfall distribution becomes somewhat more apparent when one considers that about 30 percent of South Africa receives less than 250 mm of rain a year; about 34 percent between 500 and 750 mm and the remainder more than 750 mm (Reader's Digest, 1984). The reliability of the annual rainfall varies by from 65 percent in the North Western Cape to more than 90 percent along the Western part of the South Coast.

1.2 Problems in Arid areas

Urban areas (or places where people live in denser concentrations) are largely dependent on storage dams and piped water. People in rural areas - which are frequently semi-arid to arid - find that because of the sparsely distributed nature of their settlement have to depend on individual water supplies. These areas are typified by low annual rain resulting in very few streams/surface water which means people have to depend on subsurface aquifer water. More than half a million boreholes have enabled people to farm in areas which would otherwise have been uninhabitable in South Africa.

Groundwater by nature is classified as a good source of water because it is usually free of harmful pathogens and is normally of an acceptable colour. South African groundwaters almost always contain dissolved solids in varying concentrations. In arid areas these will manifest themselves as dissolved salts (e.g. chlorides, fluorides) in unacceptable concentrations sometimes exceeding 2000 mg/l. In some cases such as the Northern Transvaal area groundwaters have been found with an iron content of 20 mg/l.

Because of these factors as well as the fact that the population is growing at an annual rate of about 3%, the government, research institutions and other development organization are always seeking ways to create new supplies to supplement those administered by the Department of Water Affairs.

1.3 Rainwater Harvesting

Rainwater is one of the supplies which in recent years has observed an increasing appreciation as a viable and important source of good quality water. The concept of collection and storage of rainwater is as old as recorded history. The earliest record came from the Negev desert in Israel where Evenari, Shanari and Tadmor (1971) described cisterns which collected rainwater run off from terraced slopes almost 4000 years old. In South Africa rainwater harvesting is popularly practised in roof collection systems, especially in rural and/or arid areas. In this context a rain collection system is complete with the simple addition of a storage tank to an existing guttered roof (provided the roof material is not of lead, Asbestos or thatch which could lead to adverse water quality problems).

Rainwater collection using ground catchments, on the other hand, has not been practised to significant accounts in the country except in cases where small dams have been built to concentrate drinking water for game in nature reserves. This paper seeks to argue therefore that rainwater harvesting from ground catchments has potential to increase usable water - especially in semi-arid areas of the country.

2. EXPERIMENTAL DEVELOPMENT AND PROCEDURES

2.1 Objectives of CSIR work

The objectives of the work started at the CSIR to optimize ground catchment systems were to:

- improve supplies for people in semi-arid areas above what can be harvested from roofs
- economically increase the yield
- evaluate quality and potential uses for water derived from differently treated catchments
- compare ground catchment water with other water supplies.

2.2 Experimental Design

2.2.1 Selection of Catchment Materials

There were two aspects attributable to the experimental design: water quantity yield as well as the water quality derived. Hence, the initial stage was to determine which treatment(s) could be suitable for use for local application (based on relative availability and cost implications). Once a suitable treatment(s) had been established, then water quality obtained would be investigated.

An investigation into locally available materials suitable for catchment run off evaluation narrowed the choice to the three: paraffin-wax, a tar product, and gravel-covered sheeting.

Technically, materials like concrete and corrugated iron are also feasible for application. However, whilst they are easily available the cost involved in purchasing and application was deemed beyond reach of most people in rural areas.

The second stage of the experiment involved isolating the catchment(s) with the best results and then evaluating it for water quality obtained and thereafter making an assessment of possible uses for the water.

2.2.2 Description of plots

Field experiments were conducted on a representative loamy sand soil (sand - 62%, silt - 28%, clay - 2%, fine gravel - 8%, and mean liquid limit 40.45%) for a period of 2 years at the CSIR Roads test site, Pretoria.

Approximate sizes for catchment plots used was 3 - 4 m^2 square-shaped). A 200 l subsurface storage thank was provided for each of them.

In preparing them the soil surface was first cleared, with rough stones removed. It was then smoothed and compacted. Cement mix dykes were constructed around the perimeter of each plot (to prevent uphill runoff from interfering with the catchment water. A soil sterilant was also applied to prevent plant regrowth. Fink, et al 1979 suggested a type that is immobilized within the solid profile and will not contaminate the runoff water.

a. Gravel-covered sheeting

A polyethylene waterproof membrane (200-250 microns thick) such as the one used under tiled roof was laid on the impervious surface for collecting the precipitation. A shallow layer of uniform-sized gravel (4-8 mm) was spread over the membrane to protect the membrane from sunlight weathering processes and to provide some resistance against minor mechanical damage (Fink et al 1979)

b. Paraffin was

A powder paraffin wax was applied at a uniform rate of about 5 kg/m^2. Heat had to be applied to melt it to 'sink' to a depth of about 10 mm thereby making the top soil water repellent.

c. Tar product

A tar product was applied at the rate of 20 l/m^2 on another catchment plot.

d. Sand filter

Treatment on this plot consisted of a sand medium (20-30 mm) underlain by uniform gravel layer. (15-25 mm).

Clean river sand (1-3 mm), was used to inhibit turbidity build-up on the water flow down the catchment slope. The gravel, on the other hand, reduced the rate at which the sand particles could be carried away and also served to improve the drainage pattern.

e. Plain catchment

This final plot was only compacted for treatment and served as a standard against which relative water yield and quality improvements obtained from the other catchments could be evaluated.

2.2.3 Experimental procedures

i. Gravel-covered sheeting, paraffin-wax, tar product plots (derived from rain gauge reading).
The amount of water received per rain event (rain gauge reading) as a product with the catchment size were recorded as the absolute amount of water received. This was compared against the water actually collected in the storage tank.

ii. Gravel-covered sheeting sand filter plots
Turbidity and bacteria content were evaluated.

3. RESULTS

TABLE 1. Efficiency of collection for various catchment Treatment

Run-off yield (%) over 12 rain events.

	GRAVEL-COVERED PLASTIC SHEETING	TAR PRODUCTS	PARAFFIN-WAX	PLAIN CATCHMENT
Mean	90	77	40	35
StD	4.2	3.6	7.6	37

TABLE 2. Turbidity results (NTU) obtained over 3 rain events

	GRAVEL-COVERED PLASTIC SHEETING	GRADED GRAVEL AND SAND	PLAIN CATCHMENT
Mean	82*	202	>1000
StD	1.5	18	

TABLE 3 Bacterial analysis of results

TOTAL PLATE COUNT (PER 1 ml)

GRAVEL-COVERED PLASTIC SHEETING	GRADED GRAVEL AND SAND	PLAIN CATCHMENT
$45x10^4$		$11x10^5$
$11x10^4$	$75x10^4$	$16x10^5$
$14x10^3$	$53x10^3$	$16x10^4$
$97x10^3$	$20x10^4$	$29x10^4$

TABLE 3b Bacterial analyses of results

TOTAL COLIFORMS (PER 100ml)

GRAVEL-COVERED PLASTIC SHEETING	GRADED GRAVEL AND SAND	PLAIN CATCHMENT
38	82	94

MAXIMUM PERMISSIBLE CONCENTRATIONS

	TURBIDITY (NTU)	TOTAL COLIFORMS/ 100 ml	TOTAL PLATE COUNT
Who	9	<10	<100
South Africa	5	<5	-

3.1 Maintenance Requirements

All the media evaluated is relatively easy to prepare, and as can be seen from the results above, various yield improvements can be derived from a properly treated catchment surface. However, a certain amount of maintenance work is involved to maintain a good yield.

The plastic sheeting evaluated succumbed to sunshine weathering effects and had to be replaced after a year (it became very brittle to the touch). With the passage of each rain event it was realized that some sand from the top layer was being transported away with the collected water in the sand filter catchment. Hence this sand had to be replaced after some intervals. The paraffin wax plot was noticed to have lost its repellent feature after above two months and needed some reapplication. It took more than six months before the tar product had to be reapplied and since rain falls over a six months period in South Africa, this means an annual reapplication rate.

3.2 Comparative Cost of Catchment Preparation

The cost of the media was: Paraffin (R9.30), Tar product (R2) and gravel-covered sheeting was R1.50/m^2. While that of the sand filter was F1.65/m^2.

The preparation of the ground catchment cost R0.13/m^2 (will vary from place to place).

4. DISCUSSIONS

Regarding the efficiency of collection results (Table 1), the gravel-covered sheeting medium demonstrated the best yield followed by the tar products.

The paraffin wax results were poor at a mean of 40% (this was due to poor melting patterns and cracks that later developed). The high Std for the paraffin wax was because the treatment deteriorated rapidly and had to be reapplied.

If a family of five were to use a gravel covered sheeting catchment (95% efficiency), assuming 20 l/c/d, the annual requirement for water would be 36400 l. Therefore a catchment area of 79.1 m^2 (ie. 8 m x 10 m) would need to be treated.

The life expectancy for a gravel-covered sheeting catchment is approximately 15 years with good maintenance. Assuming only the plastic membrane has to be replaced annually (at R0.22/m^2), then the average cost of water per Kl from such a plot over the 15 years will be 70 cents. This compares favourably with municipal piped water charged at about 68 cents.

The quality of water (Turbidity, bacteria) derived from the three catchments evaluated exceeded both WHO and SA drinking water quality standards.

There are various ways in which this water could be upgraded to drinking water quality standards - the simplest (although not very efficient) being to let the water stand for extended periods of time. A good method is to treat the water with coagulating tablets with a slow chlorine release mechanism (e.g. chlor-floc; the trade name may vary from country to country). In places where this is not available, a sand filter will be just as efficient in purifying the water.

From the discussion above it becomes apparent that the cost associated with higher levels of the treatment of ground catchments makes them viable if the water is meant for potable use. Otherwise for non-potable needs such as agriculture and stock drinking water, runoff from a minimally treated catchment (clearly, smoothing, compacting) should suffice.

5. CONCLUSIONS

Recent work done at the CSIR indicates that it is possible to collect more than 90% of rainwater run off from ground catchments treated with gravel-covered sheeting. The water quality from ground catchments is not good due to accumulated dust, bird droppings, etc. However, there are various methods which can easily be used to bring this water to drinking water quality level (such as passing it through a sand filter, etc.)

Although the idea of rainwater harvesting is universally used in the country, ground catchments are still a fairly novel idea and, hence, needs a concerted effort from government and/or development agencies to promote. This could be in the form of demonstration plots in real life situations.

6. ACKNOWLEDGEMENTS

I would like to thank the Division of Water Technology for supporting me throughout the carrying our of this work and giving me permission to publish this.

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OPTIMAL CISTERN SIZE FOR HYDROPONIC GREENHOUSE OPERATION

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ABSTRACT

Hydroponic farms are starting to be adopted in the American Pacific Island for a variety of reasons. There are currently hydroponic operations in Hawaii, American Samoa, Guam and the Marshall Islands. Many of these operations use cistern stored rainwater, because of a lack of reliable water supplies, or because of the quality of available water supplies is unsuitable for hydroponic culture. Many of these sites are prone to periodic droughts. Thus, sizing the cistern is of vital importance to the economic viability of the operation. The cost of construction of an oversized cistern is an unnecessary expense, while the construction of an inadequate cistern exposes the operation to a higher risk of a loss of crops.

This paper develops a simple methodology for the optimal sizing of cisterns given the rainfall history of the site, the water use of the hydroponic system and the costs of construction. Specific examples are developed for Guam and the Marshall Islands.

INTRODUCTION

Hydroponic greenhouses require a reliable source of high quality water for their operation. Where community water supplies are available, these are usually the most appropriate sources. However, in some locations community water sources are not available, or else they do not provide water of an appropriate quality for hydroponics. In these instances, the best or only source of water for a hydroponic farm may be a rain water catchment system in the form of roof collectors and a cistern for storage.

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There are currently hydroponic operations in Hawaii, American Samoa, Guam and the Marshall Islands. Most of these use community water supplies, but some rely on cisterns or locally available surface water. In southern Guam, there are fairly large tracks of agricultural land which are currently unused or underutilized because of a lack of available irrigation water. So far, all attempts at hydroponic farming on Guam have been located on sites with community water available, foregoing the lower land cost of waterless sites. On the atolls of the Marshall Islands and the Federated States of Micronesia, there are few sources of surface water, and frequently, there are no adequate community water supplies. On these islands, a hydroponic farm is often forced to catch and store its own water supply.

RAINFALL PATTERNS AND DATA

This paper uses daily rainfall histories from Guam in the Mariana Islands and Majuro in the Marshall Islands to develop a fairly simple technique for sizing the storage cistern of a hydroponic farm in an optimal manner. The method is called simple, because it does not rely on the complex statistical analysis of the rainfall patterns, and because it makes use of a "spreadsheet" type software with which most users of personal computers are familiar. The method does require the availability of rainfall data on a daily or weekly basis for a period of at least 10 to 15 years. In our examples, we work with daily rainfall histories of 31 years for both Guam and Majuro. Average rainfall data is not appropriate for the sizing of cisterns for as the truism states "On average, it rains everyday". The use of average rainfall data will result in the undersizing of the cistern.

Guam has a dry season which usually runs from January through May and a wet season from July to October. The months of June and December are normally transition months as can be seen in Figure 1. Rainfall is episodic. It often occurs in short, intense periods associated with tropical low pressure systems. There are also marked variations between years in the intensity of both wet and dry seasons. Sometimes there is no marked dry season. However, the dry season can be usually long and severe such as in 1966 and 1969 where the rainfall for the first eight months of the year totaled less than 850mm. This corresponded to an average daily rainfall of 3.5mm, well into what would normally be the rainy season. Thus, the sizing of a cistern for a hydroponic farm on Guam requires sufficient storage capacity to endure these longer than normal dry seasons.

Majuro is wetter than Guam with an average annual rainfall of about 3,400 mm. The wet and dry seasons are not as marked. January to March are the driest months with an average daily rainfall of 6.2 mm in February. The rainy season peaks in October with an average daily rainfall of 11.8 mm as shown in Figure 2. As in Guam, the yearly total rainfall shows considerable variation. Over the history of the dataset, it has ranged from a low of 2,190 mm to a high of 4,370 mm.

Both datasets had some missing values. The Guam dataset was over 96 percent complete, and the Majuro dataset was over 99 percent complete. Rainfall for missing days was calculated as the average of the values for the same day in all following years.

Once a complete dataset was obtained, each year was divided into ten day periods and total rainfall for the period was calculated. The last, or thirty-seventh, period of each year contained only five on six days depending upon whether or not it was a leap year. These shorter length periods were corrected for in the calculation of water demand in the simulation model.

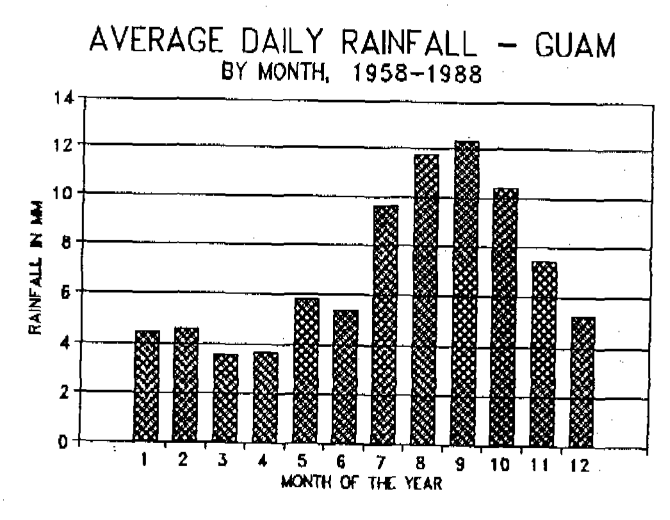

Figure 1

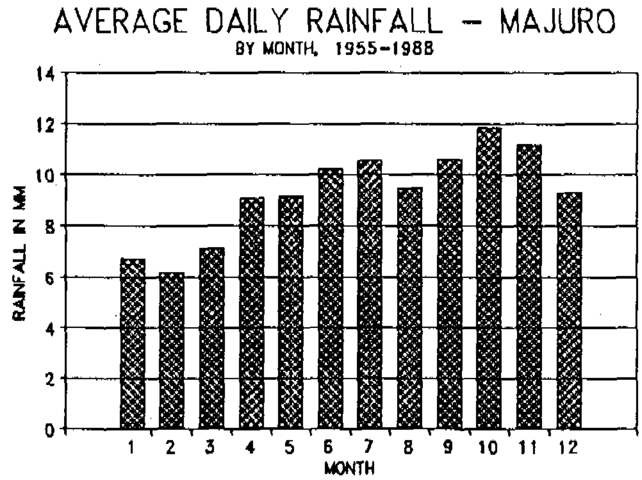

Figure 2

EVAPOTRANSPIRATION AND WATER DEMAND

In order to build a simulation model an evapotranspiration rate for the greenhouse crop was needed. We chose to work with tomatoes on a 120 day production cycle. Experience has shown that on Guam hydroponic tomatoes flower at roughly 45 days from seedling, start producing at 75 to 80 days from seeding and continue production for forty days. Thus, 120 days are required for a production cycle, and three crops planted 40 days apart will give continuous production. At the end of every forty day period, one-third of the greenhouse is replanted. Thus, at any given time, one-third of the greenhouse is newly planted, one-third is flowering and one-third is in continuous harvest.

We found no studies of daily evapotranspiration rates of hydroponic tomatoes. Phene et al., 1985 report total evapotranspiration rates ranging from 600 to 696 mm for field grown processing tomatoes in the San Joaquin Valley of California during 1984 depending on the cultivar used. Phene et al., 1989 report total evapotranspiration rates ranging from 695 to 711 mm for California field-grown processing tomatoes in 1987. They found no differences due to irrigation methods.

Phene et al., 1989 give a total evapotranspiration rate of 708 mm for the high frequency subsurface drip irrigation treatment. They graph the daily evapotranspiration rates in their Figure 1. We approximated the area under this curve using a series of linear approximations: for the first 60 days - 1.5 mm/day on 90 mm total; for the next 45 days - 1.5 mm/day increasing to 7.5 mm/day or 202.5 mm total; and for the final 55 days - 7.5 mm/day or 412.5 total. This approximation totaled 705 mm which is very close to the reported 708 mm total water requirements.

After consulting with the agricultural engineer at the University of Guam, Dr. Prem Singh, it was decided that the following estimate of evapotranspiration rates for hydroponics would be used: for the first forty days - 2 mm/day or 80 mm total, for the second forty days - 2 mm/day increasing linearly to 8 mm/day or 200 mm total, and for the final forty days - 8 mm/day or 320 mm total. This gives a total evapotranspiration rate of 600 mm for the crop.

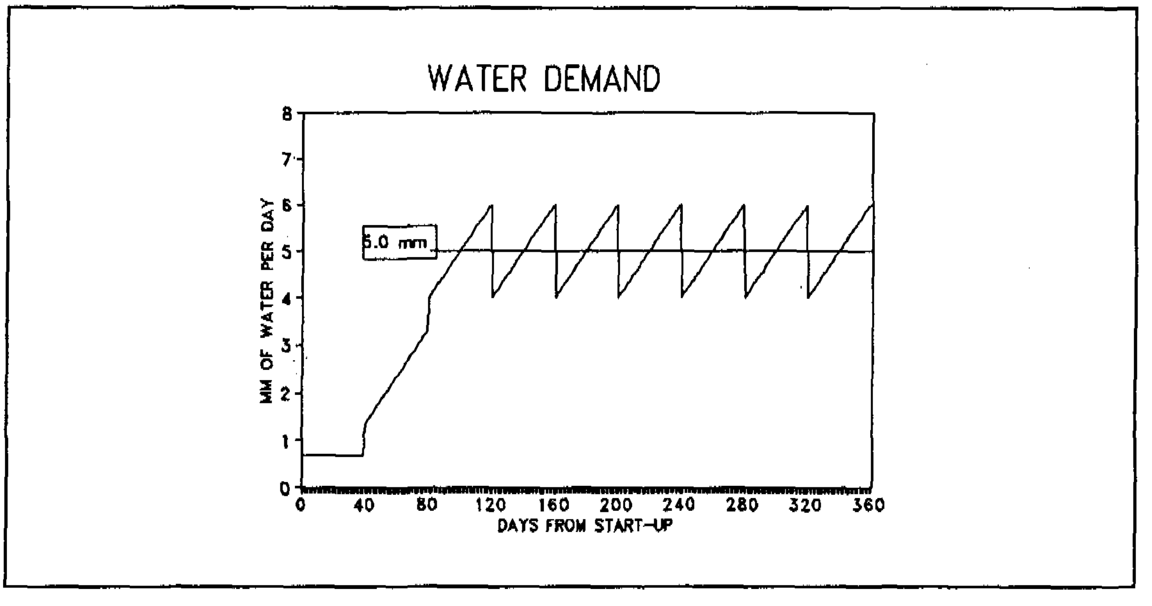

Figure 3

Since one third of the green house will be in each phase of the crop cycle at any given time, the average evapotranspiration rate will follow a saw toothed pattern as shown in Figure 3 which is the simple average of the water demand for each of the three phases. Once the greenhouse is fully planted, the average evapotranspiration rate will be 5.0 mm/day or 50 mm per ten-day period. This is the figure which was used in our simulation model for the water demand of the greenhouse.

SIMULATION

The simulation model was set up in a straightforward manner on an IBM compatible personal computer using a Lotus 123 type spreadsheet. The first column contained the time-series of the ten day rainfall data. The second column calculated the new water depth as (Rainfall-evapotranspiration) times (area of greenhouse/area of cistern) + old water depth. The third column set the current water depth to the cistern height if an overflow was predicted, and the fourth column set the water height to zero if an underflow was predicted. The fifth column evaluated the status of the system as to whether the crop was growing (status = 1) or the cistern was accumulating water (status = 0). The sixth column counted the number of times the cistern ran dry over the period of the simulation. A graphical output of the simulation is shown in Figure 4 for Guam and Figure 5 for Majuro.

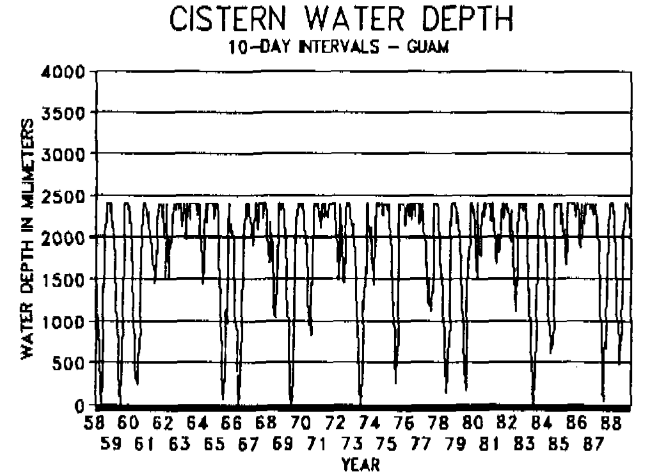

Figure 4

The parameters of the system were: 1) the ratio of the area of the greenhouse to the area of the cistern, 2) the height of the cistern, and 3) the depth to which the cistern was allowed to refill after the cistern ran dry and before the greenhouse is replanted.

The parameter of interest in this study was the ratio of the area of the greenhouse to the area of the cistern. A greenhouse area of 1,860 square meters with a cistern of 372 square meters has a ratio of 5:1. The ratio of the area of the greenhouse to the area of the cistern determines how fast the water height in the cistern changes with excesses or deficiencies of rainfall. A ratio of 5:1 will produce a 5 cm change in cistern water depth for every centimeter of excess or deficiency of rainfall. The higher the ratio is the faster the cistern empties or refills. Thus, higher the ratio the shorter the drought a cistern will be able to sustain, and therefore the higher the ratio the more likely the cistern is to run dry.

The height of the cistern was set at 2.4 meters to allow for a gravity driven system of gutters. This is the cheapest and most reliable method of filling a cistern. The height of refill before restarting was rather arbitrarily set to 50 percent of the cistern height after some preliminary exploration of the dataset.

COST ANALYSIS

The most obvious cost of a cistern is the cost of construction. For a given size greenhouse, the higher the ratio of smaller the cistern will be and the lower will be the initial cost of constructing the cistern. However, the larger the ratio is the more likely the cistern is to run out of water. This is the second type of cost involved in the design of a cistern. When the cistern is emptied, there are two losses due to the lack of water. The first loss is due to the death of the plants in the hydroponic system and the wait for the newly replanted tomatoes to start producing. This loss is eighty days of production every time the cistern runs dry. The second loss is the lost production while waiting for the water level in the cistern to rise to a sufficient level to safely replant the system. This period will vary with the actual rainfall.

The rule for finding an economically optimum size for a cistern is that the cistern size should be increased until the increase in the cost of construction equals the decrease in the expected present value of the cost of running out of water over the useful life of the cistern. The basic economic principal is that the total cost of the cistern is minimized at the size where the marginal gain from not running dry equals the marginal cost of an increase in size of the cistern. There are two caveats to this condition. The first is that the graph of the marginal cost cuts the graph of the marginal gain from below. This assures that the cost is minimized. The second is that there may be multiple local minimums which meet the above condition, so a wide range of sizes should be examined.

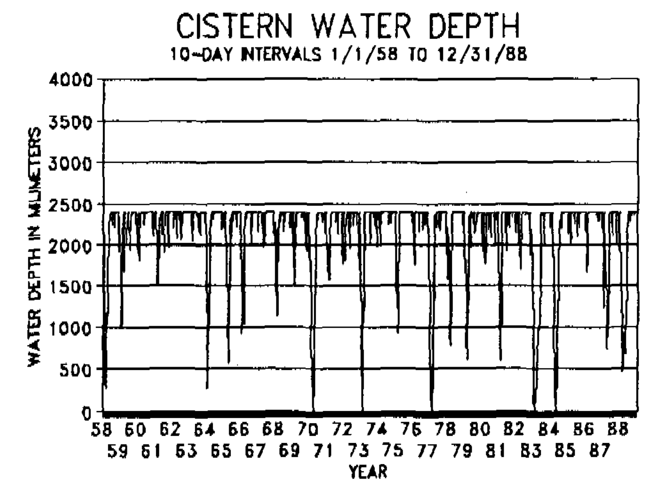

Figure 5

The information required is then in two parts. The first part is how cost of construction changes with the size of the cistern. This is the marginal cost of increasing the cistern size. Current construction cost of a cement cistern on Guam is estimated to be $215-323 per square meter ($20-30 per square foot). We used $269 per square meter, the mid-point of this range, as the cost of adding extra capacity to the cistern. The same costs were used for Majuro. No sensitivity analysis was done on the construction cost parameter.

The second part is how the expected present value of running out of water decreases with an increase in the size of the cistern. This is the marginal gain from increasing the cistern size. The value of avoiding an unwanted shut-down of operations to a farm is the difference between the total revenues less the variable costs which can be avoided during the period. This is the same as the lost profits plus the fixed costs (which must be paid whether the farm is in operation or not) during the period of shut-down. We used three estimates of the daily cost of shutting-down the hydroponic farm: 150, 200 and 250 dollars per day in the analysis of cistern size. These are slightly below the ranges given by Brown et al. (1991) for an 1860 square meter hydroponic greenhouse on Guam.

The costs of shutting-down the farm will occur in the future if they occur at all. The probability of shutting-down the system will vary with the size of the cistern, and how it varies can be estimated by systematically varying the ratio of the greenhouse area to the cistern area while running the simulation model over the actual rainfall data. Table 1 shows the change in the probability with cistern size and the mean duration of the shut-downs for both Guam and Majuro in the first two columns. The expected cost of shutting-down the system in a year is the product of the probability of shut-down times the length of the shut-down times the daily cost of shutting-down.

The final step is the estimation of the present value of avoiding the shut-downs over the planning horizon of the project. Present value accounts for the fact that avoiding a cost in the future is not of the same value as avoiding a current cost. The formula for the present value of an expected cost is:

$$EPV = EC * \frac{1}{r}\left[1 - \frac{1}{(1 + r)^{N}}\right]$$

where:

EPV is the expected present value
EC is the expected cost in each year
r is the time value of money (discount factor)
N is the length of the planning horizon in years.

Table 1.
Analysis of risks and total expected cost of various sized cisterns

	Cistern size(m^2)	Annual prob.	Mean Duration	$150 per day	$200 per day	$250 per day
GUAM						
	186	0.68	141	156982	192642	228303
	209	0.58	147	151666	183471	215277
	232	0.52	154	151410	181047	210684
	255	0.48	155	152962	181033	209103
	279	0.45	156	153791	180054	206318
	302	0.45	152	158233	183895	209556
	325	0.42	149	157616	180989	204361
	348	0.39	147	157361	178564	199768
	371	0.39	138	159996	179995	199994
	395	0.26	149	149260	163596	177933
	418	0.19	138	142498*	152498*	162497
	441	0.19	138	148748	158748	168747
	464	0.16	134	149215	157287	165359
	487	0.13	138	151128	157754	164381
	511	0.10	133	151957	156776	161595
	534	0.06	125	152786	155797	158809
	557	0.03	110	153976	155301	156626
	580	0	0	156250	156250	156250*
	604	0	0	162500	162500	162500
	627	0	0	168750	168750	168750
	650	0	0	175000	175000	175000
MAJURO						
	93	0.58	116	100538	125717	150896
	116	0.45	119	91608	111727	131847
	139	0.32	125	82678	97737	112797
	162	0.23	121	74471	84711	94952
	186	0.16	132	73854*	81805	89757
	209	0.16	128	79381	87092	94802
	232	0.10	140	77680	82740*	87800*
	255	0.10	140	83930	88990	94050
	279	0.06	145	85481	88975	92469
	302	0.03	170	87394	89442	91490
	325	0.03	170	93644	95692	97740
	348	0.03	170	99894	101942	103990
	371	0.03	170	106144	108192	110240
	395	0.03	160	112033	113960	115888
	418	0.03	140	117560	119247	120933
	441	0.03	140	123810	125497	127183
	464	0.03	0	125000	125000	125000
	487	0.03	0	131250	131250	131250
	511	0.03	0	137500	137500	137500
	534	0	0	143750	143750	143750
	557	0	0	150000	150000	150000

* Lowest total cost for each daily cost of shut-down.

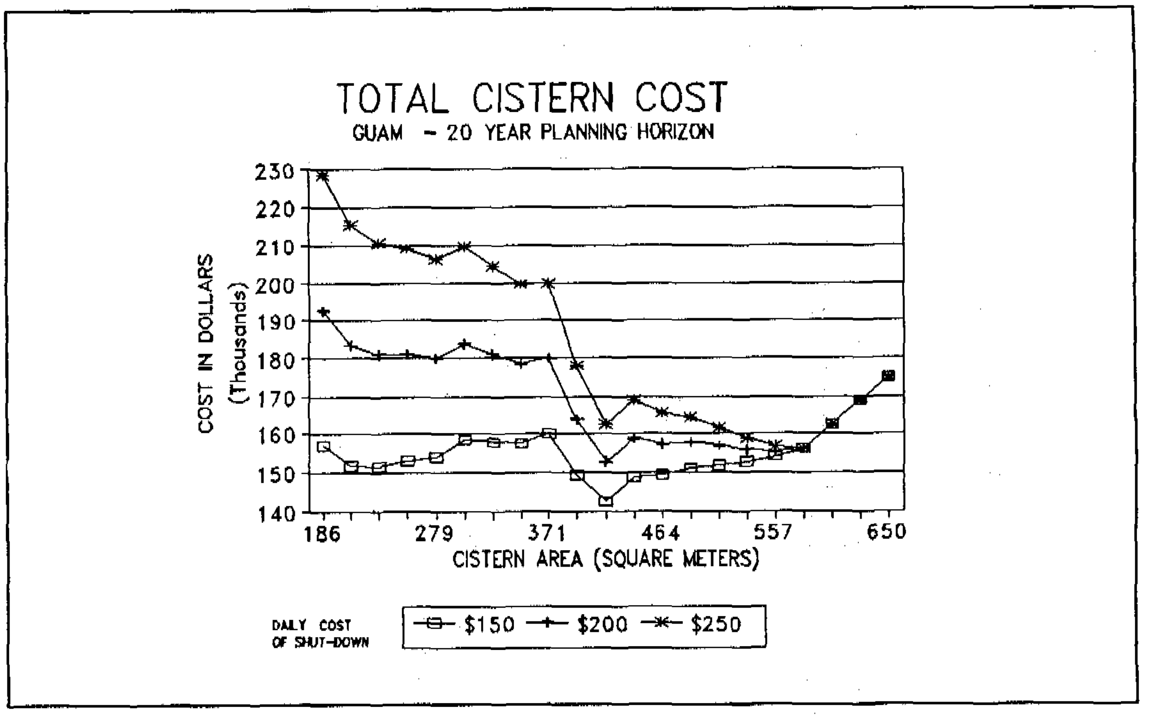

Figure 6

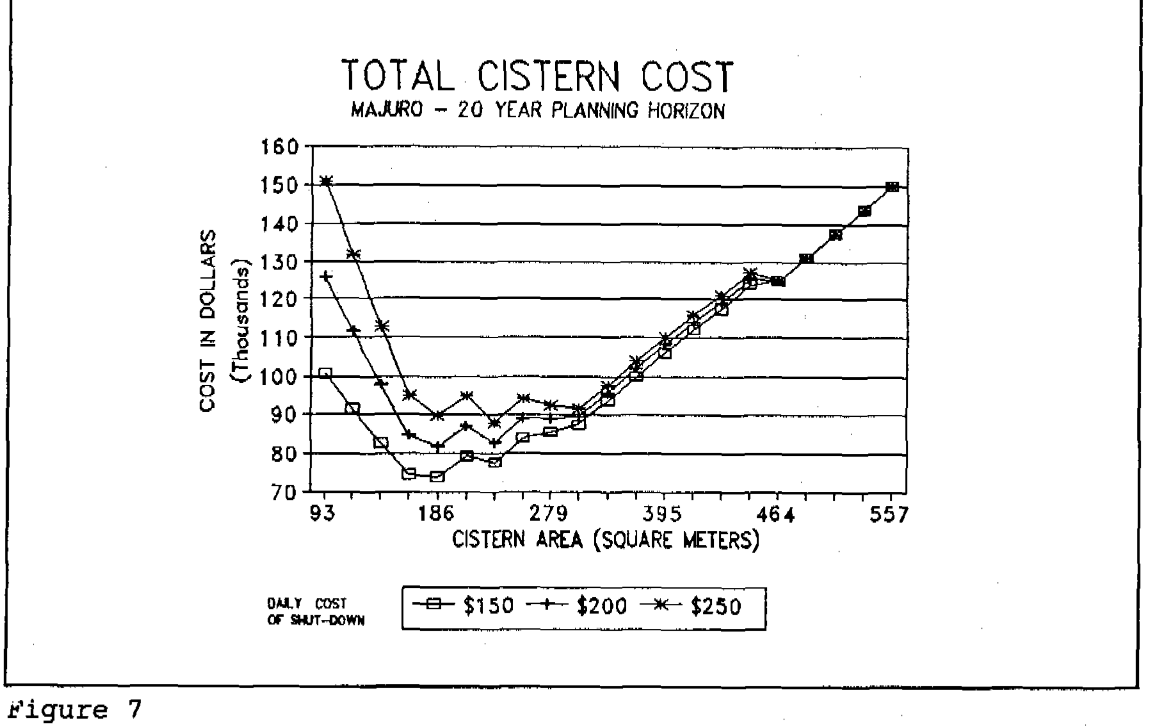

Figure 7

The final three columns of Table 1 give the total expected present cost of the cistern and lost production as the daily costsof shutting-down are varied from 150 to 250 dollars per day.

CONCLUSIONS

Guam, because of its longer and more intense dry season has a larger optimal size of cistern for all three daily costs of lost production. At a daily cost of 150 or of 200 dollars per day, it is optimal to accept an annual risk of 19 percent of running the cistern dry and losing production for 138 days by building a cistern of 418 square meters. When the daily cost of lost production is 250 dollars per day on Guam, it pays to build a cistern of 580 square meters which is large enough to avoid the expectation of running out of water.

On Majuro, because of its shorter and less severe dry season, it is preferable to build a smaller cistern. At a daily cost of 150 or of 200 dollars per day, the optimal size cistern is 185 square meters which has an annual risk of 16 percent of running dry and loosing production for 132 days each time. When the daily cost of running out of water is 250 dollars per day on Majuro, the optimal size cistern is 232 square meters which reduces the annual risk of shut-down to 10 percent.

The total expected cost of the cistern component of a hydroponic farm is quite high particularly on Guam. With inexpensive public water available on large parts of the island, it is not surprising that all attempts on Guam so far at hydroponics have chosen to forgo the lower costs of property without water. On the atolls of the Marshall Islands, there is often no choice other than to build a cistern for a water source. Fortunately the shorter, less intense dry season requires a smaller system there.

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Economics of Flood Irrigated Cereal-Hay Production

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ABSTRACT

Insufficient rainfall makes dry-farming an undependable method of food and feed production in many parts of Iran. Moreover, groundwater (GW) mining for irrigation of crops is threatening the very existence of the desert dwellers. Therefore, augmentation and conservation of GW for later, wise utilization holds the key to the prosperity of the future generations. Flood-water spreading (FWS) is a very easy and economical means of crop production in the arid and semi-arid areas.

Flood irrigation of wheat and hay in the Joonegan County, Mamassani (mean annual precipitation, MAP-579mm) in 500 ha of rainfed wheatfields during the 1980-81 growing season resulted in substantial gains in grain and hay production. The grain yield on a 40 ha tract ranged 1214-1685 kg ha^{-1}. The highest grain yield in control farms was 700 kg ha^{-1}. The forage yield ranged from 1500 kg ha^{-1} for Medicago scutellata Mill. to 3000kg ha^{-1} for Trifolium alexandrinum L. Improved yield for wheat of up to 3200 kg ha^{-1} have been reported of up to 4300 kg ha^{-1}, and for medic of up to 3200 kg ha^{-1} have been reported for more recent years. Disregarding the extra benefits accrued through artificial recharge (AR) and flood mitigation (FM), the benefit to coast ratio (BCR) was 5.1.

A 650 ha FWS system was constructed in the SE corner of the Gareh Bygone Plain (MAP=150mm)for barley production. The grain yield of individual farms ranged 700-2000 kg ha^{-1} with the mean of 1400 kg ha^{-1} in the 1984-85 crop season. The highest grain yield of control plots was 700 kg ha^{-1}. Disregarding the extra benefits accrued through Ar of GW, FM, and forage production in the fallow period, the BCR compounded yearly at 15% for 10 years was 2.2. Should the real cost of irrigated grain and hay production be considered, the BCR would be larger than the reported figures.

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INTRODUCTION

Producing food and fiber for an ever-increasing world's population is the greatest challenge that agronomists are facing today, and undoubtedly, to a much higher degree in the 21st century. The "quantum leap" made in breeding and releasing the high-yielding varieties notwithstanding, development and implementation of new management systems, particularly with respect to water and fertilizers, have been crucial to the success of the Green Revolution. Unpredictability of the amount and distribution of precipitation in arid and semi-arid regions makes irrigation the most important practice of a viable crop production system. Furthermore, irrigation to supplement precipitation is used increasingly in [sub] humid regions to stabilize crop productivity (Ritchie, 1987) . However, the frailty of such systems was utterly proved during the oil crisis in 1973 when the high price of fuel oil, which energized the pumps, as well as the scarcity of the oil based fertilizers and pesticides, substantially decreased the area of irrigated agriculture in India (Mellor,1976).

Shrinking arable land resources and severe competition for the limited supplies of water force soil and water conservationists to carefully examine the available alternatives, and design production systems, which best fit crop water requirements and local constraints. It is only through careful implementation of such management plans that potentially exhaustible soil and water resources can be made renewable (Timmons and Amos, Jr., 1982).

Water has been and will be the major cause of conflicts all over the world, particularly in the Middle East and Northeastern Africa. The war over water is not only between nations, but within the different sectors of economy in most developing countries as well, since rising affluence usually leads to increased water demand. These conflicts shall certainly intensity during the droughts which will occur in the coming years.

Irrigated agriculture, which consumes more than 95% of water resources in Iran (Bybordi, 1989), and perhaps in other arid zones, is the main target of planners who are expected to find new water supplies for industries and municipalities, because even a slight reduction in the percentage of irrigated area, and/or the water consumption of crops, would make a large difference in the volume of water which might be allocated to other sectors.

Although taking land out of irrigation in arid areas and increasing the irrigated hectarage in humid regions is practicable in countries with an efficient infrastructure, such as the U.S. (Ritchie, 1987), it is unthinkable for most of the developing world.

Increasing the rooting depth and exploiting a larger volume of soil through genetic manipulation and addition of chemical amendments of the soil is another alternative (ibid) which may hardly be implemented by those most in need of food. However, flood irrigation (FI), utilizing the usually wasted floodwaters, offers a practical method of growing food and feed crops on fertile soils, as well as on most of potentially arable lands. Although the importance of timely inputs of supplemental irrigation in producing high crop yields in drylands is established (Singh et al., 1979), FI, through its effect on the amount of profilestored water, favorably affect crop production. Application of this technique not only saves the ordinary sources of water for growing specialized crops and for industrial and municipal consumption, but may also reclaim eroded lands, recharge groundwater, mitigate flood damage, and improve the environmental quality through retention and recycling of water borne nutrients. Moreover, inclusion of leguminous fodders in the rotation, besides providing some of the crucially important feed for the livestock, supplies most, if not all of the nitrogen required for growing cereals and other crops. This would also protect the soil surface from water and wind erosion.production. A

The objectives of the study reported here were to (i) evaluate the feasibility of utilizing FI in production of wheat and barley under two contrasting rainfall regimes, and (ii) investigate the possibility of growing barley on a sediment reclaimed moving sand tract in a low rainfall area.

MATERIALS AND METHODS

The high rainfall study site is located at the Joonegan County (JC), Mamassani (30°31'N, 51°31'E), 150 km to the NW of Shiraz, Iran. The elevation ranges from 1038 to 1050 m above sea level. The soil, which has developed on a colluvial-alluvial valley floor, is classified as fine loamy over loamy skeletal carbonatic hyperthermic Typic Ustorthents.

The climate is Mediterranean with hot summers and mild winters. The mean annual temperature (MAT) is 21.3°C, and the absolute minimum and maximum are -5.0 and 46.2°C, respectively; the mean annual precipitation (MAP) is 579 mm, which usually occurs during the Oct., through May period (Noor Abad); the mena annual evapotranspiration (MAET) is 2800 mm (Anon., 1976), The soil type and climate of the JC make it representative of a vast area in the southern Zagros Ranges.

Five hundred ha of dryfarms were put under FI during the 1980-

81 period in the JC, of which some representative samples are described below. Seven level-silled channels (LSCs) were laid down and constructed according to the procedures described by Quilty (1972a) on a 40 ha, north facing, 1.5 to 4.0% sloping tract in the winter of 1980. The vertical intervals (V.I) between successive channels were 1.5 and 3.0 m for <2% and > 2% slopes, respectively. However, a contour, shallow ditch was placed midway between every two LSCs on the slopes steeper than 2% to facilitate better water distribution, and also to serve as a guideline for contour cultivation of the fields, A 125 H.P. D_6 Caterpillar with a 3.25 m wide blade and 0.60 m long rippers were utilized for construction of the FI system.

Interception of the runoff of road culverts by channels number 1 and 7, and the flow of 1-3 natural waterways at the foot of the adjacent mountain by the remaining LSCs, eliminated the need for the design and construction of a diversion-spreader channel as recommended by Quilty (1972b).

Tillage operations consisted of a moldboard plowing plus two disk harrowing, the second of which was applied after hand-broadcasting of 100kg ha^{-1} of Oroji, a local tall wheat variety. Tillage operations which were performed on the contour were accomplished during the 3rd week of Dec. 1980, following 19.0 mm of rain which fell from 11 to 13 Dec. and soaked the soil down to the plowing depth.

An 8 ha tract was seeded to snail medic [Medicago scutellata (L.) Mill.] at the rate of 100kg ha^{-1} (in pods) on 17 and 18 Jan.1980. Ammonium phosphate (46% $P_{2O}5$; 18% N) was hand-broadcasted at the rate of 50 kg ha^{-1} along with the seeds. The same operations were repeated on an adjacent, 4 ha field on 5 and 6 Feb.1980. Tillage operations for these and the clover planting (following paragraph) were done exactly as reported for the wheat.

A 1.5 ha tract was seeded to berseem clover (Trifolium alexandrinum L.) at the rate of 15 kg ha^{-1}. Ammonium phosphate was hand-broadcasted along with the seeds at the rate of 50 kg ha^{-1} on 30 Jan, 1981. The same operations were repeated on an adjacent, 2 ha field on 5 Feb. 1981.

The wheat was combine-harvested during the 2nd week of June 1981. The medic was hand harvested during the 4th week of May 1981. The clover was manually cut on 20 Apr. and 20 May 1981 on the 1.5 ha tract, and during 26-30 May 1981 on the 2 ha field.

Detailed descriptions of the low rainfall study site, the Gareh Bygone Plain (GBP) have been presented elsewhere (Kowsar, 1989,1990). However, a few relevant data are presented here: The MAT, MAP, and MEAT of the GBP are 19.0°C, 150mm, and 2860mm, respectively, A 650 ha, north facing tract in the SE corner of the GBP was selected for the barley experiment. Two adjoining FI systems were constructed in the tract in 1984 as described for the JC with the following modifications:

1. Floodwater to each system was supplied through a conveyor-spreader channel which sloped 3 0/000 in the direction of flow;
2. The VI of 1.10 m was selected for the LSCs; this resulted in the average spacing of 120 m between them;
3. The soil of the FI site is classified as fine-loamy carbonatic (hyper) thermic Typic Calciorthids.

A local variety barely was hand-seeded at the rate of 60 kg ha^{-1} on the fields after moldboard plowing in Nov.1984. The seeds were then turned under with disk harrowing. Fertilizers, in the from of sheep and goat manure, was brough in by floodwaters and spread on the fields. The fields did not receive chemical fertilizers, herbicides or pesticides. Barley was combine-harvested during the second half of May 1985.

Although rain-fed barley grown on the loamy sand (coars-loamy over loamy skeletal, carbonatic (hyper) thermic Typic Calciorthids) of the GBP with the MAP of 150 mm usually meets with total failure, most farmers practise it against professional advice. However, modification of the texture by sedimentation of the suspended load, and the extra water provided by floods, have improved the situation following the flood of 19-20 Dec,1985. This field had been flooded three times before; 3,23-24 Jan.85, and 12 May 85. Cultural practices were those as reported for the 650 ha tract.

RESULTS AND DISCUSSION

It should be emphasized at he outset that the yield data presented here are based upon observation of the authors, or the figures fornished by the owners of the fields on which FI had been practised, rather than statistical analyses.

High Rainfall Area

Flood irrigation of wheat in the JC on 18 Dec. 1980, 12 and 26 Jan.,27 Mar., and 1 May 1981 resulted in a substantial increase in the yield of grain and stubble of the treated fields. The relatively adequate amount and very favorable distribution of precipitation (Table 1) notwithstanding, FI enhanced the yield by increasing the profile water storage and/or adding some of the lacking nutrients.

Grain yield of the wheatfields in kg ha^{-1} ranged from 1214 in a

17 ha farm to 1685 in a one ha field. The yield of the latter had never exceeded 675 kg ha^{-1}. It is worth mentioning that growth of wheat plants to 180 cm in the low spots and their lodging due to the intense rain of 1 May 1981 was the main reason for the lower gains in some fields. The yield of Arvand 1, an improved variety of Mexican stock, was 1435 kg ha^{-1}. The low yield of this variety was mainly due to infestation by stem rust (Puccina graminis Pers.) and leaf rust (P. recondita Rob ex Desm.). These two shortcomings were corrected by introducing Byat, a short-strawed wheat of Mexican origin which is rather resistant to the rusts. The grain yield of Byat ranged 1550-2000 kg ha^{-1} in the 1982-83 season, with the mean of 1700 kg ha^{-1}. The highest yield of control farms (not irrigated) was below 700 kg ha^{-1} in both seasons.

Effectiveness of FI has been proved beyond doubt in the 1983-84 season (fallow year for FI fields) when a single, 4 ha farm was

Table 1. Rainfall data for Noor Abad, Mamassani during the growing season of wheat, 1980-81.

Date	Amount, mm	Date	Amount, mm	Date	Amount, mm
Nov. 9,1980	0.8	Jan.12,1981	26.0*	Feb.22,1981	0.6
10	6.2	13	1.8	23	7.4
11	1.0	14	2.0	24	3.0
12	0.8	15	1.0	29	2.0
13	1.8	16	1.3	Mar. 1,1981	2.6
14	0.3	17	0.8	2	0.4
15	4.0	18	0.3	8	1.0
16	2.0	19	5.0	9	3.0
Dec.11	5.0	20	4.0	10	4.0
12	12.6	21	27.3	12	1.0
13	1.0	22	6.6	15	1.4
16	5.4	25	0.7	16	1.6
17	46.0	26	3.0*	17	1.6
18	33.5*	27	7.0	18	0.6
28	0.4	Feb. 3,1981	0.4	19	4.5
Jan. 2,1981	5.0	7	0.6	20	5.0
3	24.2	8	0.4	26	5.0
4	1.1	10	2.2	27	16.8*+
5	1.0	11	11.4	28	12.2
6	1.7	12	1.5	Apr. 9,1981	14.8
7	1.7	15	0.4	10	4.7
8	2.2	16	0.2	16	2.4
9	2.0	18	0.2	17	11.4
10	1.2	20	26.0	May. 1,1981	34.6*+
11	1.0	21	1.0	2	6.2

*,+ Events which yielded runoff to the wheat- and forage- fields, respectively.

flood irrigated. It produced 1500 kg ha^{-1}, while the maximum yield of the rainfed farms was less than 400 kg ha^{-1}. Total precipitation during this season was 282.0 mm.

Sedimentation of the channels, and lack of maintenance have gradually decreased the effectiveness of the FI systems. However, increases have been reported by some owners who maintain their LSCs and fallow good agronomic practices. The mean yield of 4 ha of a barley of local stock in 1989-90 season was 4000 kg ha^{-1}. The mean yield of 3 ha of Byat variety, seeded at 150 kg ha^{-1} and fertilized with 50 kg ha^{-1} Urea and 100 kg ha^{-1} ammonium phosphate was 3000 kg ha^{-1}. The yield of a local variety barley of another 3 ha field in 1986-87 and 1989-90 growing seasons were 3300 and 3000 kg ha^{-1}, respectively. The same farm usually yields 3000 kg ha^{-1} of Byat wheat in alternate years. A farmer reported production of 3000 and 1500 kg ha^{-1} of barley from a 3 ha and a 6 ha field, respectively. The yield of Byat wheat in flood irrigated farms of the JC ranges 1500-3200 kg ha^{-1}; for barley, it is 1500-4300 kg ha^{-1}.

Although forages benefited greatly from FI, we can not show how effective it has been; there was no controls. The medic and clover were introduced into the JC by our group. However, selfseeding annuals which occupy the control fallow lands produce about 500 kg ha^{-1} of dry matter per year.

While the wheatfields were flood irrigated five times in the 1980-81 growing season, the forages received only two waterings (27 Mar. and 1 May 1981), this was due to the difference in geological formations which supply runoff to the various parts of the JC.

Snail medic yielded 1500 kg ha^{-1} of dry matter in one cutting. Since a variety of this medic has produced 5500 kg ha^{-1} under FI in the Negev Desert (Tadmor, Shanan and Evenari, 1971), our result was discouraging, This poor showing may be attributed to the late seeding, to the heavy infestation by weeds, and to the constant raid by livestock at inopportune times. The same field produced 3200 kg ha^{-1} with proper management 4 years later. Considering the very favorable environment of the JC it is hoped to raise the yield of snail medic there at least to that of the Negev Desert.

Berseem clover yielded 6000 kg ha^{-1} in two cuttings in a 0.25 ha parcel of the 1.50 ha tract; the remaining 1.25 ha yielded only 1000 kg ha^{-1} The 2 ha tract produced 5000 kg ha^{-1} in one cutting. The high yields were produced on low-lying, flat lands where the slope did not exceed 0.5%. The low yield was produced on a 1-3% sloping field. However, the overall yield of 3180 kg ha^{-1} from the fields which would have been under fallow otherwise was satisfactory, considering the acute forage deficiency in southern Iran.

Low Rainfall Area

Flood irrigation of barley in the GBP on 3 and 23-24 Jan., and 12 May 1985 resulted in a good crop over most of the 650 ha FWS systems. Grain yield ranged 700-2000 kg ha^{-1}, depending on the management level and depth of supplemental irrigation provided by floods; the mean was 1400 kg ha^{-1}. The yield of rain-fed farms had been so low that their harvest was deemed uneconomical. However, the fields with the lowest yield in flooded area were taken as "control" for the sake of comparison.

The date and amount of rainfall events during the growing season of barley in 1985-86 are presented in Table 2. The total depth of precipitation for this period was 145.0 mm. Moreover, there were 18 dewy nights when the amount of dewfall at the height of 1.2 m was 0.2mm (the minimum amount that the recording rainguage registers). However, floods of 19-20 Dec.85 and 7 Mar.86 added equivalent of 460 mm of water to the fields. Since deep seepage is prevalent in the sandy soil of the site the amount consumed by the barley was perhaps less than 400 mm. Further research at the site will clarify this point.

Table 2. Rainfall data for the Gareh Bygone Plain during the growing season of barley, 1985-86.

Date	Amount, mm	Date	Amount, mm
Dec. 5,85	19.2	Feb. 1,86	0.4
19	40.0	9	5.6
20	15.8	Mar. 2,86	0.6
22	1.8	7	14.8
23	2.4	27	11.2
24	0.4	Apr. 9,86	5.0
26	0.6	10	2.8
27	13.2	11	2.4
Jan.26,86	2.6	23	5.0
31	0.8	28	0.4

The grain yield of the one ha sediment improved sand in the growing season of 1985-86 was 1000 kg ha^{-1}. This was beyond expectations. Apparently, the favorable conditions (adequate profile storage, timely floods, timely seeding, etc.) made this harvest possible, This points to the potential of floods in reclamation of sandy soils. Further study of this topic is highly recommended.

ECONOMIC FEASIBILITY

High Rainfall Area

Although extreme variations in agronomic practices amongs farms makes precise analysis difficult, some safe and simplifying assumptions may be made: wheat yield for flood irrigated and control farms in alternate years is 1700 and 700 kg ha^{-1}, respectively; straw yield is 1.5 times grain yield; forage yield for the treated and control farms in alternate years is 1700 and 500 kg ha^{-1}, respectively; the costs of crop production and harvesting are the same on both types of farms; the FWS systems function for 10 years; the maintenance costs are 167% of the initial expenditure. The costs and prices reported here are as those of 1985-86.

Benefits (per ha):

Wheat: 1000 kg yr^{-1}	@ 50 rials kg^{-1}	50000 rials
Straw: 1500 kg yr^{-1}	@ 10 rials kg^{-1}	15000 rials
Shbtotal		65000 rials
Total benefits from wheat + straw for 5 years		325000 rials
Forage: 1200 kg yr^{-1}	@ 25 rials kg^{-1}	30000 rials
N-fixed 50 kg yr^{-1}	@ 10 rials kg^{-1}	500 rials
Subtotal		30500 rials
Total benefits from forage + N for 5 years		152500 rials
Total benefits for 10 years		477500 rials

Costs (per ha):

Surveying	@ 5000 rials $hour^{-1}$	1000 rials
Bulldozer rental	@ 3500 rials $hour^{-1}$	7000 rials
Supervision		2000 rials
Miscellaneous		2000 rials
Total		12000 rials

Compounded yearly at 15% for 10 years 12000 x 4.046 = 48552 rials
Cost of planting forages for 5 years 5000 x 5 = 25000 rials

Maintenance for 10 years	2000 x 10 =	20000 rials
Total		93552 rials
Benefit to cost ratio,	477500 : 93552 =	5.1

It should be emphasized that while the wheat, straw and hay prices have tripled since 1985, construction and maintenance costs have doubled; Therefore the BCR has also increased accordingly.

Low Rainfall Area

Leguminous forages have not been introduced into the GBP so far; therefore, the fields are left in fallow for alternate years. Furthermore, our yield data cover only one season.

The initial costs of constructing FWS systems in the GBP are the same as those reported for the JC. However, installation of rock and cement chutes noticeably increased the costs per ha.

Benefits (Per ha):

Barley: 700 kg yr^{-1}	@ 50 rials kg^{-1}	35000 rials
Straw: 1050 kg yr^{-1}	@ 10 rials kg^{-1}	10500 rials
Subtotal		45500 rials
Total benefits from barley + straw for 10 years (5 years in fallow)		227500 rials

Costs (per ha):

Surveying	@ 5000 rials hr^{-1}	1000 rials
Bulldozer rental	@ 3500 rials hr^{-1}	7000 rials
Supervision		2000 rials
Miscellaneous		2000 rials
Chute construction		18000 rials
Total		20000 rials

Compounded yearly at 15% for 10 years	20000 x 4.046	= 80920 rials
Maintenance for 10 years	2000 x 10	= 20000 rials
Total		100920 rials
Benefit to cost ratio,	227500 : 100920 = 2.2	

CONCLUSIONS

Considering the very high price of wheat, barley, straw and hay in Iran, installation of FWS systems for production of these commodities is very feasible. The benefits,particularly when leguminous forages are included in the rotation, are so high, that theoretically, even the yearly reconstruction of the whole systems is economically feasible. If other benefits, such as artificial recharge of groundwater, flood mitigation, and soil reclamation are taken into account, the BCR would become much higher than the reported figures. The current commodity prices and the impending water shortage for agricultural production make FI more feasible indeed.

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OPPORTUNITIES FOR RAINWATER CISTERN SYSTEMS IN RURAL ECONOMIC DEVELOPMENT

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ABSTRACT

Lack of sufficient supplies of safe drinking water plagues the development of rural communities. Selecting an appropriate system to supplement freshwater supplies depends on economic, social, and institutional components of the community. Rain water cistern systems are recognized as an effective, alternative means for providing safe drinking water to rural areas worldwide. Rural rainwater cistern systems are generally government initiated. Successful implementation, however, requires both community acceptance and community cooperation in the construction and use of the new systems. This paper examines the relationship between rural water supply systems and stages of economic development, and suggests opportunities for implementing rainwater cistern systems to meet rural development goals in Asian-Pacific countries.

INTRODUCTION

The United Nations (1990) recently assessed human development in 130 countries. The countries were ranked with a newly developed index based on life expectancy, adult literacy, and purchasing power. Among those rated as having low human development were

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Afghanistan, Bangladesh, India, Nepal, Pakistan, and Papua New Guinea. In these countries, a majority of the impoverished population resides in rural areas. Disease, low life expectancy, and infant mortality are serious problems. The severity of these problems can largely be attributed to poor or nonexistent sanitation facilities and insufficient supplies of safe drinking water. In these poor countries, millions of people are without access to an adequate supply of safe drinking water. The drinking water needs of these and other Asian and Pacific Basin countries are displayed in Table 1.

TABLE 1. RURAL DRINKING WATER NEEDS IN SELECTED ASIAN AND PACIFIC BASIN COUNTRIES

Country	Rural Drinking Water Needs		Total	
	Population (%)	Population (millions)	Rural Population (millions)	Per Capita Income ($)
Nepal	93	12.37	13.30	130
Afghanistan	92	11.73	12.75	170
Papua New Guinea	90	2.24	2.49	650
Thailand	88	33.68	38.27	590
Sri lanka	86	9.18	10.68	230
Burma	84	20.24	24.09	160
Pakistan	83	46.91	56.52	270
Indonesia	83	88.98	107.20	380
Vietnam	80	33.11	41.39	150
Solomon Islands	76	0.15	0.20	430
Philippines	67	20.07	29.95	600
Malaysia	34	3.29	9.68	1320
India	33	162.86	493.50	190
Bangladesh	30	23.23	77.43	100
Fiji	26	0.10	0.40	1690
Western Samoa	15	0.02	0.13	na
Tonga	na	na	0.05	460

Source: World Health Organization, 1981.

A safe and reliable supply of water is critical to rural development. In response to an overwhelming need for an improvement in worldwide health conditions, the United Nations launched, in 1980, a global effort to provide all people with a safe and adequate supply of drinking water. The United Nations General Assembly proclaimed 1980-1990 as the International Drinking Water Supply and Sanitation Decade. This paper examines drinking water needs in Asian and Pacific Basin countries, and assesses the potential of alternative supply systems for meeting national development goals. Rain water cistern systems of various types are proffered and discussed.

WATER SUPPLY DEVELOPMENT

System selection and implementation

Economic conditions will restrict the choices of water supply systems available to rural communities without heavy financial assistance. The organizational structure of the community, the technical sophistication of the system, and the capabilities of the community members should be considered when selecting a system. The administration, operation, and maintenance of a rural water supply system must, of necessity, rest upon the users. Rationing, for example, may be required in the short term to assure adequate supplies throughout the year. Also, systems must be maintained regularly to assure long term reliability and safety. Thus, both community factors and system factors are critical in selecting a new source of water supply.

The success of a newly implemented system will depend on the cooperation of individuals and the support of the entire community. Ideally, a government representative should meet with the community leaders to instill community understanding, cooperation, and support. As part of the implementation process, community members should be exposed to good health practices to learn the importance of clean water and sanitation. Selected individuals can be trained in the construction methods and can direct other community members in the actual construction process. In this way, community organization is fostered and progress toward community self reliance is expedited. Additional support from the government in helping to locate and develop reliable supply sources of construction materials can be very fruitful.

Alternate water supply systems

In the poorest communities, water is fetched from a nearby stream or lake and carried by hand to the location where it is needed. Hand carrying of water extracts a heavy toll on the time and energies of community members and, in the process, impedes their opportunities for attaining economic progress. In these areas, water shortages due to droughts are frequent. Although conservation measures could mitigate the severity of an impending drought, the common property nature of the water supply discourages conservation. With water, as with all common property resources, individuals have no incentive to use the water more efficiently. Hence, when water is available, it is used in low valued activities (eg. washing, agriculture), and wasted through spillage and evaporation.

More developed water systems, such as shallow wells and stand pipes can provide communities with a convenient and reliable supply of drinking water. With these types of systems, the distance that the water must be transported is generally much shorter, and the supply is more abundant. Because the water needn't be carried as far, less is lost to spillage and evaporation. Also, in the event of a drought, the supply is more easily rationed. Like other systems supplied by surface and ground water, however, these systems are subject to contamination if local sanitation facilities are inadequate. Filtration and water purification technology can be adapted, but the investment, operation, and maintenance costs are often prohibitive.

The modern water delivery systems that supply the urban public are, understandably, highly desired by rural communities. A public water supply would most certainly satisfy rural needs for a safe, convenient, and reliable supply of drinking water. The high capital costs and sophisticated maintenance and administrative requirements of these systems, however, rule them out as inappropriate. A brief description of alternative drinking water supply systems is displayed in Table 2.

TABLE 2. ATTRIBUTES OF DRINKING WATER SUPPLY SYSTEMS

Type	Cooperative Effort Required	Per Capita Income Required ($)	Source of Water
Minimal/survival	none	<<50	Any
Fetched water	none, team	50-150	Stream, ground, lake,
Rainwater catchment	none, team	150-300	Rainfall, fog drip
Shallow well	none, team	50-300	Ground
Stand pipes	team	300-500	Ground, surface
Public supply	community, city	500+	Ground, surface, stored

Source: World Health Organization, 1981.

RAIN WATER CISTERN SYSTEMS

Rainwater cistern systems can and have played a major role in the growth and development of rural communities. Cistern systems tend to be successful for several reasons. Among alternative water supply systems, rainwater cistern systems are one of the most affordable. With minimal financial assistance, even the poorest communities can acquire and benefit from a rain water cistern system. As part of a program to facilitate rural development, low interest government loans can be used to help villagers overcome the initial construction costs.

Cistern systems require little or no outside materials or expertise. They can be built with local materials, local construction methods, and local labor. Thus, rainwater cistern systems are efficient. Government sponsored training programs can be used to teach community members how to construct their own a rainwater cistern systems. The trained personnel can in turn instruct other community members. Roof catchment systems are particularly convenient for community members in that they provide water on-site, at the point of use. This eliminates the need to fetch and transport water resulting in a significant human savings in time and energy. Most importantly, the water collected is generally very clean. In laboratory tests, cistern water samples have been found to be free of fecal bacteria.

Pond collection systems and used containers are the least expensive storage facilities. Storage of these types are already commonplace in many areas. As communities become more prosperous, or as their demand for water increases, cement and ferrocement jars can be installed to upgrade an existing collection system or to initiate a new one. The advantage of cement and ferrocement jars, in addition to their low cost, is that they can be fitted with tight lids (to keep debris out) and with taps or pumps (to prevent contamination from dipping). Their larger dimension and unique shape makes visual inspection and simple maintenance relatively easy.

As communities develop, increase their income, and become self sufficient, they can expand their surplus water supply by investing in additional collection and storage systems. The expanded systems may comprise replicates of the initial system. Alternatively the community may elect to upgrade to a system that is larger, more sophisticated, or composed of higher quality materials. System choices include: brickwork, sheet metal, reinforced concrete, fiberglass, and redwood. The affordability, design simplicity, and operational ease, of rain water cistern systems make them an attractive alternative for supplying developing rural communities with much needed fresh drinking water. A listing of various types of rain water cistern systems is displayed in Table 3.

TABLE 3. ATTRIBUTES OF RAIN WATER CISTERN SYSTEMS

Type	Cooperative Effort Required	Per Capita Income Required ($)	Unit Cost ($/m³)
Ponds	none	<<50	<10
Used Container	some	50-150	<10
Cement Jar	none, team	150-300	10
Ferrocement (jar or tank)	none, team	150-300	15+
Brick Work	team	250-300	25+
Sheet Metal	team	500-1000	100
Reinforced Concrete Tank	team, contractor	500-1000	150
Fiberglass	factory supplied	1000+	160
Redwood	contractor	1500+	250+
Public supply	government	500+	200+ (per household)

Source: World Health Organization, 1981.

Large scale development of rural rain water cistern systems was recently initiated in Thailand. Thailand government established a national policy to supplement rural drinking water supplies with rain water cistern systems as the springboard project to develop rural areas. Extension agents, from the regional university in Thailand, trained villagers to construct and maintain cement jar systems. The newly trained villagers were then sent to villages to work with local teams. In Thailand, the initial rain water cistern systems were the centuries old, clay jars. The size and shape varied from one location to the next. Cement jars have gradually begun to replace the old clay jars. Through this community development, the 2000 l cement water jar has become standard. The 2000 l size, with careful usage, can supply a family of seven through the entire the six month dry season.

The Thailand water development project was financed through a revolving fund of consecutive two year loans. To date the program has been successful. Rural economic conditions have improved and loans have been repaid. Villagers, appreciative of the convenience afforded by stored rainwater have continued, on their own, to enlarge and expand their home storage systems. With the program, villagers worked cooperatively and essentially solved their drinking water problems. The strong community support fostered by the water development project has helped the government launch additional rural development projects. Projects to improve school systems, repair county roads, and construct health care facilities are well underway (Hewison and Tunyavanich, 1990).

SUMMARY REMARKS

Rain water cistern system offer a low cost, practical means for improving both the supply and quality of public drinking water in rural areas. The supplemental supply of clean, fresh water can help reduce disease transmission, curb infant mortality, and increase longevity, thereby promoting human development. Rain water cistern systems can also spawn economic development by venting a supply of human labor that would otherwise be expended obtaining and transporting water. Selecting the appropriate water supply system for a community should, in any case, take into consideration community needs, system costs, construction materials, community support, and operation and maintenance requirements. As part of a government initiative to improve the quality of life in rural areas, rain water cistern systems can play an important role.

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A METHOD OF ECONOMIC APPRAISAL OF RAIN WATER CISTERN SYSTEMS AS APPLIED TO HIGH-RISE BUILDINGS

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ABSTRACT

The revival of Rain Water Cistern Systems (RWCS) and their adaptability for application in high-rise buildings are of relatively recent origin. A prime mover for acceptance of RWCS in high-rise buildings by both society and any water authority is to establish the economic viability of such systems. In this paper, the capital and operating costs for an RWCS in high-rise buildings are considered. The benefits are limited to savings in water utilized and the deferring of capital-intensive schemes due to this saving. The methodology used for the latter is the "Unit Cost of Leakage" approach. A typical case study is costed in the Singapore context to establish the net benefits that can be reaped by adopting such RWCS in high-rise buildings.

INTRODUCTION

The revival of RWCS which has come about within the last two decades has been exemplified in the four International Conferences on Rain Water Cistern Systems. The success of RWCS can be largely attributed to its applicability and adaptability to developing countries and, most important of all, its economic viability. The benifit-cost ratio is all the more important in the case of RWCS which are being adopted to high-rise buildings where there are existing water supply systems but the rain falling on roofs is going to waste. The main objective of this paper is to study the costing method of such an RWCS for high-rise buildings where rainwater is used as a supplementary source and to appraise the economic viability of the system.

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MAJOR FACTORS INFLUENCING THE UTILIZATION OF RWCS IN TERMS OF ADAPTABILITY AND ECONOMIC VIABILITY

A methodology to develop an approach for the use of RWCS in developing countries has been exemplified taking into consideration socio-economic factors and the technological level of understanding of the populace (Appan and Lee 1987). This approach has also considered the need to build cheap RWCS using indigenous material wherever possible.

Besides simplicity and adaptability, the overall cost of RWCS is a major factor in the utilization of RWCS. Economic systems which are largely influenced by materials used for cisterns have been described (Vadhanavikkit & Viwathanathepa 1986, Thiensiripipat 1986, Lee et al 1987). Detailed breakdowns of the various components in a simple system have also been provided and, in some cases, costed (Office of Health 1984, Hayssen 1986) In case studies in different countries, the relative cost of such systems against existing modes of conveyancing rain water have been exemplified (Morris et al 1984, Somashekar et al 1987, Geselbracht 1987, Latham & Schiller 1987).

The feasibility of utilizing RWCS in high-rise buildings has been of more recent origin and has been pursued in terms of group of structures in urban areas and the collected water was proposed to be used only for toilet-flushing. (Ikebuchi & Furukawa, 1982). A dual mode of supply (DMS) has also been proposed in high-rise buildings so that rainwater can be used exclusively for flushing and the conventional supply will be made use of only when and if the rainwater supply is not available (Appan et al 1987). Cost estimates for such systems In this system in a block of high rise flats including the details of computation of the different components are detailed below.

COSTING METHODOLOGY OF RWCS ADOPTED FOR HIGH-RISE BUILDINGS

Classification of high-rise buildings

In water supply systems for high-rise buildings, water can reach the top most floors directly in case of high-pressure supply. But such systems are generally avoided as the pressure in the watermains will have to be maintained at a very high level especially when the buildings are very tall. In most cases, water supply system can reach the first four to six floors and beyond this there is the need to boost the water pressure to reach the top most floor either directly or through a storage cistern. Classification can be arbitrarily made to classify buildings as follows:

Low-rise	1 to 4 storeys
High-rise	5 storeys and above

Typical RWCS in high-rise building

To cost the RWCS in a high-rise building, it is imperative that some assumptions or computations be made with regard to the system to be adopted, the sizes of the units and other features, some of which are as follows:

(a) Since the prime criteria is to collect roofwater, some light roofing is provided above the roof slab. This roof could be sitting on a reinforced concrete or steel structure and be so designed as to maximize the collection.

(b) A cistern of optimum size has to be specified. It is to be made of approved material and acceptable cost.

(c) There is an appropriate type of dual-mode supply system including appropriate piping incorporated in the RWCS.

(d) Structural computations should be made to ensure that the additional imposed loads due to the RWCS will not unduly hamper the structural stability of the existing high-rise building. Alternatively, some additional load-bearing members can be incorporated.

Rationale for costing

The capital costs involved along with the maintenance expenditure are compared with unit cost of saving that can be effected by incorporating a RWCS. This unit cost is inclusive of the savings effected by using less water from the existing source and also the deferred capital cost due to a decreasing demand pattern. Some details of these costs are:

(a) Capital Cost: This cost will depend on the type of roof structure, DMS selected and also the associated piping costs.

This total may be considered to be a fixed sum repayable over a period of the life of the whole system.

(b) Annual Operation Cost: The reduction in the relevant annual operating costs incurred by an undertaking in supplying water will consist of a reduction in energy charges for pump or boosting, a reduction in the quantities of chemicals used for treatment and, in some cases, a reduction in cost incurred for the bulk purchase of water. Due to difficulty and complexity of estimating most of these values, a simplified approach may also be adopted where it can be assumed that the reduction in annual operating cost is equivalent to:

(i) energy saved for boosting a volume of water to the required height in the high-rise structure.
(ii) cost of abstractable water by the RWCS.

(c) Deferment of Capital Costs for future schemes: The second element in costing is the "Unit Cost of Leakage" approach (National Water Council 1980) for deferring certain capital-intensive schemes. A reduction of water consumption will lead to a reduction in supply requirements for all subsequent years which will enable demand-related schemes to be deferred. The period of deferment will be the same for all these schemes. This concept is shown with reference to RWCS in Figure 1.

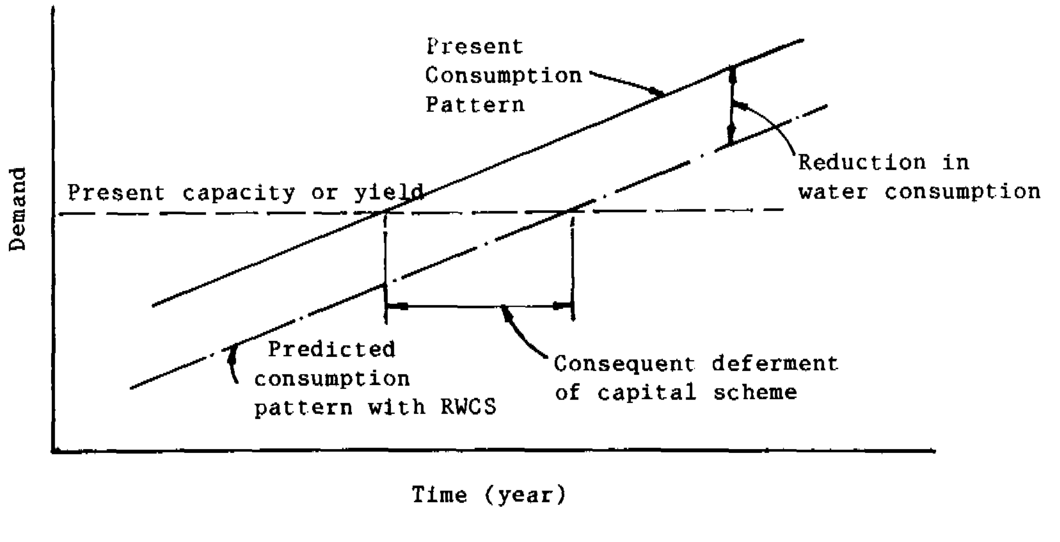

Figure 1
Deferment of Capital Costs by establishing RWCS

Formulation of costs

The investment for the implementation of RWCS consists of the initial capital outlay and operation and maintenance costs of the RWCS.

The initial capital outlay includes the costs of:

(a) cistern and associated fittings
(b) light-roofing including erection
(c) installation of DMS incorporating a rainwater priority system
(d) additional pipes including installation

The operation and maintenance expenditure arise mainly from the energy cost of pumping and maintenance of the electrical and mechanical components in the DMS system.

The cost of different types of cisterns and materials for roofing can be obtained from a market survey.

For the type of roofing structure to be adopted, construction problems (especially in existing high-rise buildings), life span, maintenance, erection problems etc are factors that have to be taken into consideration.

Taking all these factors into consideration, the Total Capital Costs

$$TCC = C_c + R_a * C_r + C_{em} + C_p \qquad \text{Eqn. 1}$$

where C_c is the cost of cistern and associated fittings
R_a is the plan area of RWCS catchment (roof)
C_r is cost per unit area of roof
C_{em} is the material & installation cost of DMS
C_p is the cost of pipes and installation

The Annual Operation and Maintenance costs of the DMS can be calculated or estimated as a percentage of its initial capital outlay.

Hence, the Annual Operational and Maintenance cost of the DMS will be,

$$AOM = (p/100)\, C_{em} \qquad \text{Eqn. 2}$$

where p is the assumed percentage of capital outlay

The Total Present Worth (Grant et al 1982) of Total Capital Investment =

$$TCC + AOM\ (P/A,\ i,\ n) \qquad \text{Eqn. 3}$$

where P/A is the series present worth factor
i is the interest rate per interest period
n is the number of interest periods

<u>Benefits or Savings Due to RWCS</u>

The benefits of RWCS consist of savings due to the difference in annual operation costs and interest saved due to deferment of future schemes.

Cost of annual savings in water

$$C_{as} = C_w * V_w \qquad \text{Eqn. 4}$$

where C_w is the unit cost of water being supplied
V_w is the volume of water being saved/annum

Energy saving/annum in pumping

$$E_p = V_w\ H_w * E_c \qquad \text{Eqn. 5}$$

where H_w is height to which present water is pumped
E_c is unit cost of energy in (say) cents/Kwh

Therefore, Reduction in Annual Operating Cost = Eqn. 4 + Eqn. 5

$$R_{aoc} = (C_{as} \quad E_p) \qquad \text{Eqn. 6}$$

To calculate the deferment of demand-related schemes affecting a reduction in capital investment, most recently constructed water projects and their cost should be evaluated. Using the concept explained earlier on, the savings in interest due to deferment of capital scheme

$$I_{sd} = T_d * C_c \qquad \text{Eqn. 7}$$

where T_d is the period of deferment
C_c is the cost of the equivalent water project

Hence, the Present Worth of Total Benefits due to undertaking of RWCS = Eqn. 6 + Eqn. 7

$$= R_{aoc}\ (P/A,\ i,\ n) + I_{sd}\ i \qquad \text{Eqn. 8}$$

CASE STUDY

In a study undertaken for appraising the feasibility of RWCS incorporating a dual-mode supply system in Singapore. It was deemed that the average height of the block of flats was 12 floors, the occupancy rate was 4.8 persons per flat and 60 m^3 cisterns were to be used 1(Lim & Loh 1985). The percentage of population living in high-rise buildings was assumed to be 80% (HDB 1984).

(a) Selection of materials

From a market survey that included the cost of construction and installation of pumps, piping etc, the costs of cisterns was as shown in Table 1.

Table 1

Cost of 60 m^3 cistern and accessories

Material	Cistern	Accessories	Total
Concrete	S$ 3500	S$ 850	S$ 4350
Fibre-glass	S$ 19200	S$ 1000	S$ 20200
Steel	S$ 10000	S$ 1000	S$ 11000

The structure found to be most suitable for putting up a roof was deemed to be steel as it was the easiest to transport, erect and fabricate on site, had a long life span and had the least maintenance problems.

The materials considered for light roofing included light-concrete, tarpaulin, steel, fibre-glass etc. Some costs of light-roofing are given in Table 2.

Table 2

Cost of light roofing and accessories

Material	Roof Cost per m^2	Accessories	Total per m2
Klip-lok	S$ 14.95	10%	S$ 16.44
Spandek	S$ 20.45	15%	S$ 23.52

Based on the above survey, concrete cisterns and klip-lok roof seated on a steel structure were chosen.

Capital and Maintenance costs

Assuming a covered roof area of 1250 m^2 per block of flats, the detailed cost breakdown is as shown in Table 3.

Table 3

Capital costs for RWCS in S$ million

Cistern	Roofing	DMS System	Piping	Total	Operation & Maintenance
10.79	50.96	1.24	20.83	83.82	0.25

The annual operation and maintenance cost was assumed to be 20% of the initial outlay.

Total Present Worth
of capital investment = 83.32 + 0.25 (P/A, i,n). Eqn. 9

Benefits or Savings

The benefits are mainly due to savings in the volume of water used in conventional sources including operation and maintenance. Besides there will be deferment of capital and the associated interest. Details of the savings effected are outlined in Table 4.

Table 4

Benefits due to RWCS in S$ million

Water saved	Energy saving	Reduction in Annual Operating cost
3.09	0.3	3.39

The above figures are arrived at based on current treated water costs (PUB Annual Report, 1984) and assuming that water is being pumped to a height of 33m in high-rise buildings.

To calculate the deferment of demand-related schemes affecting a reduction in capital investment, the Sungei Seletar Dam and water treatment plant completed in 1983 were considered. The cost of the 135 Ml/d scheme was S$324 m (Southeast Asia Construction, 1985). Assuming that the annual growth of water demand is 5.27%, using the Unit Leakage Approach, it was computed that by installing RWCS in high-rise buildings, the period of deferment of a capital scheme would be 0.37 years and the savings in interest due to such a deferment would amount to 119.88 i.

Therefore, the Present Worth of total benefit due to RWCS (in million S$)

$$= 3.39\ (P/A,\ i,n) + 119.88i \qquad \text{Eqn. 10}$$

Comparison between Capital Investment and Savings

A suitable loan period of repayment and the most appropriate market value for interest rate may be selected. The cost of roofwater will be the difference of capital investment with benefit of RWCS divided by the rainwater collected during the period of repayment.

Using suitable parametric values and a loan repayment period of 20 years with interest rates of 10, 12 and 14%, the costs shown in Table 5 have been worked out.

Table 5

Present Capital Investment vs Benefits

Interest Rate %	Series Present Worth Factor	Present Capital cost ($S\$x10^6$)	Cost of Benefits ($S\$x10^6$)	roofwater $S\$/m^3$
10	8.514	85.95	40.85	0.398
12	7.470	85.69	39.70	0.406
14	6.623	85.48	39.23	0.408

CONCLUSIONS

(1) The methodology for costing and determining the economic benefits in RWCS adopted for high-rise buildings has been outlined and a case study described. There will always be a need to modify the model and make necessary adjustments to suit different locations and systems.

(2) The establishment of the concept of deferred capital expenditure has to be interpreted appropriately in terms of water schemes that, preferably, have been completed most recently. The deferred costs should be computed accurately to be a true reflection of the effective savings by such RWCS in high-rise buildings.

(3) The unit cost of water obtained from RWCS adopted to a high-rise building is shown to be economically viable and even cheaper than the existing conventional source.

(4) Even if the unit cost of water from the RWCS does not turn out to be less than that of the available systems, the utilization of roofwater that otherwise would go to waste has to be considered especially in societies where water demand keeps increasing and potential for water resources development is limited.

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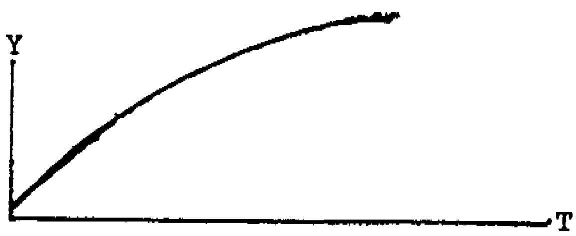
DERIVATION OF SOME OPPORTUNITY COST ANALYSIS SOLUTIONS FOR ECONOMICALLY OPTIMAL. TANK AND CATCHMENT SIZES IN RAINWATER COLLECTION SYSTEM DESIGN

Carmelo M. Gendrano*

I. For Constant Catchment Area Size

Assuming an RWCS with known catchment area A, constant and known demand D, and operating under known rainfall pattern and rainfall-runoff relation:

A. Simulating its operation for various tank sizes T using the relevant rainfall record will result in a range of total usable yields Y. Plotting Y versus T.



a(T){ A,D constant

Fig.1: A Y=a(T) Curve.

Denoting the average annual yield derived by dividing Y with the length in years of the rainfall record used an Y_{ay}, if the relationships between T and annual tank costs (depreciation, interest, repair and maintenance,etc.) C_T is known this a(T) curve can be transformed as illustrated below:

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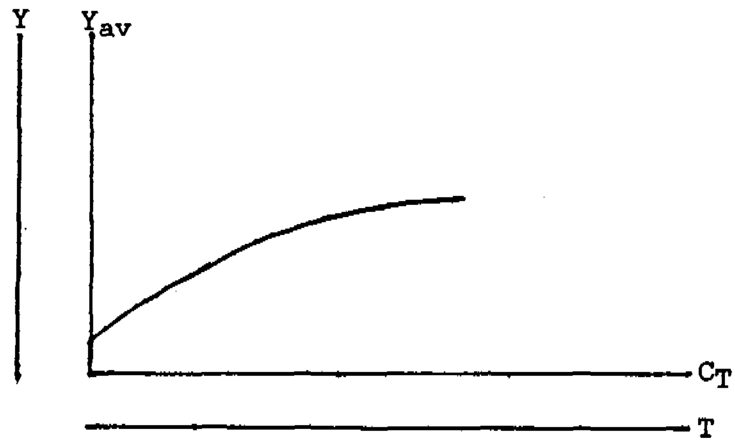

Fig.2: A $Y_{av}=a(C_T)$ Curve.

B. If the users of the RWCS have alternative sources of water, with unit cost of water C_{alt}, then T is optimal tank size T_o at the point P_o in the curve where $da(C_T)/dC_t=1/C_{alt}$:

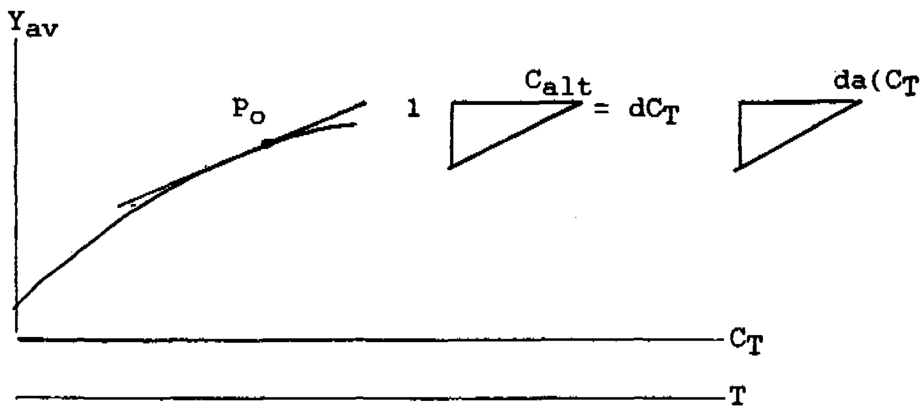

Fig.3: Graphical Representation of $da(C_T)/dC_T=1/C_{alt}$.

C. This method is tedious if used in toto, so the following techniques are suggested:

1. Generation and Use of Specific Curves

Instead of a $Y=a(T)$ curve for a given A and D, a $Y_{av}/A=a(T/A)$ curve which is more general purpose in nature can be generated. Using the relevant rainfall record, generating several such curves for a reasonable range of D/A values likely to be encountered in the field result in templates for ready transformation into $Y_{av}=a(C_T)$:

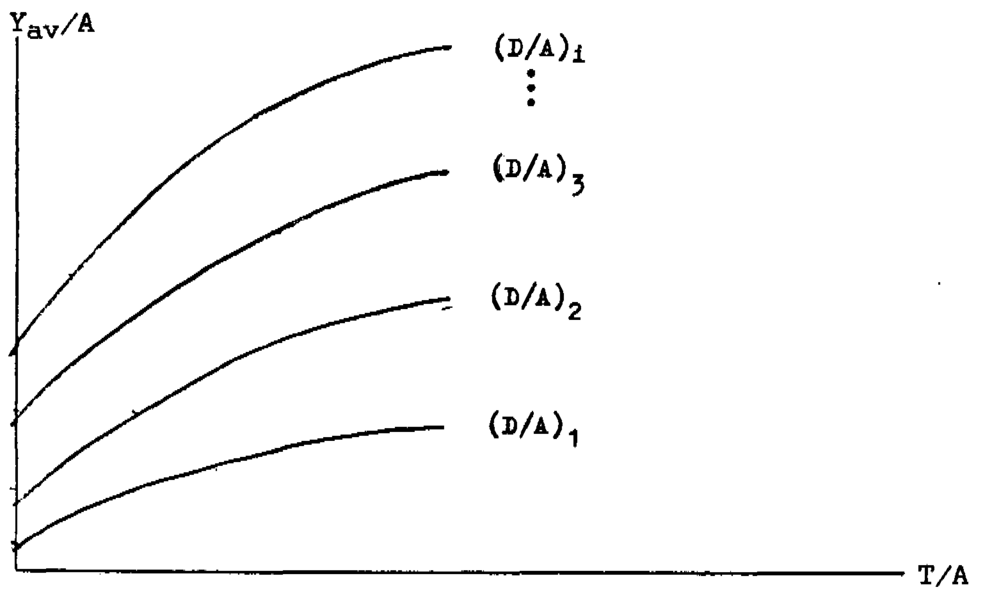

Fig.4: A Family of Specific $Y_{av}/A=a(T/A)$ curves Generated From a Rainfall Record

Conversion can be done by multiplying T/A, Y_{av}/A or D/A values of points by A.

solutions for interstitial values of D/A can be worked out by trigonometric interpolation.

2. Method Computerization

From rainfall records and rainfall-runoff relationships, such curve families can be generated by computer. Manipulation of the former can also be done in this manner. Specific curve families and $T\text{-}C_T$ relationships can be stored as a) general empirical equations (which can also be derived through computer programs); b) computer database files; and c) in graphical form for graphical solutions.

D. Aside from facilitating economically optimal solutions for RWCS tank design capacities, specific curves can also be used for evaluating Y_{av} of existing systems (e.g., reduce observed T and D into T/A and D/A; look up corresponding Yav/A and transform it to Y_{av}).

The curves can also indicate volumewise reliabilities of RWCS (i.e., $Y_{av}/Y_{required}$ at 100% satisfaction of demand). Conversely, tank capacities can be solved for desired volumewise reliabilities.

The foregoing method is not applicable to RWCS design for irrigation ,where water demand rates and opportunity costs in the form of crop yield losses due to water deficits vary with other factors like climate and crop stage. Also, being only as good as the reliability and length of relevant rainfall records,it does not reflect the effect of dry spells with return periods longer than the record.

II. For Variable Catchment Area size

In many RWCS situations, catchment costs cannot be ignored.For example, in Botswana the use of the ground and its lining with impermeable films to serve as catchment areas not only result in lining costs but also foregone installation on existing roofs for their express use as catchments also impute costs which are a function of catchment area size.

Consider, therefore an $a(C_T)$ curve:

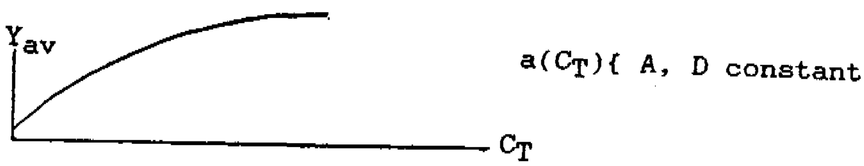

Fig.5: An $a(C_T)$ Curve.

If the annual catchment costs C_A are taken into consideration, a corresponding a (C_T+C_A) curve would be:

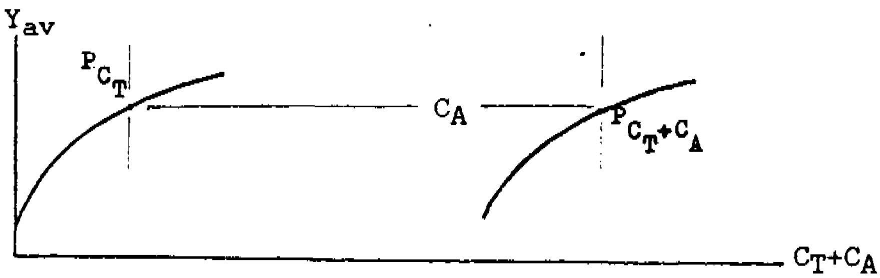

Fig.6: Comparison of an $a(C_T)$ Curve With an $a(C_T+C_A)$ Curve.

Note that all points in the right hand curve are displaced from corresponding points in the original by the amount C_A.

Generating an a (C_T+C_A) curve family from a specific curve family for a given demand,

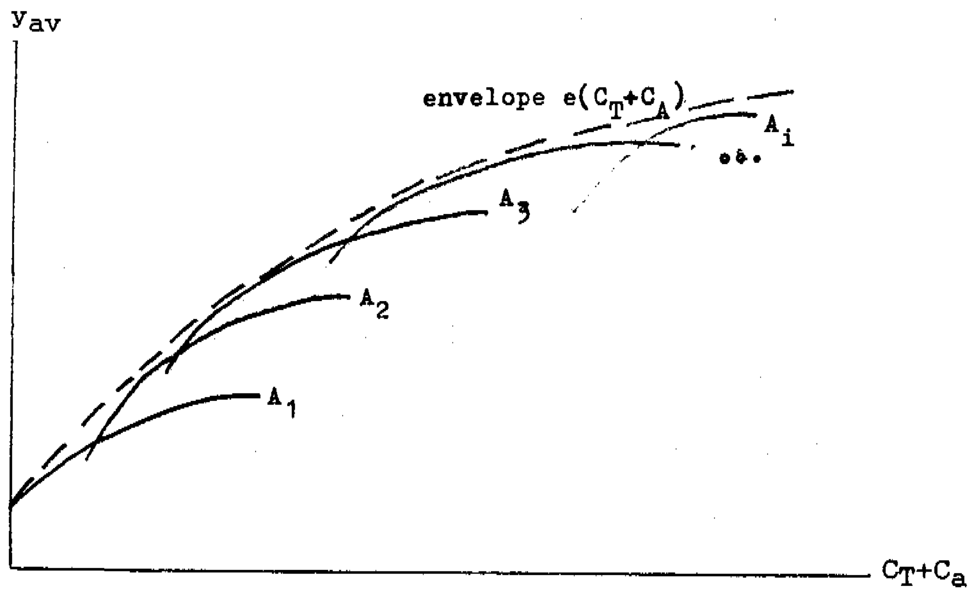

Fig.7: An $a(C_T+C_A)$ Curve Family.

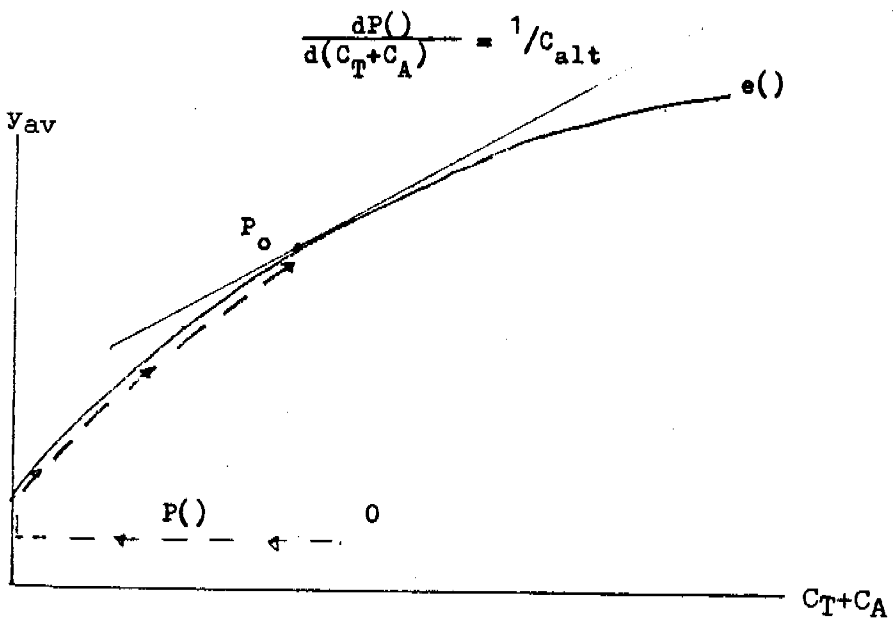

Fig.8: Path of Most Economical Variation of T and A Combinations.

It can be noted that an envelope curve $e(C_T+C_A)$ for this family exists: the points below this envelope are Y_{av}, C_T+C_A values for all possible corresponding combination of T and A.

The path curve $P(C_T+C_A)$ of most economical variation of T and A can be defined as the curve where $d(C_T+C_A)/dY_a$ is as minimal as possible, Starting at any point o below the envelope, the path is plotted thus:

The explanation for the above is as follows:

1) The most minimal value of $d(C_T+C_A)/dY_{av}$ is negative infinity. Thus p() moves parallel to the C_T+C_A axis until it hits either the Y_{av} axis or the envelope e().

2) If it hits the Y_{av} axis first, the most minimal possible value of $d(C_T+C_A)/dY_{av}$ becomes 0 so the path follows this axis going up.

3) Hitting the envelope in turn, since no point in the path cannot be above the former, the minimal $d(C_T+C_A)/dT_{av}$ becomes that of the envelope. When this occurs,the path is constrained to follow the envelope until $de()/d(C_T+C_A)=1/C_{alt}$. With P_o found, A_o and T_o can be determined.

In most RWCS situations, however, area is variable only up to a certain finite value A_{max}. In this case, p() may touch the A_{max} curve first before reaching P_o so it is constrained to follow the said curve until $da_{max}(C_T+C_A)/d(C_T+C_A)=1/C_{alt}$ to obtain real P_o,A-max.

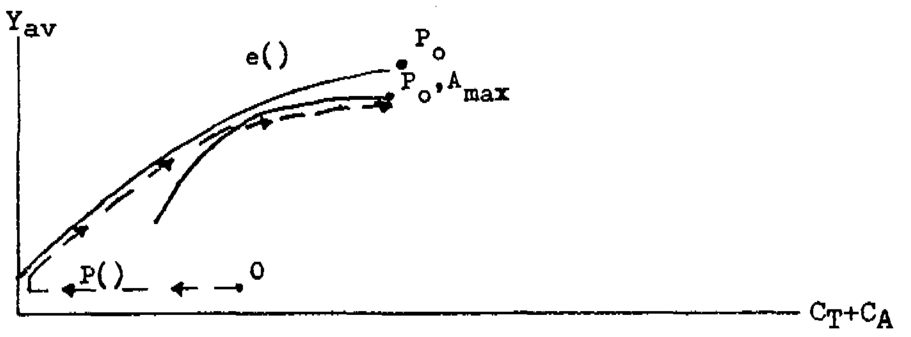

Fig.9: Obtaining P_o, A-max if Amax is Limiting.

The foregoing analysis presupposes that the envelope loci can be derived. This is easy to do if the curve family is expressed in an empirical equation, but tedious if the envelope has to be derived empirically or by optical inspection.

The following alternative analysis dispenses with the necessity of deriving the envelope:

1) At point P_o, the envelope is tangent to a certain $a(C_T+C_A)\}A=A_o$ curve and $da(C_T+C_A)/d(C_T+C_A)=1\ C_{alt}$

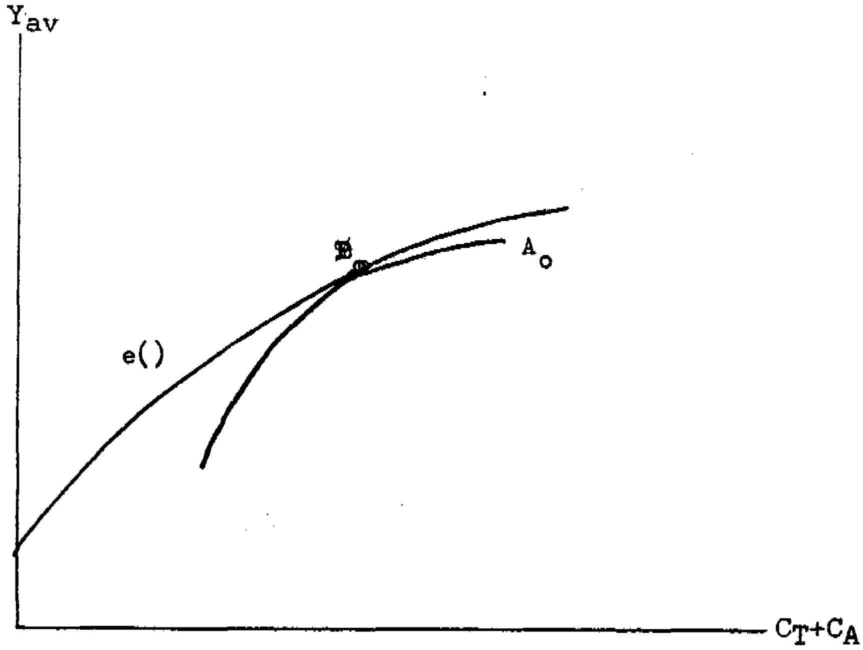

Fig.10: An $a(C_T+C_A)A=A_o$ Curve at P_o.

2) Defining a curve $g((C_T+C_A)\}$ all points in all a() curves where $da(C_T+C_A)/d(C_T+C_A)=1/C_{alt}$, then o is an element g() and g() touches e() at this point:

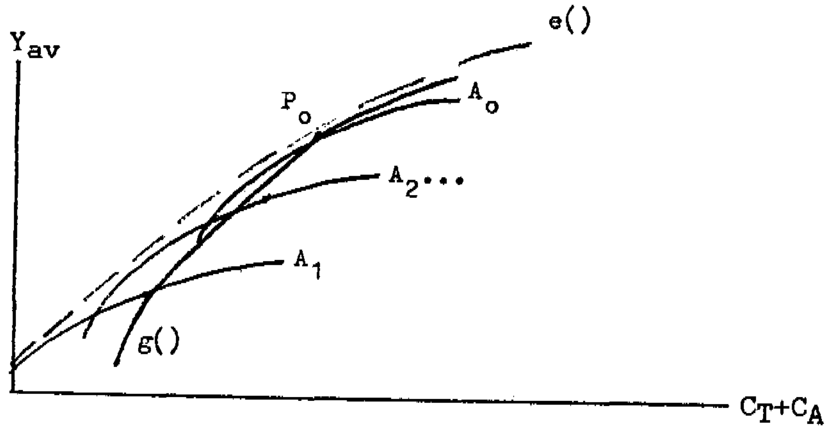

Fig.11: A g( ) Curve.

3) However, since g() cannot cross e() (it is made up of points from the a()curve family, which by definition cannot exit beyond the envelope), and since it is continuous beyond the Ao curve then g() must be tangent to e(), and dg()/d(C_T+C_A) at this point (P_O) equals de()(C_T+C_A)/d(C_T+C_A)=1/C_{alt}:

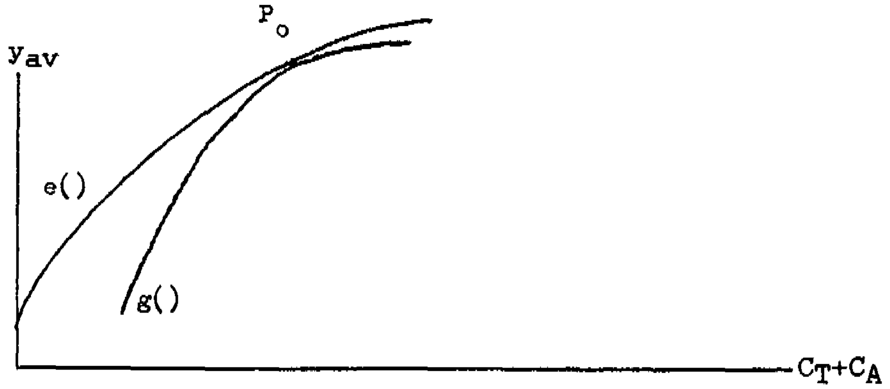

Fig.12: A g() Curve is Tangent to the Envelope at P_O.

Therefore, to find P_O:

1) synthesize the g() curve by finding all points p}da()/d(C_T+C_A)=1/C_{alt}:

2) locate the point at g() where dg()/(C_T+C_A)=1/C_{lt}.

3) as in the previous analysis, if corresponding Ao_O≤A_{max} then real P_O=P_O. Otherwise, real Po is found at the A_{max} curve where da()/d(C_T+C_A)=1/alt.

TSRESO1/ dd23

BENEFITS, FAVOURABLE SITUATIONS, AND COST OPTIMIZATION OF RAINWATER HARVESTING SYSTEMS

Dr.George MICHAELIDES*

Abstract

The benefits of rainwater harvesting from house roofs for domestic water supply are: the rainwater supply is next to the user,s house; it is compatible with the approach of "user participation" and "local resources" technology; its technical simplicity; it promotes water conservation; schemes are suitable for construction in stages and in conditions of uncertain initial data on water use; no land requirements; and, operation and maintenance are simple. Favourable situations for the development of rainwater harvesting systems are: dispersed settlements; existing house roofs; and high average rainfall (reduced catchment area required) and little seasonal or annual variability in rainfall (reduced storage volumes required) result in relatively low total costs. The cost of rainwater harvesting systems can be optimized through appropriate planning, design and construction of roof catchments, storage techniques, storage size, use of water. Costs can be saved by the use of unreinforced storage tanks, durable tanks and by planning storage into construction of new buildings.

1.BENEFITS

Rainwater harvesting (RWH) has a significant role to play for water supply.
The potential benefits of RWH (especially roof catchments) call for a closer investigation of this technique.

1.1 Proximity to user
The rainwater (RW) supply is next to the user's house and this is a very important advantage. The distance to the source is similar to that of a piped house connection. The time and human energy saved by not having to fetch water from distant sources can be used for

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other important development activities. (One important factor is how the time and energy saved in carrying water might otherwise be used).

WHITE et. al. (1972) studied the costs of obtaining water in East Africa by estimating the amount of energy used in carrying the water. The lowest costs per litre were found in households using RW.

PARKER (1973) quantified the effect of roof rainwater harvesting (R-RWH) systems on the time saved fetching water in a S.E. Ghana village. With the RWH system available then only a maximum of 11 minutes per person per day in the wettest months was saved over months with little or no rainfall because of a lack of storage capacity and under-utilisation of existing roofs by guttering. If the percentage of roof utilized were increased from 22 to 90 and the average storage capacity increased by a factor of 2.3 (from 167 to 376 litres), then the number of hours of fetching saved per household per year would increase from 72 to 163 hours. The days' supply of water saved per year would increase from 73 to 165. It was found that a benefit-cost ratio of 3 is achieved if 100% of the time saved was allocated to directly productive work, and a ratio of 1.7 if 57% of the time saved was allocated. The benefits were measured in terms of the value of people's time, with the costs in terms of the prices of the materials for the R-RWH systems used. It therefore follows that if general productivity of labour rises relative to the price of materials, the attractiveness of the systems will increase proportionately. In Parker's method, no account was taken of important benefits such as improved health, time allocated to household tasks and time saved by children.

1.2 Use of resources and development process

The fact that RWH has been used throughout history indicates that it can be kept simple. It encourages self-help projects and self-reliance, which constitutes a substantial step towards the development objective. It is compatible with the approach of "user participation" and "local resources" technology (MICHAELIDES AND YOUNG, 1984). With RWH, it is possible to use extensively local materials, equipment and skills. In contrast, large complex systems would require the simultaneous mobilization of vast quantities of resources, the importation of materials and expertise, and loss of precious foreign exchange. Large tanks built with manufactured or imported materials may cost more per unit volume than smaller tanks built with locally available materials (KELLER, 1982). Additionally, what the locality offers can be upgraded by setting up small local industries or training local people. For example, in kola, kenya a workshop makes water jars (BYRNE,1983). Rural employment is promoted. RWH is a relatively attractive option where the organizational infrastructure does not exist to make arrangements for public works.

1.3 Technical simplicity

RWH systems are simple to design, construct, operate and maintain, and can be built rapidly.

1.4 Water conservation

RWH promotes water conservation. Owners dependent on R-RWH for the most part use less water than city dwellers.

1.5 Incremental increase in water quantity

RWH schemes are suitable for construction in stages and in conditions of uncertain initial data on water use. An example is water jars. Jars may either be installed individually or by connecting jars to one another by a pipe.

1.6 Land requirements

Most of the R-RWH systems use the existing residential rooftop areas as a catchment area.

1.7 Operation and maintenance

RWH is economically feasible on a long term basis. Operation and maintenance are simple and breakdowns are rare. RWH promotes energy conservation; no fuel or power is consumed.

No pumping is required when harvested RW is stored above ground and minimal hand pumping when stored underground. No or limited water treatment is employed in RWH systems.

RWH may be considered as socially acceptable because it is of traditional origin and it is under the householder's own control. According to COTTON (1986), a major advantage of RWH is that it can be operated on a household scale. The maintenance of communal rural water supply facilities presents tremendous problems to the institutions involved and any step which reduces this burden is an important advance; COTTON believes that it is perhaps in this respect that household RWH systems have most to offer. Similar views are stared by GESELBRACHT (1984) for the case of Micronesia.

2. FAVOURABLE SITUATIONS

No simplistic guidelines are possible which would indicate the situations where RWH schemes are the most economic solutions to supply water. Every situation requires individual analysis. It is possible, however, to indicate factors which result in relatively low total costs in any specific area. But in such conditions (wet rural areas) the alternative forms of water supply are also likely to be inexpensive. RWH schemes will be attractive where the costs of exploiting alternative water supplies are relatively high, and in areas where limited fresh surface water or ground water exists. Such circumstances exist on many islands and isolated peninsulas.

2.1 Climate

High average rainfall (reduced catchment area required) and little seasonal or annual variability in rainfall (reduced storage volumes required) result in relatively low total costs for RWH schemes in a specific area. When compared to other water sources, RWH only becomes suitable in tropical and sub-tropical climates (KELLER,1982) which are characterized by wet and dry seasons, short torrential bursts of rainfall and very high potential evaporation rates often exceeding 2 m per year.

2.2 Settlement pattern

Rural areas in developing countries are frequently characterized by dispersed settlements. The lower the density of human settlements, the more favorably R-RWH compares to other means of water supply because distribution costs are negligible.

2.3 Available roofs

A substantial cost reduction can be realized if existing impervious roofs of houses and public buildings are utilized as catchment areas at no cost to the water supply system. In cases where there is a need to improve the roof catchment surface, such a step will achieve another goal: improved housing standards.

3. COST OPTIMIZATION

3.1 Planning

Though RWH systems are often individual systems, a joint community effort at the planning stage would optimize the quality of projects. Some technical knowledge on working out basic dimensions of schemes, on construction techniques and on features optimizing the quality of water (MICHAELIDES AND YOUNG, 1983; MICHAELIDES AND YOUNG, 1985) harvested is required. A district board might provide free advice on technical matters. Records on costs and performance should be kept.

3.2 Design
For a given rainfall pattern, water demand and desired reliability, various possible combinations of catchment areas and storage volume may be calculated, and the least cost solution chosen. Usually, however, the roof already exists (or other factors determine its size) and thus no investigation of alternative combinations of catchment area and volume is needed. Costs can be minimized by standardizing dimensions of systems for an area so as to use the same materials, tools and procedures in construction.

3.3 Roof catchments
The construction of the roof should be single-sloped, if possible, so as to save in gutters and the ridge. Sheet metal roofing is light-weight, requires little maintenance, gives good runoff, does not affect water quality and is durable except in coastal regions where it tends to rust because of salt action. Tiles can be produced locally and on a self-help basis. Tile roofs are very durable and require a stronger supporting frame. Thatched roofs are less durable than corrugated galvanized iron sheets or tiles. Roof catchments made from cement, bituminous paper and sisal-reinforced materials are in use but are not yet common. Fiber reinforced cement corrugated sheets are economically promising (UNIDO, 1978).

3.4 Storage techniques
Generally, the storage unit is the most expensive component of the RWH system. A wide range of construction methods and materials for building storage tanks exists. Research is required to determine the optimum solution for any given conditions. Investigations should include the mechanical and physical properties of reservoirs of different capacities, shapes, materials, reinforcement and thickness of walls. Research is also required on the use of indigenous materials, local availability and cost of materials and the possibilities of involving the local people in construction.
A useful proposition would be to tabulate and quantify all materials, their durabilities, tools, labour and time required for building of each alternative RWH procedure or system over a range of catchment areas or storage capacities. These lists would then be supplied to the prospective promoters of water supply projects who would put unit and total prices for each method or system in

accordance with their particular situation and eventually make a choice. Moreover, the effect of the use of a method on the whole economy of the area or country could be considered and, if necessary, some materials could be subsidized or others taxed.
When values are quoted in a unit of value like the dollar, then data (in the literature) which compare costs of different schemes built in different parts of the world at different times, is of limited significance. Valid comparisons could be offered by: a) comparisons based on more fundamental assessments;
and b) comparison for groups of data published for the same place at the same time.
An example of a fundamental assessment was offered by WHITE et. al. (1972). Their method was based on estimating the amount of energy (and consequently the cost of food needed to supply this energy) and time required to carry water. Such a method is, however, suitable for comparing different water supply methods. When using the literature to draw conclusions about least cost solutions of storage techniques, then groups of data are acceptable. Such data is shown on Table 1. Even so, most of the values shown do not include labour costs. (Note: not available in the references; in some cases unskilled labour is provided by owners of systems). Others include transport of materials, formwork or even gutters. Thus, not all costs are comparable. According to the results of the research project at Khon Kaen University in Thailand (VADHANAVIKKIT,1984), it has been found that then newly developed ferrocement and interlocking-mortar block tanks are less expensive than the bamboo reinforced concrete tank. Furthermore, the latter requires steel formwork which is very expensive ($870 for one set). The ferrocement tank is slightly less expensive and requires less skill to build that the brick tank. The interlocking mortar-block tank is the least expensive tank (as compared to steel reinforced concrete, bamboo, bricks and ferrocement) in the Thailand case (VADHANAVIKKIT, 1984) but its long term behavior is uncertain.
Water jars are probably the least expensive storage vessels (See Table 1). The literature, however, does not quote prices for large cement jars. Conventional methods of construction, using steel or reinforced concrete, can accommodate a great range of storage capacities but these generally tend to be relatively expensive (See Table 1).

3.5 <u>Unreinforced storage tanks</u>
Cement jars, granary baskets and cast concrete rings can be promising. Cement jar capacity can be as great as 10 m^3 if reinforced and 1 m^3 if unreinforced (NISSEN-PETERSEN, 1982) A tank

using a granary basket of woven sticks as a built-in framework should not exceed 3.5 m^3 (NISSEN-PETERSEN, 1982), The maximum capacity of a tank made of unreinforced concrete rings is 4.25 m^3 (WATT,1978). Unreinforced tanks can decrease costs.

3.6 Durability

The durability factor is significant. Tanks that last longer save in maintenance and replacement costs. According to OMWENGA (1984), a concrete block tank lasts 50 years, a granary basket 20 years and a galvanized iron tank 5 to 10 years. Moreover, unlike metal tanks, cement tanks can be repaired easily.

3.7 Size

As tanks increase in volume, their ratio of wall and cover area to capacity decreases. Thus, larger tanks will tend to have lower materials costs per unit volume of capacity, for example the 71 m^3 concrete block tank in Table 1. Whilst large tanks show economies of scale, with smaller tanks, there is more scope for using local materials and cutting costs that way.

3.8 Use of water

Small storage tanks and consequently less expensive systems may be built if the RW supply only satisfies partial needs. For example, in regions with sufficient, slightly brackish groundwater or surface water not suitable for drinking without prior treatment, RW can be utilized for drinking and cooking only.

3.9 Storage into new buildings

Costs of tanks may be reduced by planning storage into construction of new buildings.

TABLE 1 COST OF ALTERNATIVE TYPES OF STORAGE

Tank counting T=Transport L=Labour F=Formwork G=Gutters	Volume (m^3)	Materials cost U.S. $ per tank	per m^3	Place and date	Source
Plastic	1.0	117	117	Thailand	Vadhan-avikkit 1984
Steel	1.5	91	61		
Steel reinforced concrete	9.0	235	26		
Bamboo reinforced concrete	9.0	149	16		
Bamboo reinforced concrete	15.0	186	13		
Bricks	12.0	179	15		
Bricks	14.5	198	14		
Ferrocement	12.0	170	14		
Interlocking mortar block	9.0	115	13		
Interlocking mortar block	12.0	141	12		
Mortar jars			8-13		
Steel drum	0.17	2.50	14.90	E. Africa 1969	White et al, 1972
"Tin" tank	1.4	39-84	28-60		
Cement mortar jar	0.25	0.50	2	Thailand, 1974	Watt, 1975
Pottery jar	0.3	5	17	Thailand, 1973	
Cast concrete ring (not F)	4.2	40	9.4	Thailand, 1977	Watt, 1978
Corrugated galvanised iron (not T)	4.5	138	31	Kenya	Omwenga 1984
Corrugated galvanised iron (not T)	9.0	255	28		
Granary basket (ghala) (L)	1.5	68	46		
Concrete block tank (L)	5.0	309	62		
Concrete block tank (L and T and other sale conditions)	5.0	619	124		
Cement pot	0.3	1	3.3	E. Africa	McDowel UNICEF 1976
Cement pot	3.0	10	3.3		
Corrugated metal	4.0	100	25		
Oil drum (used)	0.2	5	25		
Ferrocement (G; not F)	9.0	62.50	6.90	Zimbabwe, 1973	Farrar and Pacey, 1974
Galvanised corrugated iron	9.0	112	12.50	Zimbabwe, 1973	
Partially buried concrete block (G)	71.0	260	3.70	Ghana, 1973	
"Sand-sausage" open tank (from Ground catchment)	45	75	1.67	Botswana, 1973	

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RAINWATER HARVESTING COSTS AND BENEFITS

Sampson K. AGODZO

ABSTRACT

In this paper, it is argued that rainwater as an important alternative source of community water supply cannot only be viewed in terms of cost justification but also in terms of such unquantifiable benefits as time savings and improved hygiene. An attempt has been made to provide guidelines for cost calculations of rainwater harvesting projects, bearing in mind that when resource constraints are applied to the selection of an appropriate community water supply technology, it may turn out that improvement of traditional sources is the only feasible option.

1.0 INTRODUCTION

One of the aims of the United Nations INternational Drinking Water Supply and Sanitation Decade was to provide reasonable access to safe drinking water for all people in the developing countries. Even though several countries made ambitious plans to do this, many are still very far from achieving their planned programmes mainly because of financial constraints.

Due to constraints on financial resources, "low cost" options were and still being sought to provide reasonable access to drinking water for all, where low-cost does not necessarily mean cheap technology but considered mainly on cost comparative basis to other water supply technologies.

Rainwater harvesting, identified as one of the low cost options for rural water supply, is still widely practiced in the world today and it is important to note that on some tropical islands, rainwater continues to be the only source of domestic water supply. Even though there have been a lot of bias towards groundwater exploration for rural water supply, rainwater remains potential alternative source of rural water supply. However, the community water supply technology chosen "should give the

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community the highest service level that it is willing to pay for, will benefit from, and has the institutional capacity to sustain" (Arlosoroff et. al., 1987).

2.0 COMMUNITY WATER SUPPLY COSTS

Before the start of the Water and Sanitation Decade (1981-1990),the World Bank (1980) estimated that assuming 100% coverage in both water supply and sanitation, the total cost for the Decade would run in excess of US$600 billion. Using a reduction of coverage to about 80% and putting more emphasis on community standpipes rather than the more expensive house connections, a second option of a total cost of US$300 billion was expected for the Decade which was a reduction by more than half the initial estimate. Biswas (1981) argued that this latter estimate was a gross under-estimation of the financial needs of the water supply and sanitation programme for the Decade since this amount only considered new installations and did not include costs for operation, maintenance and repair. The WHO (1980) also criticized this meager expected expenditure of US$300 billion for 10 years, saying that the Decade was not much more compared to the global military spending of US$500 billion a year.

The background information on the investment implications for providing safe drinking water for all has already revealed the difficulties in implementing community water supply projects in the developing countries. As earlier mentioned, there came up the idea of "low cost" community water supply technologies if there were any chance of providing reasonable access to safe drinking water for all people in the developing countries. Arlosoroff et. al. (1987) suggested that when resource constraints are applied to the selection of an appropriate water supply technology, it may turn out that improvement of traditional sources is the only feasible option. In this rare case, they suggested that no further comparison with other options is needed though in most situations, however, comparison is needed of several feasible options in which the costs and benefits expected from the different service levels vary.

3.0 RAINWATER HARVESTING COSTS

There are three most important rural community water supply options namely: (i) groundwater/handpump option; (ii) surface water/household connection or public standpipe option; and (iii) rainwater harvesting option. Sadly to note, government sponsored rainwater harvesting programmes are few whereas a lot of emphasis is rather placed on other options. On cost comparative basis, it may well mean that rainwater harvesting provides one of the low cost options as shown, for example, by experience from Thailand in Table 1. Surveys in Thailand showed that rainwater storage and capped shallow wells are the only facilities which consistently provide safe, potable water, and that treatment to improve the quality of water from other sources is not practical. Even though shallow tubewells are by far the cheapest form of domestic water supply in terms of the number of households served in Thailand, rainwater storage in jars is equally economic, costing about the same per household per year as a covered shallow well equipped with a pump.

Table 1: Costs of Rural Water Supply Options in Thailand (US$)

Type of system	Capital cost	Maintenance cost	Total annual cost	Households served	Annual cost/ household
Rainwater jar	19	0	2.50	0.31	8.15
Rainwater tank	245	1.85	29.00	1.00	16.00
Shallow dugwell without handpump	93	0	15.00	20	0.75
Shallow dugwell with handpump	540	93.00	165.00	20	8.15
Drilled deepwell with handpump	2660	93.00	440.00	20	22.00
Pond	1850	3.70	305.00	20	15.25
Weir	10000	18.50	1625.00	100	16.25

Source: Arlosoroff et al (1987).

Since it cannot be overemphasized that rainwater harvesting provides an important alternate source of safe, potable rural water supply for developing countries, there is the need not only to view it in terms of cost justification but also in terms of such unquantifiable benefits as time savings and improved hygiene.

3.1 Cost Elements of Rainwater Harvesting Projects

Rainwater harvesting involves interception, collection, conveyance and storage of rainfall. Depending on the type of catchment surface, a rainwater harvesting system can be classified as a roof catchment or ground catchment system.

Since their costs also differ, an attempt has been made to define the various cost components of both systems as shown in table 2 and this is meant to provide guidelines for cost calculations of rainwater harvesting projects. Detailed costs of materials and services for each cost element listed, however, needs to be worked out separately before applying the guidelines provided in the table.

Ground catchment systems are obviously more expensive than roof catchment systems because of the costs of land development in the former. Initial costs of owning a rainwater harvesting system may be too high for some families while others can afford the investment. In the case of the former, funding arrangements can be made through the low interest loans and grants from government and non-governmental agencies. Here, the issue of cost recovery and the willingness of the beneficiary to pay back loans becomes important if there is any chance of more people benefiting from the loans and grants.

3.2 Cost Recovery

Katko (1990) suggested a list of factors and the possible range of their effects on consumer's willingness to pay for water in rural areas of developing countries. Sense of ownership regarding a water point, privacy of drawing water, reliability of water supply and household income levels are some important factors that are likely to influence the willingness of the owner of a rain catchment system to pay back loans.

4.0 BENEFITS

Rainwater harvesting for community water supply provides some benefits which are immediate and highly visible. Sense of ownership and privacy regarding water drawing are important benefits to the user. Access to a convenient source of clean water brings time savings and reduced drudgery, leading usually to improved personal hygiene, better living conditions and better health.

Because people readily perceive the relationship between improved water supplies and time savings, the World Bank has placed increasing emphasis on the time saved in carrying water as one way of assessing benefits of improved supplies (Arlosoroff et. al., 1987). Irrespective of the precise value attributed to time, comparison of the estimated benefits from time savings with the calculated costs of a rainwater harvesting system can provide an indication of the usefulness of the technology.

Health benefits, on the other hand, can be realized in terms of

Table 2: Guidelines for Cost Calculations in Rainwater Harvesting Projects

System	Cost Elements	Unit Cost Calculation
Roof Catchment	Investment Costs	
	1. Storage tank/jar (cement and reinforcement)	Cost per unit volume
	2. Roof gutter	Cost per unit length
	3. Foul flush trap	Cost per unit volume
	4. Dowpipe/overflow pipe	Cost per unit length
	5. Sand and gravel (filter material)	Cost per unit volume
	6. Low-lift handpump*	Cost per unit machine
	7. Screen for downpipe and overflow pipe	Cost per unit area
	8. Technical Support Services	Cost per unit household
	- design of water harvesting system - training in construction - user education	
	Operation Costs	
	1. Roof, gutter, tank and foul flush trap cleaning	Cost per manhour used+
	2. Repair of gutter and pipe	Cost per unit length
	3. Repair of tank and foul flush	Cost per unit volume
	4. Repair of handpump*	Cost per unit machine
Ground Catchment	Investment Costs	
	1. Land development (clearing, grading, compaction or surface lining	Cost per unit area
	2. Collecting drain	Cost per unit length
	3. Silt trap	Cost per unit volume
	4. Storage tank	Cost per unit volume
	Operational Costs	
	1. Regrading and recompaction of catchment (if surface not lined)	Cost per unit area
	2. Repair of lined surfaces	Cost per unit area
	3. Repair of tank and silt trap	Cost per unit volume

*Investment in low-lift handpump is not necessary and should be considered only in the light of families that can afford. Alternatively, water can be drawn using rope and bucket. Applies in ground catchment system also.

+Labour provided by the user/owner can be ignored.

Note: Detailed materials and service costs must be worked out separately.

reduced medical care, improved productivity etc, even though improvement in community water supply through rainwater harvesting is not a sufficient intervention itself to improved health and quality of life.

5.0 CONCLUDING REMARKS

In government-run community water supply programmes in many developing countries, a rural community requires a certain minimum population to qualify for a borehole and handpump. It means that it is not everybody who needs safe drinking water that gets it. But with rainwater harvesting, anyone with some kind of shelter with the required roofing material can collect the rain and store in any quantity (Agodzo, 1987). The problem has always been with size of storage and cost effectiveness of individual household ownership.

There are clear advantages in individual household ownership in terms of operation and maintenance and long-term sustainability. Therefore rural water supply policies in many developing countries must actively support rainwater harvesting such that even housing policies for the rural community must take into consideration rainwater catchment and storage facilities. Since a substantial amount of the rainwater harvesting costs is taken up by the storage system, research efforts must be intensified to find cheaper but durable water storage tanks.

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FINANCIALLY SUSTAINABLE GRAVITY FED WATER CATCHMENT SCHEMES IN KENYA - "FOLLOWING A NEW APPROACH"

Janet K. Lugonzo-Campbell

INTRODUCTION

In 1982, the Canadian Hunger Foundation (CHF) carried out a study of village water projects in kenya to find out why they had such a high failure rate. Many of the projects studied had received donations from development agencies or NGOs which were used for the purchase and installation of materials. However, without a sound institutional framework, water would flow only for a short time much to the bewilderment of the donor, who would not understand why the project had `failed'. The result would frequently be an evaluation seeking technical flaws that excludes an assessment of the institutional aspects. Repairs or modifications would then be carried out for the technical flaws, but water would still not flow continuously. Eventually, the donor would become disillusioned and finally resign from the project.

The symptoms of institutional inadequacy were found to be:

- Poor Management skills
- Little or no organisational structure
- Lack of maintenance skills
- Absence of a sound financial plan of regular income and of administrative controls
- Absence of a sense of ownership of the water project by the community
- Ignorance of the skills and resources required to run a water project
- A 'charity' relationship between funding partner and the community groups.

It was clear that the institutional requirements of village water projects had not received enough attention. All parties concerned had grossly underestimated what is required for such projects to be

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successful and selfsustaining. It was apparent that a new approach was required. Thus the CHF embarked on the development of a new approach and used it to support a number of projects. In the case of the first CHF assisted project, the CHF commenced in 1984 and withdrew in 1987. By 1989, the group had a healthy bank balance, expanded their project by 100% and had built their own offices. It now serves as a model for other project development all over Kenya. It is the NGO which participated in the community's project not the other way round.

THE NEW APPROACH

This new approach has been developed and translated into a methodology with seven components. These are:-

- Establishement of the project by the community as an independent enterprise, owned and managed entirely by the community.
- Relationship of supporting agencies such as the CHF as a partner and investor covered by a joint venture agreement (i.e. not as traditional `donors').
- Registration of the project in the framework of a legally constituted society.
- Establishment of a business-like project management capability in the hands of the society with project manager and full-time employees.
- Establishment of the capacity for the Society to independently address and resolve all managerial, political, administrative and technical problems as when they arise.
- Establishment of a financially operation involving the payment of monthly water consumption tariffs.
- Provision for contribution from each member to establish a Society share capital fund.

The above components are fundamental and critical to the application and success of the new approach which makes rural projects self-sustaining and improves the community's ability to implement their own development initiatives in other sectors.

INITIATION OF A WATER PROJECT

A typical community water project is a long complex process spanning for generations in the life of the community. From initial inception, through its various phases of planning, construction, operation and expansion, the project must survive social, political, managerial, technical and financial hurdles if it is to achieve the long term goal of upgrading the quality of life of the community. The projects assisted by the CHF in Kenya are of this nature. All projects had been planned to operate indefinitely, with major replacements and expansions required at 10-15 year intervals. Plans are drawn up and designed by the Ministry of Water Development (MOWD) to cater for the expected population for the next ten years or so.

At the time of CHF involvement, the projects had not yet `taken' mainly due to lack of suitable institutional arrangements.

The point of CHF entry occurs after the community achieves the following:-

- Registration with the Ministry of Culture & Social Services (MCSS) as a self-help group with the intention of undertaking a water project.
- Design of the system is completed as per Ministry of Water Development criteria.
- Obtain an Abstraction Permit authorising the project to draw water from a source.
- Collection of initial funds.
- Construction of part of the system.

CHF the proceeds through the various steps with the group and work towards jointly developing the water supply system as an independent enterprise, run on sound business-like principles. These steps are set out in the following section.

CHF PARTICIPATION IN A WATER PROJECT

1. The CHF discusses and counsels the group committee over a period of several weeks or months, during which the community conducts a number of public discussions aimed at re- establishing their project with a firm legal framework and on sound business principles. Having only registered as a self- help group, CHF then assists the group to complete the requirements with the Government to become a legal Water Society. During this period, the Society's constitution must be established which is a long process involving much discussion with the community and CHF.

2. Signing of Joint Agreement
   A joint venture agreement is signed by both parties covering each party's commitments and responsibilities for the period of participation by the CHF in the Society's project.

3. Building the water system
   During an intensive period of activity each party contributes towards building the intake, main lines, storage tanks and distribution networks according to the signed agreement and project design. These activities relate to gravity-fed systems. There would be corresponding activities for other types of projects such as cisterns, dams, boreholes or shallow wells.

4. Complimentary Contributions
   CHF provides some of the materials and supervisory services. The Society contributes the rest of materials, all the labour for trenching, pipe laying, back filling and construction of tanks, and pays for all skilled tradesmen in the water system construction and the salary of a manager and accounts staff and plumber etc.

5. Training and Management Support
   CHF provides training in technical aspects, book-keeping and administration to the water Society project staff and management advice to the project Manager and Executive Committee. This phase continues concurrent with `Home Connections' following the completion of the construction phase.

6. Home Connections
   Home connections are only done when members have completed paying their dues. The dues cover the cost of pipe from homestead to the distribution line, meters, taps and a connection fee. In case of large gravity fed systems this connection period can take up to 5 years, depending on the number of members, and their particular circumstances, and notably on the number of connecting teams the Society can afford. A connection rate of 1-5 members per week is typical on these projects.

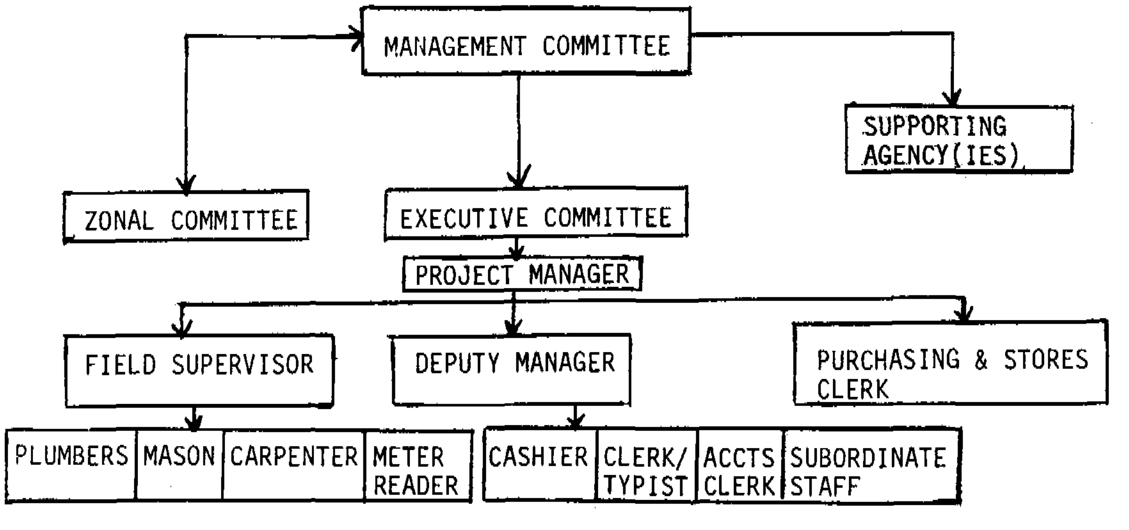
7. CHF Long-term Relationship with Water Society
   CHF reduces its direct participation in the project when the terms of joint venture agreement have been completed. At this point it is expected that five to ten percent of the members will have been connected and the Society would conduct an official opening to commission the operation of the project. Over the period of the agreement the CHF and the Society develop good working relationships.

   The relationship is not necessarily severed at the time of commissioning the project because CHF is often called upon for advice and provide training support. However, even with this extended relationship trough maintaining a monitoring role, the participation of the CHF in the water project of any Society is for only a short time period when compared to the long life of the project.

PROJECT MANAGEMENT ARRANGEMENTS

The groups that have their projects assisted by the CHF are registered as Water Societies under the Societies Act. The requirements for this registration are very exacting, including security checks on all named trustees and officials, thorough vetting of the constitution, particularly as regards to the ownership of the assets and safe guarding of the members' interests. This aspect of the institutional arrangements is a key factor in convincing the community members of the soundness of the project. The Society Officials can be held responsible in law for a number of aspects of the affairs of the Society and this emphasizes the seriousness of the persons responsible for the society's affairs. It also clarifies the question of who owns and manges the project. There is no question that the Society is responsible for the project and maintaining the required standards. It is then clear that the involvement of participating organiations such as CHF can only be conducted in a formal manner and must be based on appropriate written Agreements.

The chart below depicts project management arrangements for a typical CHF water project.



ESTABLISHING FINANCIAL VIABILITY

It is essential that each water project eventually is able to cover all its running expenses and overheads with funds generated by the sale of water. Since connecting members is a gradual process, there is a long period between commissioning the water system and reaching a break-even level. There are some identifiable stages of growth towards financial viability.

Stage I - Initial connections where there are insufficient consumers to cover monthly running costs.

Stage II - Sufficient consumers are connected to cover monthly running costs but not all overheads.

Stage III - There are sufficient consumers to cover monthly running costs and overheads thereby reach a financial break-even point.

Stage IV - There are sufficient consumers to provide a surplus thereby adding to financial reserves and to expanding the water systems.

As the Water Society progresses through these stages, greater degrees of financial viability are achieved. During the first two stages the Water Societies will adopt several practices in order to balance their income and expenditures. The Society will put into practice a combination of the following:-

- Draw working capital form their capital fund
- motivate members to pay up their share of capital contribution
- limit expenditures on controllable items
- phase staff build-up to an affordable level of cost
- employ connecting teams in balance with the rate at which members are paying for connections.

CHF experience in gravity fed projects is that it takes at least five years following commissioning before all the members are connected. The proportion of connections required to achieve financial viability varies from project to project and depends on population density, economic levels, and administrative efficiency of project management.

Village water projects are typically beset by many problems whether or not there is a partner NGO or donor involved. Generally, the more successful the project, the greater the variety of problems, because successful projects affect the lives of the entire community directly and everyone comes to depend on it. Typical problems include financial (tariff structures), social, political, planning, expansion, technical, managerial and distribution problems and combinations of all of the above.

CHF's role is not to worry unduly about such problems and not to try to solve them for the Society. Instead, CHF's role is to build up the capacity within the Society to enable it to address and resolve such problems when they arise. This is an important point which is fundamental to the New Approach.

When a problem arises during the operation of an established project, many well-intentioned agencies react by either offering to solve the problem, or show undue concern or embarrassment or offer money to resolve the issue. All of these reactions can ultimately be "Kiss of death" for the project. Form that moment on, the community does not consider itself responsible for its own affairs. The temptation to `step in' must be resisted at all costs. Though many projects assisted by NGOs and development agencies may be small and new, it is essential that the idea of the project should emerge from within the community. This starts life as a community project and should never be perceived as otherwise. throughout its life.

It is important to realise that the CHF principles of institutional development of New Approach to water project can be applicable to all community projects.

A typical agreement between CHF and a Water Society includes the following responsibilities which may be changed from time to time by mutual agreement:-

RESPONSIBILITIES OF CHF AND THE WATER SOCIETIES COVERED UNDER THE JOINT VENTURE AGREEMENT:

CHF - Finances bulk of the capital development expenditure, (including transportation of goods to the site) required for the project as designed by the Ministry of Water development.

- Provides technical staff to supervise and assist in the implementation of the entire project including the analysis of technical drawings the setting up of accounting management procedures and provide training required for the successful operation of the project.

The Society - Raise funds in cash and in kind on a self-help basis (harambee) for the establishement and furtherance of water project objectives.

- Employs the following personnel i.e. plumbers, pipe-fitters, mason, carpenters, etc during implementation for the efficient maintenance and operation of the water project.

- Assist in the location of a field office and accommodation in the area to be used by CHF staff working with the society.

- Permit the CHF Programme Officer (K) or his representative to attend all the society's Management Committee Meetings as an Ex-Officio Member.

- Provide the required local labour and materials e.g. sand, ballast, timber, etc for the construction of the water project system.
- Provide additional pipes required for home connections and other extensions not shown on the Ministry of Water Development technical drawing and plans.

AN EXAMPLE OF A SELF-SUSTAINING WATER PROJECT - "MURUGI-MUGOMANGO"

Murugi-Mugomango Water Project is one of the CHF assisted water project in Kenya which has undergone a lot of developments since the time of CHF involvement in 1984. In 1989, a study was carried out on Murugi-Mugomango Water Project to reviews progress and determine level of achievements. A new method of evaluation and monitoring community water projects was developed using Murugi-Mugomango as case study. The method involved compiling a score based on weighted assessment of the project in terms of :-

- Institutional Development
- Financial Viability

- Scheme Effectiveness
- Impact

This method has been applied to Murugi-Mugomango to assess the project as at late 1983/yearly 1984 when the CHF participation was just beginning and as at the end of 1990.

Institutional Development

Murugi-Mugomango Water Project is legally registered under the Societies Act. It operates under a set of strict society by-laws and constitution. It has 2097 registered household members out of which 1299 are connected with a tap and consuming water. The society has 13 members on the management committee who meet on a regular basis to oversee the management of the project. The project employs a staff of 18 under the directorship of a Project Manager.

Financial Viability

The project is financially viable and generates revenue from the 1299 connected and metered members who pay US$0.80 cents each for 30 cubic meters of water. Murugi-Mugomango is run following good management principles and sound financial procedures. As a result, the project is able to cover all its operation and overhead costs thereby making Murugi-Mugomango a self-sustaining rural water project.

Scheme Effectiveness

Murugi-Mugomango water project is a gravity fed water catchment system harnessing river water from the mountains to serve approximately 40,000 people. The project was originally designed by the community themselves with technical assistance from the Ministry of Water Development. The society has constructed an intake connecting 440 kms of main pipelines and distribution networks to serve water to society members. The society is currently upgrading the system by constructing a new intake upstream to increase water pressure and regulate water flow to reach members in the lower regions of the project. The upgrading of the water system will tremendously make the project self-sustaining in supplying water to the consumers.

Impact

Murugi-Mugomango water project has had a tremendous impact on the health, economic, social and environmental aspects of the community it serves. There has been a reduced workload with transportation of water which has had an impact on the health status of the women and children. The time and labour saved has enabled women to engage in other productive rural activities like food production. As a result, nutritional status of the community has greatly improved as there is a corresponding increase in food production. Members of other water societies and other interested parties are now visiting Murugi-Mugomango to see how the project is managed as a business. Environmental benefits resulting from the project is that people are now planting more trees to protect and conserve the environment.

In summary, it was found that the project exhibited the following:-

- A functioning physical water system.
- A reported reduction in time, labour and distance travelled to collect water.
- A functioning local water service organization.
- A reported improvement in personal hygiene, health and nutrition.
- An evidence of increased production of horticultural food crops in home gardens e.g. bananas, green vegatables, onions, tomatoes and maize.
- Evidence of reduced cost and labour associated with new building construction and spraying of coffee.
- An increase in planting of trees.
- Use of scheme water in the coffee-berry processing factory instead of river water to produce washed coffee beans.
- Construction of an impressive water society office and store premises.
- Creation of job opportunities for young people coming into the job market each year.

Clearly, running a village water project as a business enterprise has proved to be the key factor for this community to achieve long-term self-sufficiency.

HUNG-LOU TRANS-BASIN DIVERSION PROJECT IN PENGHU AREA

Chun-Yen Chien*, Cheng-Nan Tsay**, Jian-Chyun Wang***

ABSTRACT

Penghu Archipelago is located in southeast part of Taiwan Strait. The average annual rainfall is 1,013 mm which is no more than one half of that in Taiwan Area. In addition, evaporation is as high as nearly 1.8 times of its average annual rainfall. Since there are no high mountain and forestry in the area, most of the rainfall either infiltrates or runs off to the sea immediately. The supply of fresh water is in great shortage all year round for Penghu area. To solve the problem, the utilization efficiency of rainfall should be promoted. Cheng-Kung reservoir has usually failed to be filled up owing to insufficient inflow. In order to increase the inflow, an interception wall and conveying channel were built near Hung-Lou village to divert the runoff from adjacent watershed to the reservoir. As a result, the annual water supply has increased 20 %.

I. Introduction

Penghu Archipelago is located in the west of Taiwan in southeast part of Taiwan Strait (Figure 1). It comprises 64 small islands and is divided into six main administrative areas, i.e. Makung, Huhsi, Paisha, Hsiyu, Wangan, Chimei. The total area is 126.86 KM^2 and population is about 100,000.

Most local inhabitants rely on fishing. The agricultural development is severely restricted by poor climate and soils. Furthermore, fresh water is in great shortage. People can only grow upland crops like millet, peanut, yam there.

The geographical condition in Penghu is barely satisfactory. The topography of island is mild with higher altitude in the south inclining to the north. The peak point is located in Taimayu of

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which the elevation is 79 M while the peak of main islands (Kungpeishan or Taichengshan) is only 52 M. There are neither mountains nor lakes on the islands. The average annual potential evaporation amounts to 1,872 mm that is greatly exceeding to average annual rainfall of 1,013 mm. The islands are dry almost the whole year and water supply is quite insufficient. Therefore, the water resource development is the most urgent matter in Penghu area.

II. Meteorology

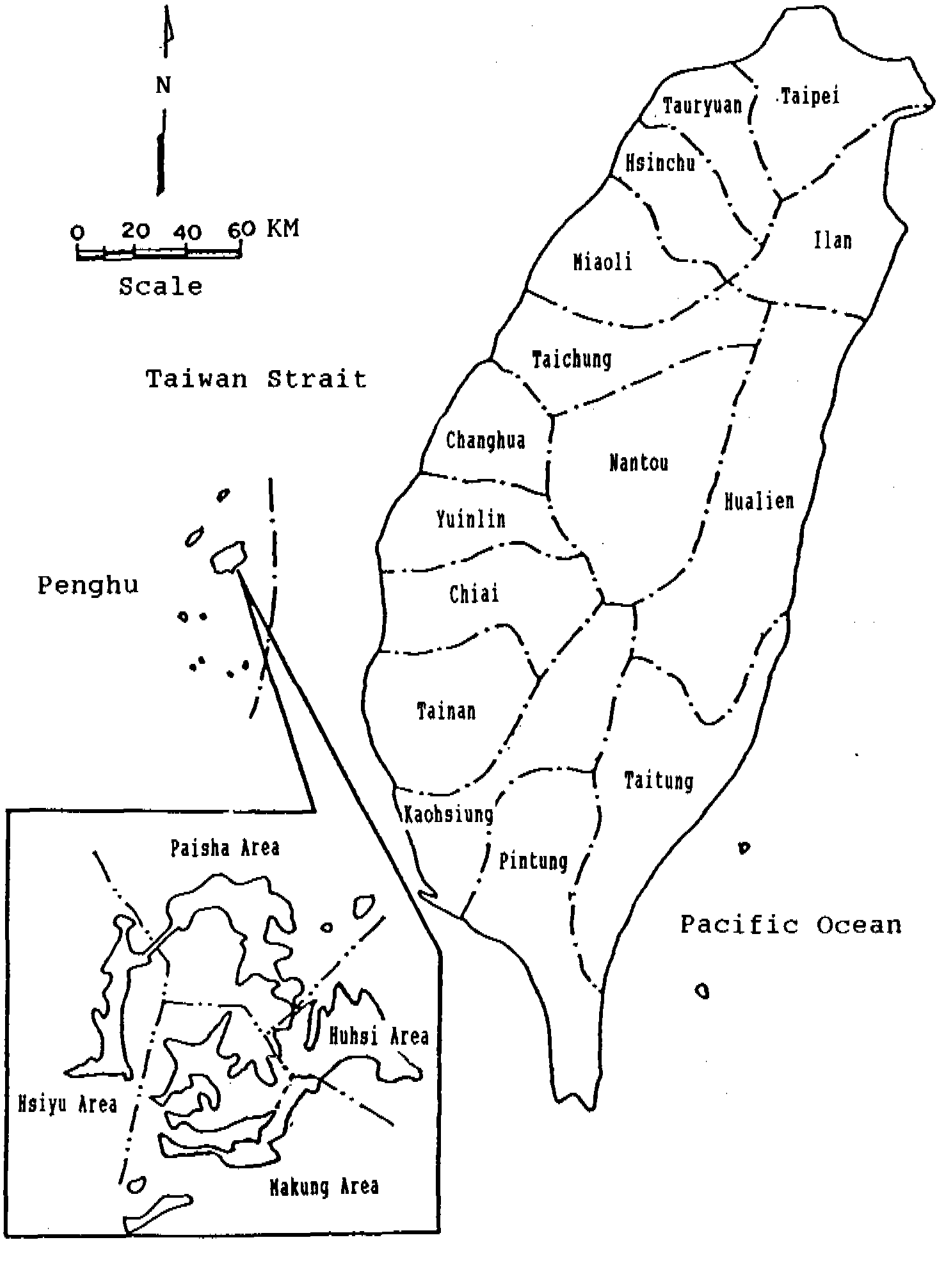
1. Climate

The climate in islands is characterized by the strong monsoon wind and little rainfall. The average annual temperature, highest temperature and lowest temperature is 30°C, 10°C respectively. The annual relative humidity ranges from 80% to 85%. Since the islands are located in the northeastern monsoon area and no mountain barriers, thee are 137 days of gales in a year mostly occurring in October through March. The average daily maximum wind velocity is 21.82 meters per second. Furthermore, the instantaneous velocity is higher than 40 meters per second. The strong wind and saline soil moisture handicap the crop growing. Therefore the islands look deserted in winter season.

2. Rainfall

The study area is located in sub-tropic and monsoon zone. Because of topographic characteristics rainfall is not as much as supposed. According to historical records of Makung station, the average annual rainfall is 1,013 mm which is no more than one half of that in Taiwan area. The record high annual rainfall 1792.7 mm occurred in 1969 while the record low 323.3 mm in 1916. The heaviest daily rainfall was 352.9 mm on July, 6, 1974. Almost 80% of rainfall is distributed in the period of April through September, only 20% occurs during dry season from October to March. The pattern is shown in Table 1.

Figure 1: Location Map of Penghu



3. Evaporation

Prevailing monsoon and dry weather result in high evaporation in Penghu area. The observation from 1901 to 1978 at Makung station reveals an average annual evaporation of 1,827.8 mm, which is nearly 1.8 times of its average annual rainfall. The monthly evaporation is more than monthly rainfall except in June (Table 1). The gaps are larger in winter season (October to March). Therefore it can expect a tremendous loss of evaporation from reservoir surface on islands.

III. The Current Water Supply

In Penghu area the water supply majorly depends on groundwater drawn from wells. Recently, due to economical development and living standard promotion the groundwater is over drawn. The groundwater table has lowered drastically. Part of deep wells salted and discarded because of seawater intruding. Since 1973, by the financial support from central and provincial Governments, four surface reservoirs (Chengkung, Hsinjen, Tungwei and Hhsian) and an underground reservoir (Chigkan) have been constructed. They help to augment the water supply capacity quite a lot. The current water supply in Penghu county is shown as Table 2.

Although the existing reservoirs help to supply water, the water supply is still insufficient in dry seasons. Groundwater remains to be the major water source. How to increase the utilization efficiency of rainfall and to decrease groundwater pumping are obviously essential and urgent.

IV. The Project of Hung-Lou Trans-basin Diversion

In order to increase surface water sources of Cheng-Kung Reservoir, an interception wall (311 M length, 5 M height) and conveying channel (2000 M length) were built near Hung-Lou village to divert runoff from the adjacent watershed into the reservoir. The project area is located in Huhsi administrative area. The location of Cheng-Kung reservoir and interception wall are shown as Figure 2. The catchment area of Cheng-Kung reserrvoir is 3.89 KM^2. The Hung-Lou Diversion Project will add a catchment area of 0.81 KM^2 to the reservoir.

Table 1 : Average Monthly Temperature, Precipitation And Evaporation at Makung Station

Item \ Month		1	2	3	4	5	6	7	8	9	10	11	12	Tatal
Temperature (℃)		16.4	16.7	19.4	23.1	25.7	27.2	28.8	28.5	28.6	25.3	22.2	18.5	-
Precipitation	(mm)	23.2	39.9	62.3	75.6	112.6	173.3	168.9	170.4	110.1	33.0	22.3	21.1	1012.9
	%	2.3	3.9	6.2	7.5	11.1	17.1	16.7	16.8	10.9	3.3	2.2	2.1	100.0
Evaporation (mm)		109.9	99.4	123.5	143.5	169.4	166.6	189.8	181.1	178.7	190.9	151.6	123.4	1827.8

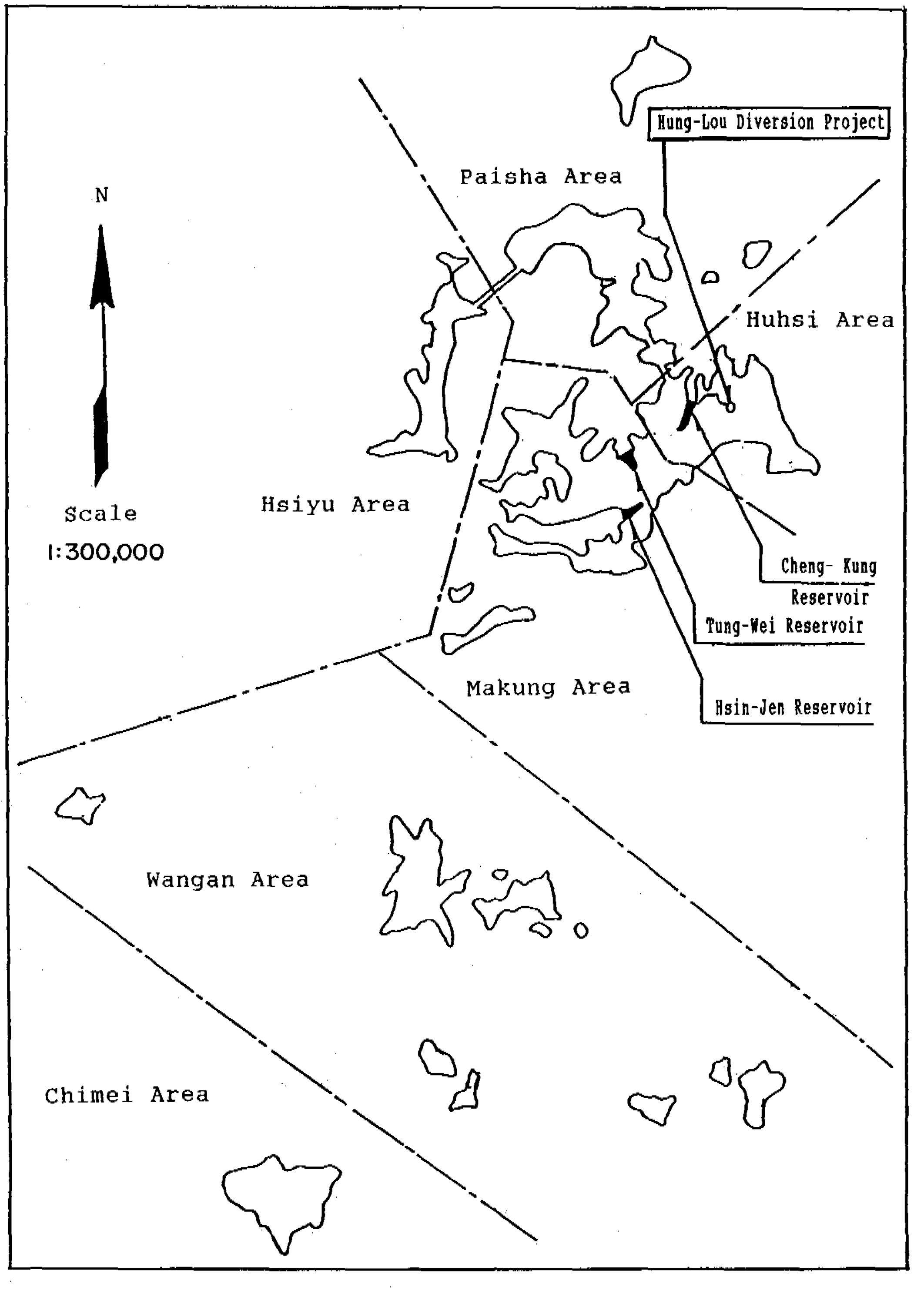
Table 2 : Current Water Supply of Makung City and Peng-Hu County

Unit:M^3/Year

Region	Makung City						Peng-Hu County			
water Resources	Surface Water			Groundwater		Total	Surface Water	Groundwater		Total
Objectives	Cheng-Kung reservoir	Hsin-Jen reservoir	Tung-Wei reservoir	Shallow Well	Deep Well			Shallow Well	Deep Well	
Water Supply	894,000	261,000	86,000	292,000 (320)	1,781,200 (44)	3,314,200	1,241,000	1,021,000 (1119)	3,851,200 (118)	6,113,200
Irrigation	-	-	-	1,340,000 (630)	-	1,340,000	-	7,676,000 (3609)	-	7,676,000
Industry & Fishery	-	-	-	-	436,000	436,000	-	-	-	436,000
Total	1,241,000			1,630,000	2,217,200	5,090,200	1,241,000	8,697,000	4,287,200	14,225,200
Remark	1. Groundwater from shallow aquifer is used for industry and fishery. 2. Deep well water supply includes the water provided by the navy (109,500M^3). 3. The figures quoted are the number of wells.									

* Source: " A Feasible Planning Report On Probable Storage Ponds In Penghu Area"

Figure 2: Location of Hung-Lou Trans-basin Diversion Project



1. Rainfall and Runoff Analysis in Hung-lou Project Area

There are only three raingage stations (Makung, Cheng-kung, and Wangan) existing in Penghu area. The Wangan station locating in a far away off island is not applicable. The Cheng-Kung station is only 1 KM away from Hung-Lou area in comparison with Makung station of 8 KM. However, the Makung station has much longer record than Cheng-Kung station. This study uses Cheng-Kung station as the key station to estimate rainfall and runoff. Firstly a regression analysis basing upon 10-day precipitation data between Cheng-Kung station and Makung station is conducted for the period 1967 to 1987. The adapted regression equation is in the following:

$$Pc = -0.1630 + 0.8826\ Pm$$

where: Pc = 10-day precipitation of Cheng-Kung station
Pm = 10-day precipitation of Makung station
R = correlation coefficient = 0.9434

Then the 10 day precipitation data for Cheng-Kung station are extended for the periods of 1950-1975 and 1988-1989. As a result, the average annual rainfall of Cheng-Kung station is found to be 907 mm. By multiplying runoff coefficient (Table 3) and catchment area with rainfall, the 10-day runoff (1950-1989) of Cheng-Kung reservoir can be estimated. The average yearly runoff volume of Cheng-Kung watershed is about $1.024 \times 10^6\ M^3$. The 10-day runoff of Hung-Lou watershed is estimated in the same way. Its average yearly runoff is about $0.212 \times 10^6\ M^3$.

2. Yield of Cheng-Kung Reservoir

To evaluate the water supply capacity of Cheng-Kung reservoir, the shortage index (S.I.) is used as a criterion. It is defined as follows:

$$S.I. = \frac{100\left[\sum_{1}^{N} (S_a/D_a)^2\right]}{N}$$

where: Sa: yearly water shortage
Da: projected yearly water supply
N : number of operation years

Table 3: Runoff Coefficient of Cheng-Kung Catchment

Precipitation (mm)	13	25	40	60	85	125	175	400
Runoff Coefficient	0.12	0.17	0.20	0.23	0.25	0.28	0.30	0.36

* Source: " A Feasible Planning Report On Probable Storage Ponds In Penghu Area "

Figure 3: Relationship of Water Supply Capacity Vs. Shortage Index

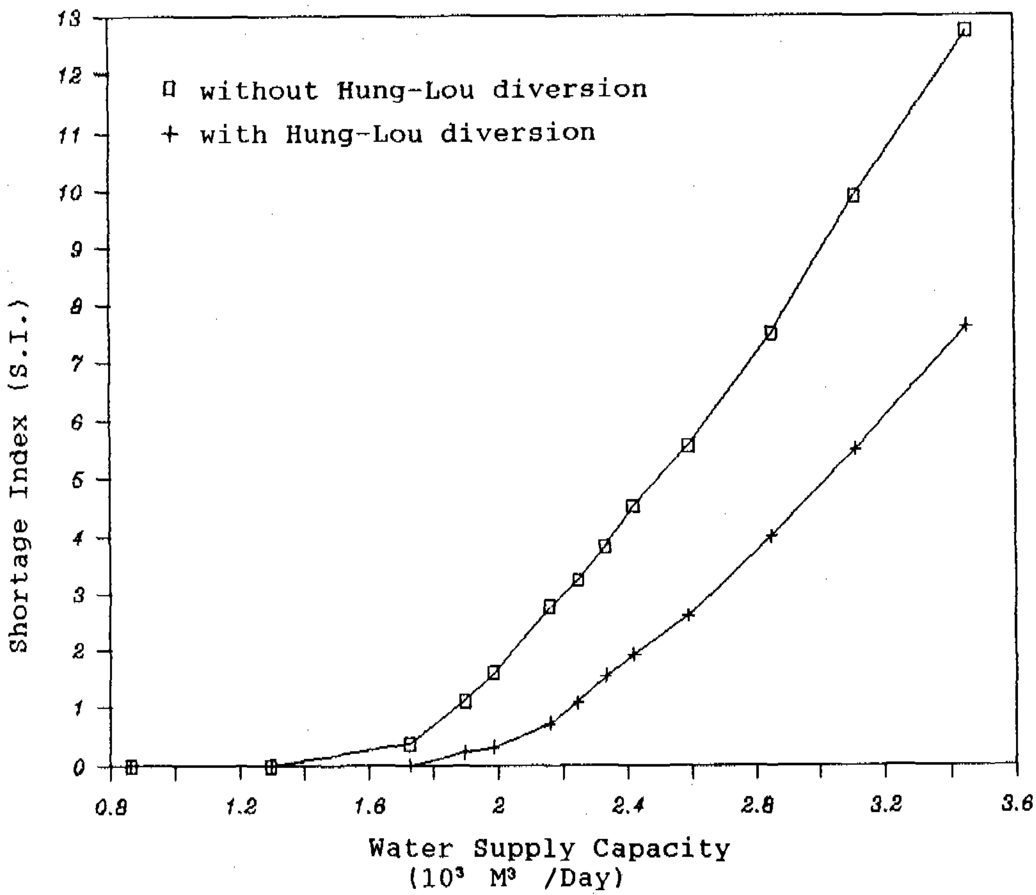


Table 4 : Comparison of Water Supply Capacity Between With-Diversion and Without-Diversion

Water Supply Capacity \ Case		Cheng-Kung Reservoir (without diversion)			Cheng-Kung Reservoir + Hung-Lou Diversion		
CMS-DAY	M^3/DAY	Actual Average Water Supply (10^4M^3)	Average Yearly Shortage (10^4M^3)	Shortage Index (S.I.)	Actual Average Water Supply (10^4M^3)	Average Yearly Shortage (10^4M^3)	Shortage Index (S.I.)
0.040	3456	90.40	35.81	12.72	102.24	23.99	7.61
0.036	3110	87.67	25.94	9.89	97.63	15.98	5.50
0.033	2851	85.02	19.12	7.49	93.45	10.69	3.99
0.030	2592	81.68	13.00	5.55	88.23	6.44	2.59
0.028	2419	78.87	9.50	4.52	83.98	4.38	1.91
0.027	2332	77.24	7.96	3.81	81.58	3.63	1.53
0.026	2246	75.49	6.56	3.22	79.15	2.90	1.07
0.025	2160	73.57	5.33	2.75	76.69	2.21	0.71
0.023	1987	69.24	3.34	1.59	71.36	1.22	0.31
0.022	1900	66.85	2.58	1.10	68.58	0.85	0.22
0.020	1728	61.89	1.23	0.37	62.97	0.15	0.01
0.015	1296	47.34	0	0	47.34	0	0
0.01	864	31.56	0	0	31.55	0	0

Two cases comprising with-diversion and without-diversion are analyzed. With the data produced in above section, the reservoir is operated for the period 1950 to 1989. Figure 3 and Table 4 show the results. With the Hung-Lou diversion the water gain is quite obvious. It is estimated that the yearly water supply of Cheng-Kung reservoir will increase by a degree of 20%.

V. Conclusions

1. For Cheng-kung reservoir the estimated average annual rainfall is 907 mm. It is equivalent to 3.533×10^6 M^3 in volume. The average annual runoff (1.024×10^6 M^3) is about 30% of rainfall. The estimated precipitation and runoff are very close to that observed.

2. The Hung-Lou diversion project can augment 20% of water supply capacity for the Chung-Kung reservoir. In this case the transbasin diversion is an effective way to develop water resources.

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Rainwater, Water Table and Soil Moisture in a Hillslope

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ABSTRACT

The objective of this work was to study the relationships between the rainfall, the water table and the soil moisture regimen in a hillslope planted with cacao. These parameters were measured daily during 270 days.

The water table was observed in a set of 5 wells located in a contour line of the hillside. Beside the middle well two sets of tensiometers were instaleled at 15, 30, 60, 90 and 135 cm depths. Also,the soil composition, density of aggregates and moisture equivalent were measured. It was found that, horizontally, the soil profile can be divided into three zones: the top zone (from 15 to 30 cm depth), not submissive to the water table rise under rainy conditions. This zone presents an average soil moisture content of 0.48 (cm^3/cm^3). In the middle zone (30 - 90 cm), the average moisture content ranges from 0,50 to 0,55 if the water table is below or above 4m depth, respectively, and the bottom zone, below 90 cm, is more submissive to that saturation although its moisture content is not statiscally different than of the upper zone. The peculiarity of the middle zone,which is composed of B21 and B22 horizons, is associated with its high clay content. Also this zone represents a water reservoir to the cacao tree. In general, the results suggested that the water table height, associated with the rainfall conditions, controls the moisture content in the whole soil profile. However at the 30 - 90 cm depth, the transpiration flow of the cacao tree may also play an important role in the soil moisture regimen.

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INTRODUCTION

In the last two decades soil water flux has been studied as an hydrological process presenting important information on groundwater recharge in hillslopes. Special mentions are made in papers which discuss the water table recharge and expansion upward in the subsoil (Weyman, 1973; Whypkey and Kirkby, 1978) and those discussing the rapid response of the water table to rainwater infiltrating in the soil subsurface of hillslopes (Ragan, 1968; Dunne, 1978; Sklash and Farvolden, 1979; Guillham, 1984). Most of these reports referred to separated storms hydrographs. Also, Leite (1987) conducted a long run period experiment in which the water table regimen is considered a climatic parameter besides the annual rainfall distribution. Additionally, Leite (Not published) found correlation between the water table residence in the soil subsurface and the annual crop production of cacao beans. Water table residence is defined as the number of successive days during which the water table is maintained near the soil subsurface. Leite thought that the influence of the water table on the cacao trees occurs indirectly through a mechanism of soil moisture increase controlled by the water table rising regimen. The objective of this work was to test this hypothesis.

MATERIALS AND METHODS

The study was conducted in a hill of 24% slope located at the Arnaldo Medeiros Experimental Station of the Cacao Research Center (CEPEC), Southeast Bahia. The hillslope forms a small watershed of approximately 0.20 ha (Fig. 1). The climate is an Af type of Koeppen with an annual rainfall of 1862 mm. The soil is an Alfisol covered with a cacao planting of about 80-yeards old. Under conditions of high rainfall (total minimum of 14 mm in successiverain days) the water table expands along the subsoil from the foot to the top of the hillside(Leite, 1987). Rainfall, soil profile moisture, and water table height were measured daily during 270 days from July 31, 1989 to March 26, 1990. The water table height was observed in a set of five wells of 4 m depth, located in a contour line 5 m apart from each other in the upper middle hillslope. The soil moisture was calculated from the mean pressure head of two sets of tensiometers using manometers at 15, 30, 60, 90 and 135 cm depth (Fig. 1). The tensiometer sets were located at about 2 m to the left and right of the middle well. Also soil composition, density of the horizons aggregates, and soil moisture equivalent were determined.

RESULTS AND DISCUSSION

Characteristics of the soil profile - Table 1 shows the physical characteristics of the soil profile in the countour line where the wells and tensiometers were located. It was found that in the B_{21} e B_{22} and B_3 horizons, the density of aggregates and the moisture equivalent were higher and their silt/clay index were lower than the same parameters of the upper horizon.

TABLE 1. Physical characteristics of the soil profile.

Horizon		Composition of Aggregates (%)				Silte / Clay Index	Density of Soil Aggregates. (%)	Moisture Equivalent. (%)
Identification	Depth (cm)	Coarse Sand	Fine Sand	Silte	Clay			
A_1	0 - 10	14	27	35	24	1.4	2.51	31.9
A_3	10 - 23	14	31	30	25	1.2	2.48	27.1
B_1	23 - 36	14	15	39	32	1.2	2.67	28.3
B_{21}	36 - 50	9	14	24	53	0.5	2.70	37.9
B_{22}	50 - 110	8	13	20	59	0.3	2.70	40.2
B_3	110 - 130	20	19	26	35	0.7	2.79	35.3

Responses of the water table height and rainfall to the soil profile moisture - Figure 2 shows the rainfall and the water table height in the study area. Figure 3 presents a summary of the relation found between the soil profile moisture and the water table height either below or above 4 m depth, Horizontally, the soil profile may be divided into three zones:the top zone (from 15 to 30 cm depth), not submissive to saturation by the water table rise under rainy conditions. This zone presents an average soil moisture content of 0.48 cm^3/cm^3; the middle zone (30-90 cm) where the average moisture content ranges from 0.50 to 0.55 cm^3/cm^3 if the water table is low (below 4 m) or high (above 4 m),respectively, and the bottom zone (below 90 cm) which is more submissive to water table saturation, however, its moisture content is statiscally the same as that of the upper zone (Table 2).

TABLE 2. Moisture content means in the soil profile under high(A) or low(B) water table.

Depth of the Soil Profile (cm)	Moisture under water table height	
	Below 4m A	Above 4m B
15	0.48 a b	0.50 a
30	0.48 a	0.48 a
135	0.47 a	0.49 a
60	0.51 b	0.56 b
90	0.50 b	0.54 b

Means with the same letter in a column are not significantly different at P = 0.05 according to Duncan's multiple range test.

The highest moisture retention between 30 and 90 cm depths during the water table rising, expressed by the deformation rightwards of line B in Fig. 3, is also associated with the high clay content in that layer (Table 1). Because of these characteristics,the middle zone is likely to represent a water reservoir to the cacao tree when the water table rises and lowers. The middle zone transfers water to the top and bottom zones where the cacao root system is inserted and takes water for transpiration. It can be understood that the soil saturation process by the water table rising functions as in a process of filling up an empty reservoir: the rain water flows from the top to the bottom and then to the upper zones, in opposition to the unique sense of the gravity. Freeze and Banner (1970) and Sakura et al. (1987) found the movement of capillary water from the water table supplying the moisture from the bottom to the middle zone which is a wetting zone of finer pores. Additionally, Feodoroff (1968) concluded that there is an attraction force (for water) of the wetting zone when the soil is dry. The gravity being of small effect on the soil moisture distribution. Likewise, in a laboratory experiment, Kaihotsu et al (1987) found that the groundwater (water table zone) recharge is independent on the hydraulic conductivity. Also Ohta (1987) concluded that, when rainfall does not occurs during a langer period, soil water is supplied from the bottom zone to the surface.

A second important point to consider in the soil moisture system studied is that the downward movement of the rainwater is rapid from the soil surface (15 cm depth) to the middle and bottom zones, as indicated by the curve No. 5 (Fig. 4). This conditions occurred on Oct. 18, 1989, after a storm of 54 mm, and No. 6, occurred two days latter (Oct. 20, 1989) following conditions of high moisture and a storm of 11.8 mm. Also, curves 3 and 7 resulted from similar pattern of rapid downward water movement, in opposition to curves 1, 2, 4 and 8 which represent the decreasing of the soil moisture in the middle and bottom zone. This was caused by the lack of rain and, consequently, the decreasing subsoil saturation. Traditionally it is thought that the rainwater infiltration should be slow throughout the soil profile. Additionally, in this case-study it is also considered that the infiltration water is likely to contribute to the moisture increasing in the B horizons if the rainfall period prolongs. Leite (Data not published, 1991) considers the possibility of the rainwater regimen to play important role in the morphology of the B horizons. In a broad consideration, Rode (1986) opines that the moisture regimen in the soil profile depends on the climate, groundwater, soil physical properties and vegetation.

CONCLUSION

In general, the results suggest that the water table height, associated with the rainfall conditions, controls the moisture content in the whole soil profile, however at the 30 - 90 cm depth the transpiration of the cacao tree mat also play an important role in the soil moisture regimen.

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FIGURE CAPTIONS

FIGURE 1. Location map of the studied watershed hillslope

FIGURE 2. Rainfall and water table in the study area throughout July 31, 1989 and March, 1990.

FIGURE 3. Summary of the relationship between soil moisture, water table height and rainfall in the 270 days of study: curve A represents the average profile of soil moisture the water table being below 4 m depth and 9 mm the average rainfall each five days period; curve B, the average moisture profile the water table being above 4 m and 46 mm the mean rainfall each five days period.

FIGURE 4. Selected curves and rainfall conditions for the moisture in the soil profile throughout July 31, 1989 and March 1, 1990.

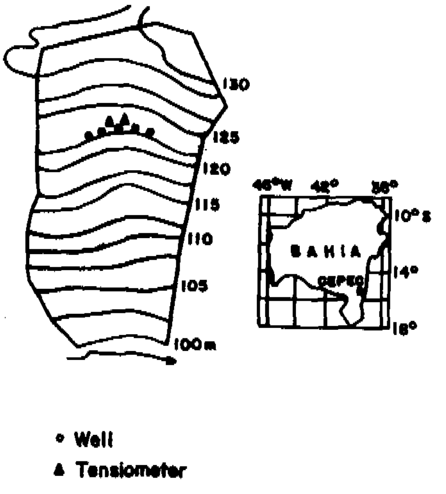
130
125
120
115
110
105
100m
46°W
42°
38°
10°S
14°
18°
BAHIA
CEPEC
Well
Tensiometer

Fig. 1

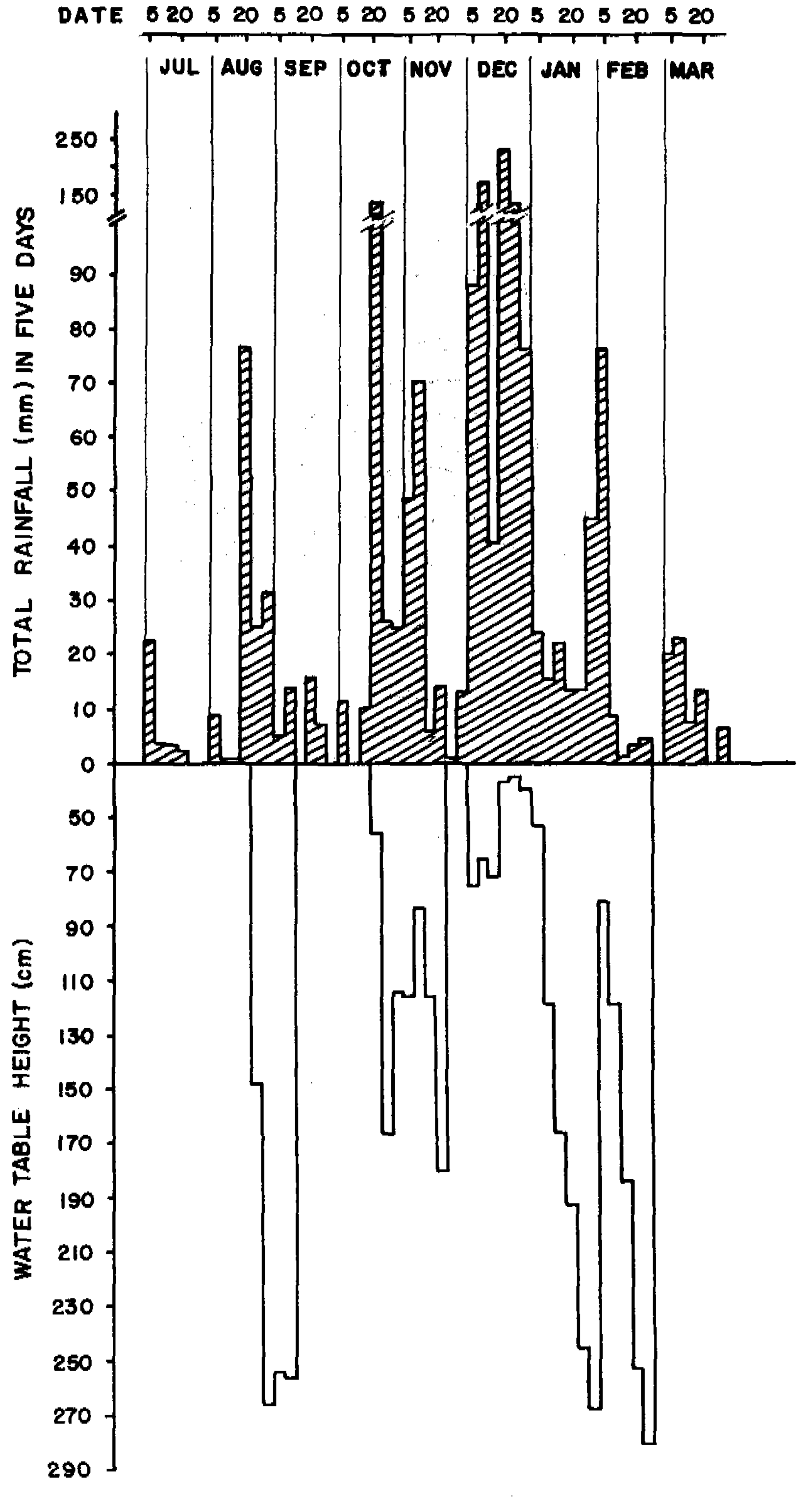
DATE
5 20 5 20 5 20 5 20 5 20 5 20 5 20 5 20 5 20
JUL AUG SEP OCT NOV DEC JAN FEB MAR
TOTAL RAINFALL (mm) IN FIVE DAYS
250 150 90 80 70 60 50 40 30 20 10 0
WATER TABLE HEIGHT (cm)
50 70 90 110 130 150 170 190 210 230 250 270 290

Fig. 2

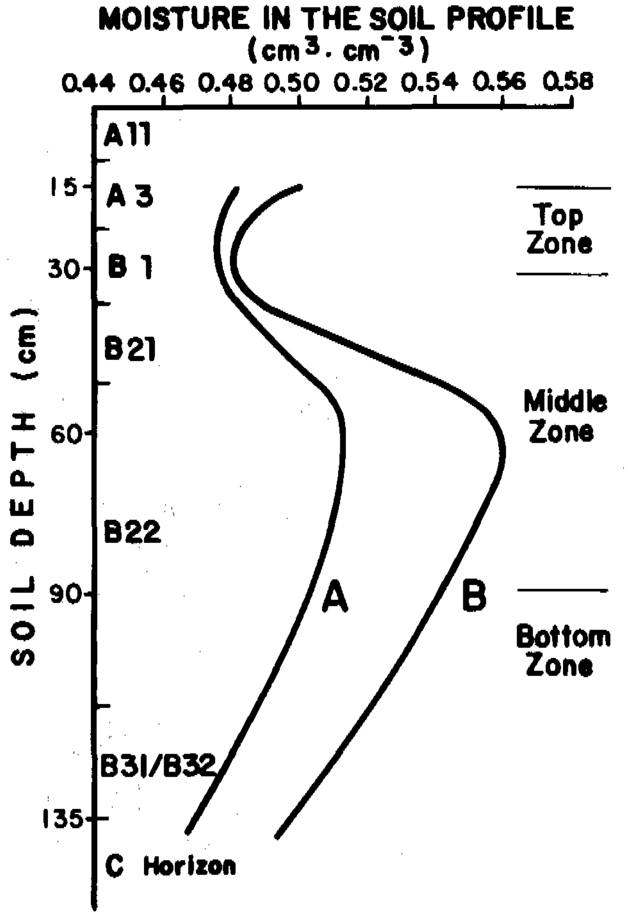
MOISTURE IN THE SOIL PROFILE
(cm3. cm-3)
0.44 0.46 0.48 0.50 0.52 0.54 0.56 0.58
SOIL DEPTH (cm)
15
30
60
90
135
A11
A 3
B 1
B21
B22
B31/B32
C Horizon
A
B
Top Zone
Middle Zone
Bottom Zone

Fig. 3

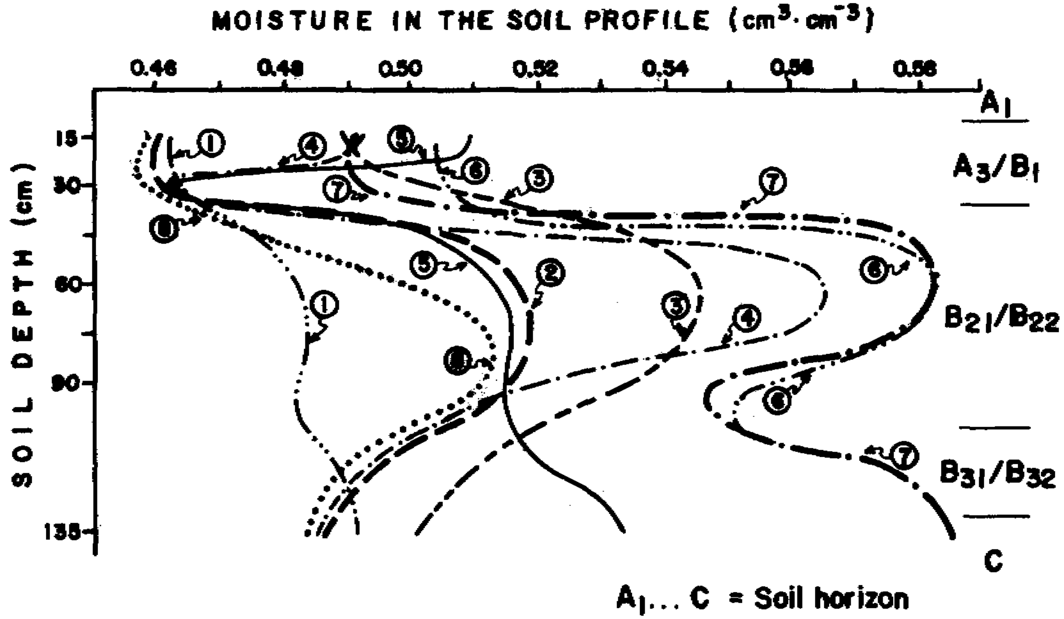

Fig. 4

RAINFALL CONDITIONS FOR THE CURVES ABOVE.

Curve No.	Date	Dry period: number of days with sporadic storms of less than 10 mm	Rainfall on the date of the curve (mm)	Total rainfall 15 days before the date of the curve (mm)
1	Jul. 31.1989	34	0.0	1.6
2	Aug. 14	48	0.5	9.4
3	Sept. 15	5	0.0	28.5
4	Oct. 17	27	1.0	22.7
5	Oct. 18	28	54.0	14.3
6	Oct. 20	0	11.8	123.3
7	Jan. 01, 1990	0	0.4	61.4
8	Mar. 03	25	0.5	6.6

Scientific Method of Kanat's Artificial Recharge, With Examples of the Efficiency of the Methods Described in Iran.

Abdolkarim Behnia*

ABSTRACT

In this research different methods causing kanat's artificial recharge are identified classified, and introduced. The results of their application have been described in Iran. These methods consist of five ways of surface recharge and three ways of underground recharge of aquifers. The five surface recharge methods as follow: construction of vast artificial pool with a specific artificial pond; storage of water in the area above the mother well; Construction of earth dams at the floodways around kanats; The expansion of the vegetation of soil and making the strips along the tarekar of Kanats. Three methods of artificial groundwater are artificial recharge by well, by joining the deep wells and kanats and lowering the ground water level. Based on the local research among the eight different methods presented for the artificial recharge of kanats, the construction of recharge well is recognized to be the cheapest and the easiest of all and is recomended as an effective method for increasing kanats discharges.

INTRODUCTION

There are numerous kanats in Iran whose discharge are less as a result agricultural programing of the basis of discharge of such kanats to the level-which brings about adequate economical efficiency is troublesome if not impossible. There are various current methods for increasing the output of the new kanats renovation and improvement of the old kanats which can be used seperately or jointly. Comparing with other methods, one which come to immediate result and higher efficiency, and helps the proper use of many of

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floads is the artificial recharge of the newly constructed or old kanats. This method is restrictively usedin some parts of Iran in the last decade. Therefore, because of its advantages to explain and discuss this method. One of objectives of this article is the presentation of this method to the extent possible.

In this method the aquifer in which tarekar* of kanats are dug are recharged artificially. Recharge of this aquifers are done through the surface (surface recharge) or underground (underground recharge).

Another objective of this article is to show the different methods used for surface recharge and underground recharge. Meanwhile some of the usefulness the methods used in Iran are discussed.

In this research not only articles and printed materials on this subject, were identified and studied, but also some of the artificial recharge projects in Iran had been observered intently and the methods as well as their defects and merits were noted. Finally, some necessary suggestions with the regards to conditions of the dry and wet kanats, have been made.

ARTIFICIAL RECHARGE OF KANATS

As it was mentioned in the introduction, artificial recharge of aquifers are possible through two ways of surface and underground recharge. Below is the detailed discussion of these two ways:

Surface Recharge

The increase of underground water the help of obstacles made on the around and holding the rainfall is called SURFACE RECHARGE. Water is spread and kept on the ground by different methods and gradually penetrates into the ground and finally joins the underground water in the area. Some of the methods used in surface recharge are similar to the regular methods in the irrigated area. The methods of this part are classified as follows:

The construction of vast artificial pond or specific recharge pool. Big ponds in quite penetrable place should be built.

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*Tarekar is the part of the kanat's tunnel that are below the water table

The method of building of the ponds is in such a way that either by with excavation from a surface vast ponds are created or walls are built on the surface of the ground which imprisoned water like the excavated area. Problems such as collapsing of walls or the decrease of penetrability of the whole area of ponds can be destroyed by applying efficient strategies like covering the inside surface of walls with gravel and sand with the thickness of 10 cm as well as ploughing or removing the silt from the bottom of ponds. The area of the ponds may reach to 3 hectars are their depth to 2 meters. There are neumerous ponds some of them are sedimentary and the others penetrable.

After a while because of the deposit of the minute particles on the bed of the penetrable ponds their penetrability is reduced. As said before in this situation the removing of silt should be done. In order to minimize the decrease of penet ratibility, the bed of the ponds are usually covered with gravel and sand. The construction of the vast artificial ponds in some parts in Iran causes artificial recharge and the increase of the groundwater level.

Storage of water at the area above the mother well of Kanat:
It is possible to store some of the current in the area above mother well. It can be done on the sloppy ground under suitable topographic conditions with drverting of water from the main direction and spread it on the ground.Efforts should be made to maximize the area of contact of water with the ground. To prevent the destruction of the soil structure water should be spread with the low velocity and density in a form of thin layer.Therefore, before storing water, it is necessary to level, the surface of the ground in a suitable way and necessary repelting groyne be built for this aim. Care should be taken to devise ways of collecting extra water to prevent consequent damage.

Construction of the solid dams and dikes at floodways around kanats:

These caus the collecting of water of floodways near kanats the penetration into the ground, and recharge of the aquifer. This is called" water entombing" in the city of yazd. Because water velocity in underground is very low, therefore with the" water entombing", the discharge kanats are increased in dry seasons. sometimes for recharge of the kanats, the abondoned kanats are used in yazd. In this method they close the mouth of kanats and direct the waterflow into the shafts. This way they try to raise the level of underground water and as a result increase the discharge of the other kanats (8). There is the risk of the collaps of the nearby layers ground. Therefore, those kanats, around which is not any kind of installations, should be used.

Development of the soil cover crops: Development of the soil cover crops via revival pastures, shrubbies and forest (4) especially at the slops for preventing water evaporation and intensifying of surface water penetration into underground water reservoirs are some of the activities which can be studied and taken into consideration of the basis of recharge of kanat water(11).

Making border strips along the kanats taredar: Border strips along kanats tarekar and along natural slope of area, are arranged in such a way that after the first border strip is filled with water, the extra water is transfered from the spillway of first border strip to the second border strip and so on to the following border strips. This method which is called" zelebandi" (12) not only cause the storage of enough water in soil to be used by crops, but also the causes increase of kanats discharge because rainfall, fload and surface waters, and mountaineous streams which flow, in the rainy season causes gradual increasing of water to the aquifers.

Ground Water Recharge

Due to following reasons sometimes the practice of the five mentioned methods of surface recharge is impossible or very costly. The reasons that make artificial recharge impossible are:

A) The lack of suitable land
B) High cost of land
C) The intended area for recharge may be residential.
D) The existance of impenetrable layers or low penetrability in areas above wet layers.
E) The low penetrability of surface layers.

When the above requirements are met, the increase of kanat water by the method of underground artificial can be done by digging imperfect handy wells. The structure of such wells are similar to the wells used for discharge of wastewater. At the bottom of the imperfect handy well dig some horizontal tunnels are dug. The depth of recharge wells and the length of horizontal tunnels depend on the kind and permeability of soil. If the permeability of soil is low, the artificial recharge system may consists of a few shallow wells which are filled with right kind of sand and silt.
Artificial recharge is done by means of deep wells. The methods of underground recharge are as follow: Artificial recharge by well. If there is a wet, free layer, it will be possible to charge kanat water, most of the time. The structure of such wells may slightly varies from the discharge well but are often similar to them and even sometime one single well is used for both purposes.

Artificial wells has some defects. The most important ones are:

A) Inadequate recharge capacity
B) Fast reduction of recharge capacity
C) Difficult and costly nature of protecting and repairing the wells.
D) Shortness of usability period(maximum 10 years).

parsi(3) describes the method of building recharge wells as follow: on the skirt of the mountains or the so-called the parts above the plains and vast vallies in which sandy layer are not too deep, wells can be dug. The depth of the wells should be to the extent that the bottom of them cut the surface of the sandy layers. The diameter of this wells (D) is chosen at meter least. For more efficiency the diameter of mouth of the wells at the surface (d) may choose to be wider than one meter (Fig. 1-A).

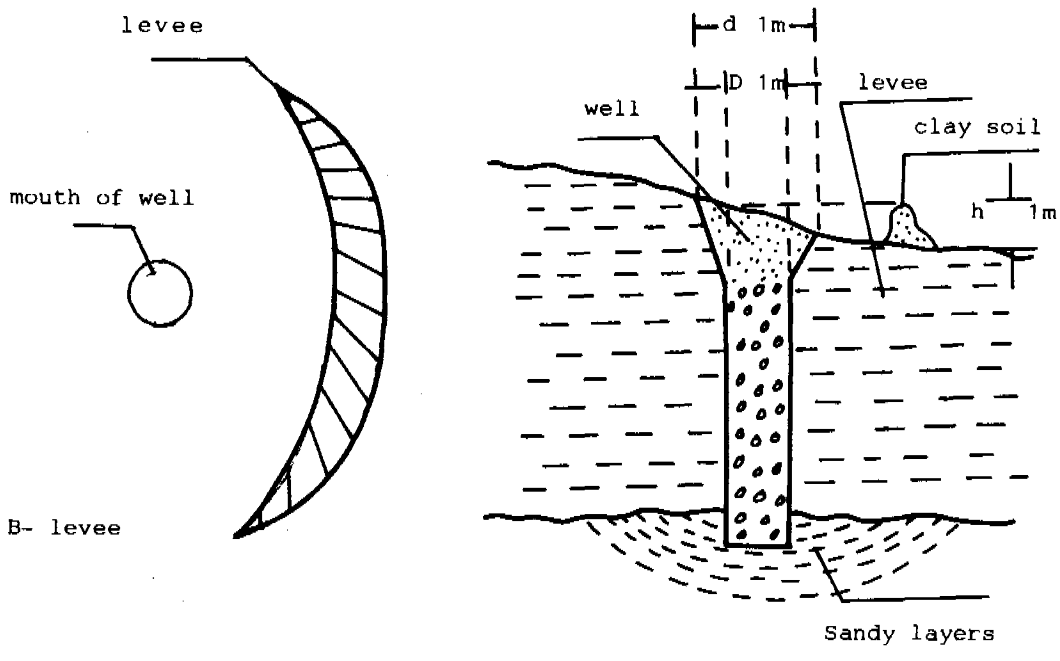

Figure 1.A diagram of a kecharge well and it's levee

These wells must be filled with the large and small gravel and sand and silt. The size of the particles from bottom to the mouth of the wells should decrease so that on the mouth of the well only sand and silt are placed. Opposite each of these wells, that is, in the general direction of the plain, some obstacles should be made where by.

Some of runoff, generated by rainfall, will be stopped and penetrate in wells(Fig. 1-B). The penetrated water in wells then, run into the intake sandylayer. In this manner we can say that in fact, the recharge wells quicken of a process which is done automatically in nature.

The same as kanats, the recharge kanats need permanent care and the remove of silt. Each two or three years, it is necessary remove and replace-up to one meter - the sand and silt which are mixed with minute clay particles after the mentioned course of time and therefore have lost their penetrability. This action cause the increasing of penetrability of these wells.

Any place can be selected for recharge wells provided that these well are dug upto the intake layer or aquifer. This evidently does not means that the bottom of the recharge wells should reach to the underground water level. One of the reasons for choosing the place of recharge wells at the foot of a mountains or vast valies is the low cost of digging. In other words, the main purpose-which is the recharge of kanats is reached by digging shallow wells. The margins around the passage of fload along the foot of a mountains or vast vallies are one of the most suitable places for digging the recharge wells. Another suitable place is the exit mouth of the vallies from mountains. It should be kept in mind that the objective is not the selection of the floadway or dry river but the side margin of this floadway must be chosen.

As mentioned earlier, making an obstacle in front of every well can be very effective, In practice, these obstacle which are made of earth and are in the shape of back of nail or in the shape of a part of a circle, are made around wells(Fig. 1-B). The height of each obstacle or levees (h) depends on the slope of earch and generally is less than one meter. This height should be that much so that the water level can be held on the mouth of the well.

Recharge wells are sometimes call" penetrable wells" (10). Sometimes it is possible to use the discharge wells for for recharge provided that the injected water be completely pure and without any pollution(10).

<u>Artificial recharge by the method of linking the deep wells with kanats</u>: usually the water of kanats belongs to the surface aquifers, wherease the water entered the deep wells belongs to the

surface aquifers and deep aquifers. The water of many deep wells dug in different parts of Iran is under relatively high pressure (underground half artesian water (5)), so that when the digging of well is finished the level of it the same pressure rises under and even may go higher than the water level of surface wells in the same place (9). Many times this condition has been witnessed by the writer in a suitable area, such as different part of Khuzestan.

Along the bottom of kanats or in the area of mother well one can dig a deep well and direct the obtained water from this well to the bottom of kanat's tunnel and whereby increase the discharge of kanat. In fact deep well in this case is considered with respect to the tunnel of kanat an artesian well and water from the tunnel will be available and used. Mixing connecting the deep wells with kanats can be considered as one of the method used for changing the dry kanats to wet kanats or increasing the discharge of wet kanats and probably one can expect promising results when applying this method in villages of Iran, where the villages face the problem of repairing water pumps and supplying fuels.

Artificial recharge with lowering the underground water level (induced recharge): If a rever or a sweet water lake with sweet water is next to an aquifer and all or some part of tunnel (s) of one or several chain of kanats are dug next to river bed or into the aquifer or they pass under the mentioned river bed, a part of the mentioned water resource are forced to move toward an aquifer ultimately directed towards the stated kanats. The reason is that the process of kanat's drainage lowered the underground water level and causes induced recharge.

Conclusions and Recommendations

With regard to artificial recharge of aquifers for increasing the kanat's discharge some research has been done so far. For example six samples are mentioned below:

A) Some repelling groynes has been constructed along floadway around the Aghna kanat's mother well in the skirds of Isfahan. Thes repelling groynes entomb the water of Zayendeh Rud (River of Zayendeh) on the mentioned mother well kanat and as a result help the fertility of that kanat.

B) A constructed ponds with the area 1.7 hectare can injecte 400 lit/sec to the ground in Tabriz plain.

C) Regarding the control of surface water empirical research on the construction of artificial recharge installation starts from 1981 in the region of Bam and Rafsanjan.

D) Experiments on the penetration of water by experimental ponds with the surface of 0.26 to 0.9 hectare has done in eighteen spots of Ghazvin plain. In one part among the mentioned 18 spots ,complex of ponds consisting of several ponds with area of 10 hectares has been founded.

E) Recharge wells were built vertically normal to the current of salty water of sea in the big and modern agricultural project of sari plain. The pure water injects to this wells till salty water is held back.

F) One sedimentary pond with the area of 10000 square meter and six infiltration ponds with dimentions of 35 x 35 meter in Garmsar plain is established. The amount of infiltration from 65 to 200 lit/sec. Since in Iran- as a dry area- nothing is more important than storage of water and artificial recharge with private invest is not practical, the action should done by cooperative institutions.

Personal investigation and local research shows that among 8 ways of artificial recharge mentioned above, the establishment of recharge wells are simpler and cheeper than all of the other methods and this method can be applied inmost part the other 7 methods needs preliminary research and the presentation of projects. Moreover, they need primary investment as well as adequate expense for protecting them. The selection of the place of the recharge well do not need full study and research, because Moghaders (specialist in kanat technology) or local well- informed persons are able to choose a place and the cost of protection includes just the change of sand and silt of the surface area of the mouth of the wells on time 2 or 3 years.

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RAINWATER CATCHMENT FOR FUTURE GENERATIONS; SMALL RESERVOIR IRRIGATION SCHEME IN THE PHILIPPINES

RODRIGO N. DE GUZMAN*

Background

The Philippine Archipelago, a country of 61 million inhabitants, lies entirely within the humid tropics between latitudes 5° and 20°N longitudes 117° and 127°. Micro climate within the islands are largely influenced by altitude (most islands have narrow coastal plains surrounding mountain ranges with height from 500 - 2,900 m) and the direction of prevailing air stream. the latter influences seasonal variation in climate, in particular the rainfall distribution pattern.

Annual rainfall is from 1,500 to 4,200 mm. In most lowland areas average rainfall is generally adequate for a single crop in the rainy (wet)season. However, rainfall is often not evenly distributed and dry spells frequently necessitate supplementary water supplies. Unfortunately, the country lies in an area recognized as having the greatest frequency of tropical typhoons in the world. Between 1948 and 1988 an average of tropical typhoons were recorded annually mostly in the months of June to December, with the highest monthly frequencies (more than three) in July, August and September.

Water resources development in the Philippines for irrigation, power, domestic water supply, and industrial purposes involves a variety of types, from simple diversion to huge reservoirs, to shallow wells, to deepwells, and to rainwater conservation through storage.

This paper presents a case study of rainwater cistern system or rainwater catchment for irrigation, flood control and soil and water conservation for future generations.

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The Projects

Location

The project area belongs to the administrative jurisdiction of Tarlac Muncipality in the province of Tarlac, some 120 km north of Manila, the capital city of the Philippines.

An enveloped area which includes the project beneficial area and the respective watersheds of four dams and reservoirs to be constructed at the Mangillog, Bulelatin, Pangasan, and Balnges tributaries of the Bulsa River is situated between North Latitude 15 deg 22 min and 15 deg 37 min and East Longitutde 120 deg 22 min and 120 deg 30 min. Its land elevation is lying between 70 m and 762 m above sea level.

The project net beneficial area is 1,030 ha of the rainfed paddy field with a gentle slope extending on the left and right banks of the above tributaries of the Bulsa River (see project map).

The direct beneficiaries of the project are estimated at 11,000 farm residents.

Meteo-hydrology

The climate of the project area is classified to be the first type of the philippine climate, which has the wet season from May to October dominated by southwestern monsoon and the dry season from November to April dominated by northeastern monsoon.

The annual rainfall rainfall is 3,455 mm in the maximum (1992), 1,291 mm in the minimum (1973), and 1,857 mm on the aver-age. Therefore, the rainfall is substantial in the wet season and decreases significantly in the dry season.

The mean annual temperature is 27.2°C and monthly temperature is highest at 29.1°C in May and lowest at 25.3°C in January. The mean annual evaporation is 1,780 mm and the monthly evaporation is largest at 215 mm in February and smallest at 102 mm in August. The mean average relative humidity is 70% and the monthly relative humidity is highest at 82% in August and lowest at 57% in April. Typhoon is most frequent in June and November.

The mean discharge of the Bulsa River, with 405 sq. km. of the catchment area, from 1960 to 1973 is 31.1 cu.m/sec. The mean monthly discharge is highest in August (rainy season at 130.3 cu.m/sec., and lowest in April (dry month) at 4.5 cu.m/sec. Hence rainfall contributes much to the river flow.

Complementary Contribution to other Nearby Project

The project will be complementary in nature with other existing projects in the area (see Fig. 3.8.1).

Purposes of the Project

The project would provide dams, reservoirs, irrigation facilities, operation and maintenance roads including a bridge in the Western Barrios area. It will contribute to increasing agricultural productivity and income, stabilize farm management, uplift living standards of farmers, strengthen farmer irrigators association, enhance rural communication and consensus, alleviate flood damage, and finally direct to the activation of rural economy and the prosperity of rural society.

Project Design

As to its component, the project would construct 4 small reservoirs, operation and maintenance roads, and one bridge. The scheme diagram of the principal facilities is shown in Fig.5.1.1. The basic information for these components are described in Table 1.

Design of Dam

The basic principles for dam design are to ensure the necessary functions and safety with economically acceptable facilities under the natural conditions of rainfall, earthquake, and geology.

Annual rainfall in this district is about 1,900 mm on the average, of which about 90% is distributed in the wet season from May to October. Failures by the dam by overtopping will be prevented by sufficient free board and installation of spillway which has sufficient capacity to discharge flood due to concentrated rainfall.

During the period from 1907 to 1985, 121 occurence of earthquakes exceeding the magnitude of 5, with epicenter within 200 km from the proposed dam sites were reported. Accordingly, consideration against earthquake was done for the design.

The typical section designs of four dams are shown in Fig. 5.2.2 to 5.2.4.

Based on watershed condition, sediment volume, and other available design data other salient features of the dam and

Table 1. Project Component and Specification

Item	Dam Height, m	Crest Length, m	Reservoir Capacity, MCM	Canal Length	Type of Dam
1. Mangillod dam and irrigation facilities	19.3	704.5	3.21	10.32	Overflow Weir
2. Bulelaten dam and irrigation facilities	10.0	215.0	0.73	1.58	Homogenous
3. Pangasan dam and irrigation facilities	17.3	195.0	1.14	3.13	Deep core french
4. Balnges dam and irrigation facilities	24.2	208.0	1.82	8.80	Overflow Weir
5. Operation and maintenace road	Total length :	23.8 km, total width: 4.5 m, effective width: 8.5 m			
6. Bulsa river bridge (permanent type)	One place :	effective width: 3.6 m, length 225 m			

Table 2. Silient Features of Dam and Reservoir

Item		Mangillog	Bulelatin	Pangasan Main	Pangasan Saddle	Balnges Main	Balnges Saddle
Watershed at Dam site	(Km^2)	8.1	2.0	12.9		27.9	
Height of Dam	(m)	19.3	10.0	17.3	5.8	24.2	5.7
Crest EL.	(m)	111.3	98.0	130.8	130.8	98.2	98.2
Crest Length	(m)	704.5	215.0	195.0	50.0	208.0	44.0
Crest Width	(m)	6.0	6.0	6.0	6.0	6.0	6.0
Volume of Embankment	$(m)^3)$	363,000	37,000	78,000	3,800	155,000	3,200
Type of Spillway		Ungated chute	Ungated chute	Ungated chute		Ungated chute	
Design Capacity	(m^3/sec)	127	26	210		266	
Crest Width	(m)	25.0	18.0	25.0		40.0	
Crest EL.	(m)	108.0	96.0	126.5		94.0	
Max. Water Surface EL	(m)	109.2	96.5	128.6		96.3	
Normal Water surface EL	(m)	108.0	96.0	126.5		94.0	
Min. Water Surface EL	(m)	99.0	91.3	120.1		84.3	
Reservoir Area (N.W.S.)	(ha)	85.3	38.4	28.6		31.4	
Reservoir Area (M.W.S.)	(ha)	71.2	34.3	22.3		25.4	
Total Reservoir Capacity	(MCM)	3.21	0.73	1.14		1.82	
Active Reservoir Capacity	(MCM)	3.11	0.70	0.98		1.47	

reservoir are presented in Table 2.

The design floods and spillway capacities were decided on the basis of 50-year flood on 100-year flood as follows:

Table 3. Design Flood

	Design Flood cu. m./sec.	Flood Surcharge $x10^6$ cu.m.	Spillway Capacity cu. m/sec.	Remarks
Mangillog	105.50	1.173	56.31	100 yr - flood
Bulelatin	17.50	0.201	9.36	50 yr - flood
Pangasan	174.20	0.618	149.58	100 yr - flood
Balanges	221.52	0.609	214.52	100 yr - flood

The maximum inflow and outflow at each dam during the design flood and the extraordinary flood have been summarized below:

Table 4. Maximum Inflow and Outflow

	Design Flood		Extraordinary Flood	
	Inflow cu.m/sec	Outflow Spillway Q cu.m./sec	Inflow cu.m./sec	Outflow Spillway Q cu.m./sec
Mangillog	126.60	81.52	151.92	99.13
Bulelatin	25.20	18.24	30.24	22.34
Pangasan	209.04	183.38	250.85	221.08
Balnges	265.82	256.47	318.91	307.80

Design of Distribution Canals

The irrigation canals consist of various related structures which are combined organically to make up the canal systems and to function as a whole system. The scope of the design includes head reach main canal and lateral canal.

As the unit design capacity, 2 li/sec/ha has been adopted over the whole canal system in consideration of some allowance for future increase or irrigation water requirement due to changes in the cropping pattern and farming practice in the command area.

Canals are designed by the following conditions:

Item	Hydraulic Design
1. Applied mean velocity formula	Manning's formula (coeff. of roughness = 0.03, std. value for small canal)
2. Min. allowable velocity	0.45 m/sec (prevention of silting of suspended sediment)
3. Max. allowable velocity	0.6 m/sec (based on canal materials clay or loam
4. Free Board	0.3 m (determined to be the min. value).

Farm ditches and O&M road along main canals are part of the project design.

The irrigation system of the project is present in Fig. 5.3.1 to 5.3.4.

Project Cost

The total financial cost of the project is about US$ 4 million. This includes the costs of construction and pre-engineering services. The annual operation and maintenance cost of the dam and irrigation facilities are estimated at US$ 15,000, all prices in 1988 level.

Project Evaluation

The project, in general has a direct positive effect and substantial benefit contribution to the project area population of 11,000 and potential or indirect benefits to the 168,000 population of its municipality.

Incremental production of 2,163 tons of rice and 3,370 tons of corns are expected annually. In economic terms this could be translated into a total of US$ 957,000 annual benefits.

The improvement of road networks resulting from the project could give a very good access (especially in marketing and deliveries of farm goods) to about 640 ha farms. In terms of monitory value this could be imputed at US$ 12,000 per annum.

Rice and corn production would help in the country's self sufficiency in rice and would contribute to corn production for feeds (which would mean a saving foreign currency through reduction of important of corn).

The reservoir area could be utilized for fish production. The net annual benefit from fisheries is estimated at US$ 32,000.

On a per capita basis, the average annual net crop income alone for a family of 6 persons would increase from a present US$ 60 to US$ 181 in the future.

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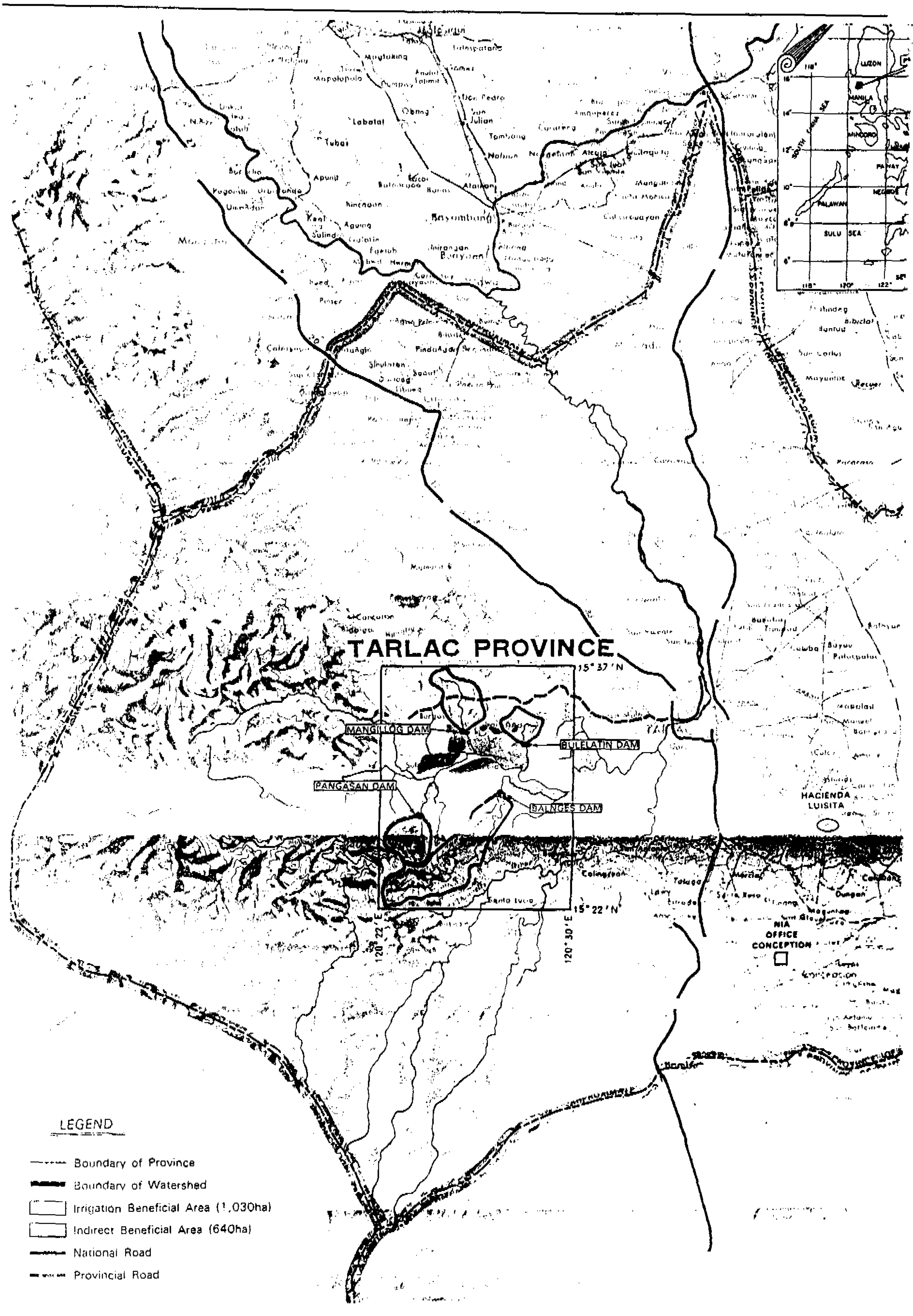

TARLAC PROVINCE
15° 37' N
15° 22' N
120° 22' E
120° 30' E
MANGILLOG DAM
BULELATIN DAM
PANGASAN DAM
BALNGES DAM
HACIENDA LUISITA
NIA OFFICE CONCEPTION
LUZON
MANILA
MINDORO
PALAWAN
SULU SEA
LEGEND
Boundary of Province
Boundary of Watershed
Irrigation Beneficial Area (1,030ha)
Indirect Beneficial Area (640ha)
National Road
Provincial Road

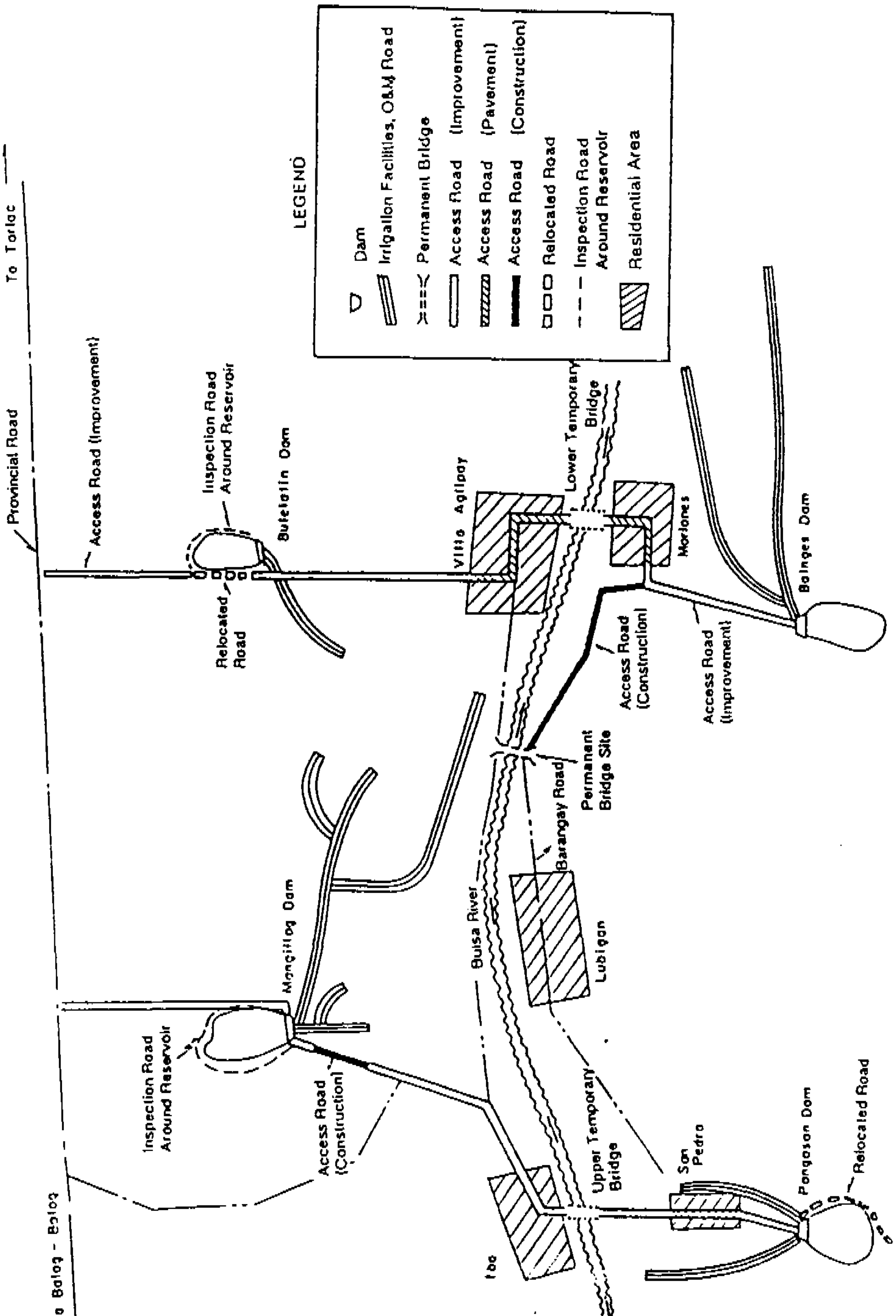


Fig.5.1.1 SCHEMATIC DIAGRAM OF BASIC DESIGN

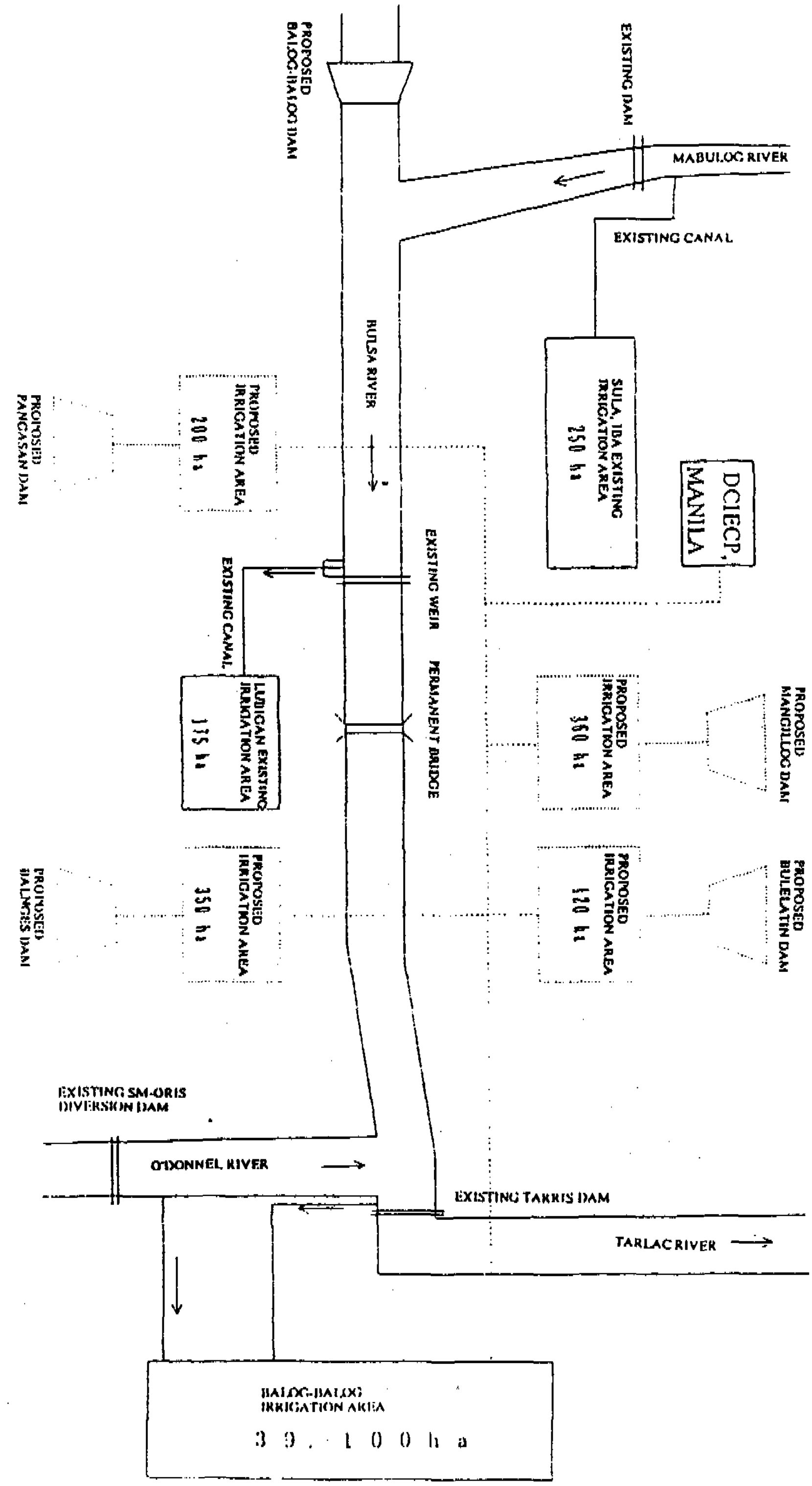


Fig.3.8.1 SCHEMATIC DIAGRAM OF DEVELOPMENT IN WESTERN BARRIOS AREA

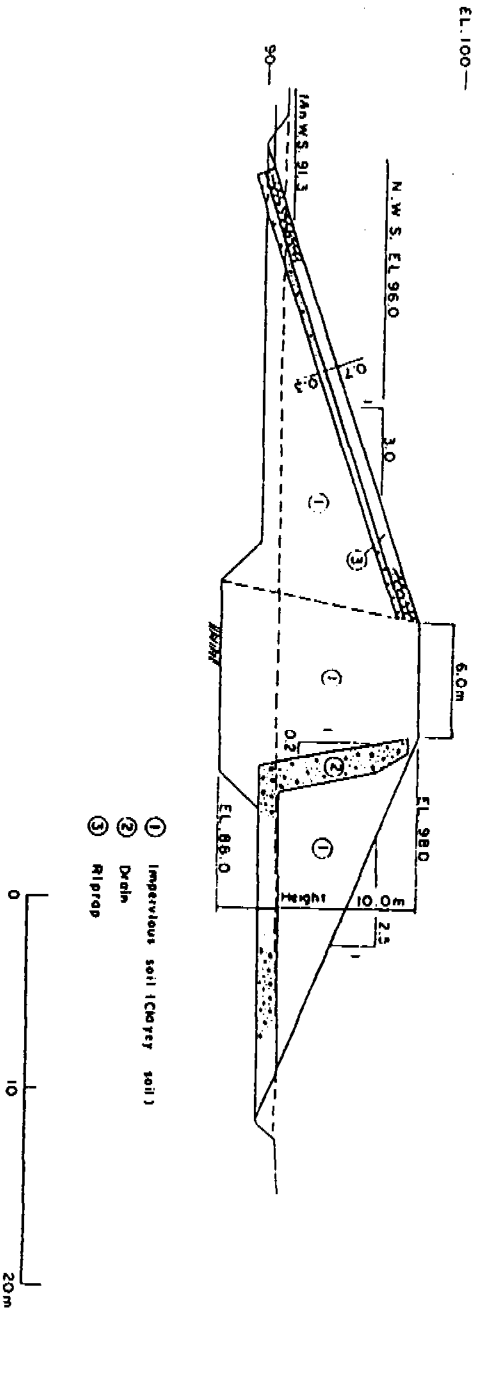


Fig.5.2 TYPICAL SECTION OF BULELATIC DAM

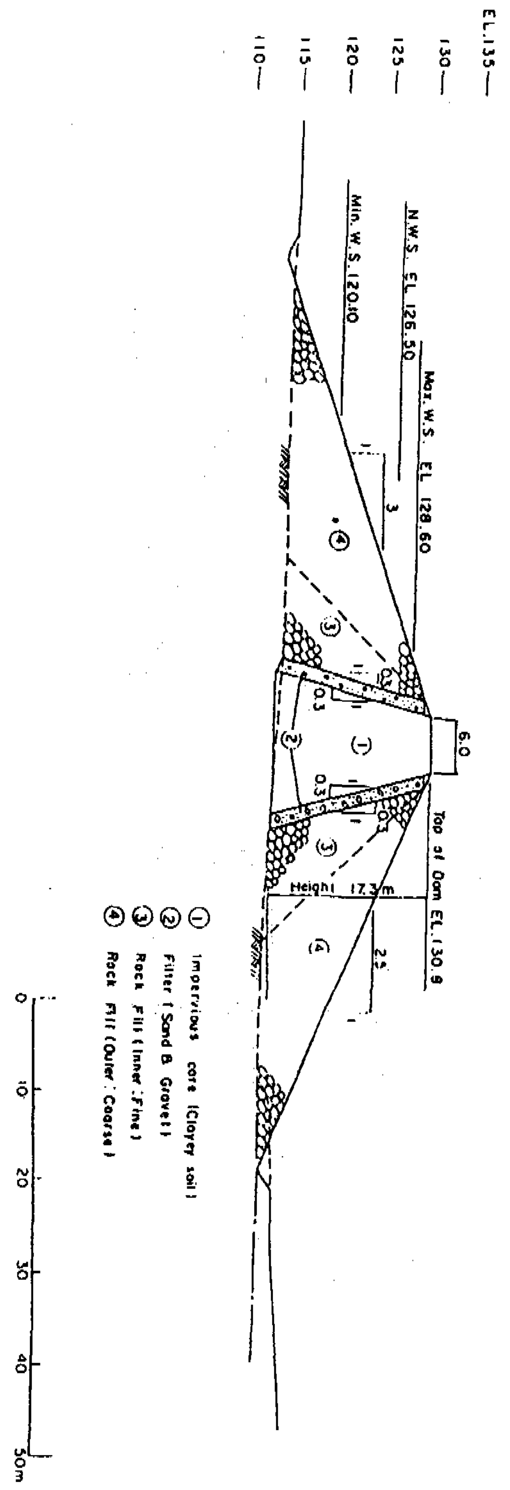


Fig.5.2.3 TYPICAL SECTION OF PANGASAN DAM

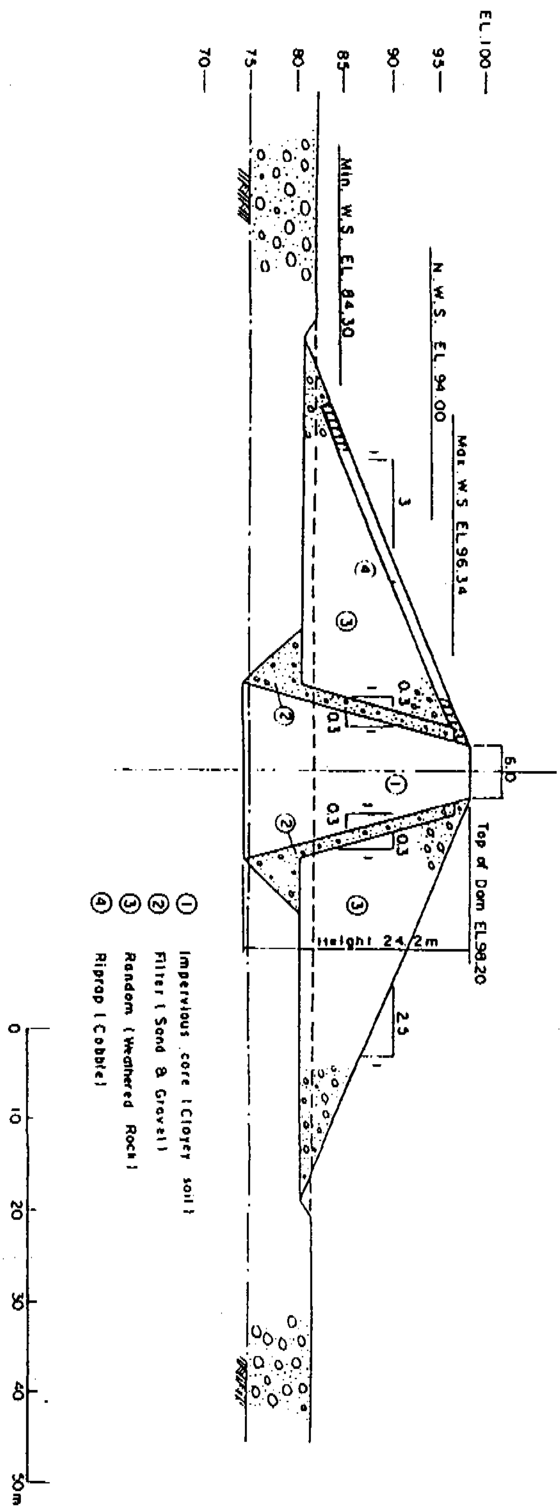
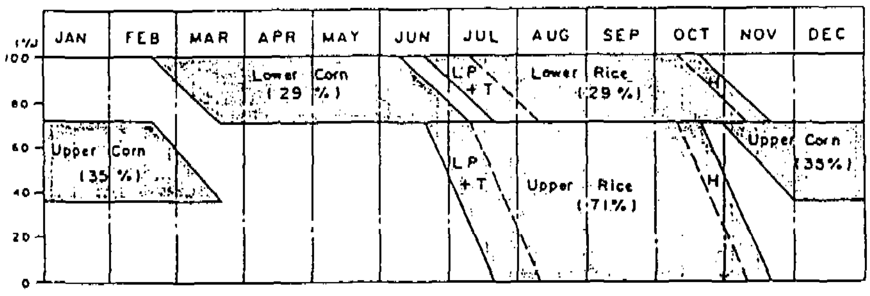
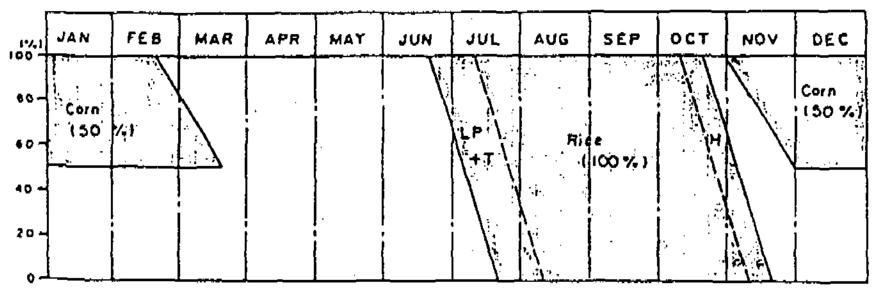


Fig.5.2.4 TYPICAL SECTION OF BALNGES DAM

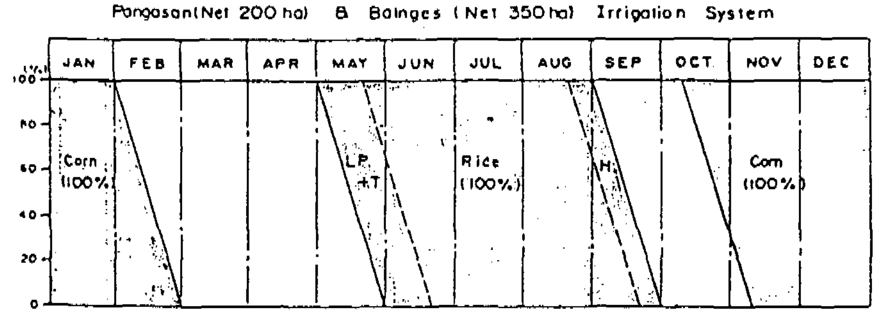
Mangillog Irrigation System (Net 360 ha)



Buleldtin Irrigation System (Net 120 ha)



Pangasan (Net 200 ha) & Balnges (Net 350 ha) Irrigation System



LEGEND:

LP = Land Preparation

T = Transplant

H = Harvest

Fig.4.31 PROPOSED CROPPING PATTERN

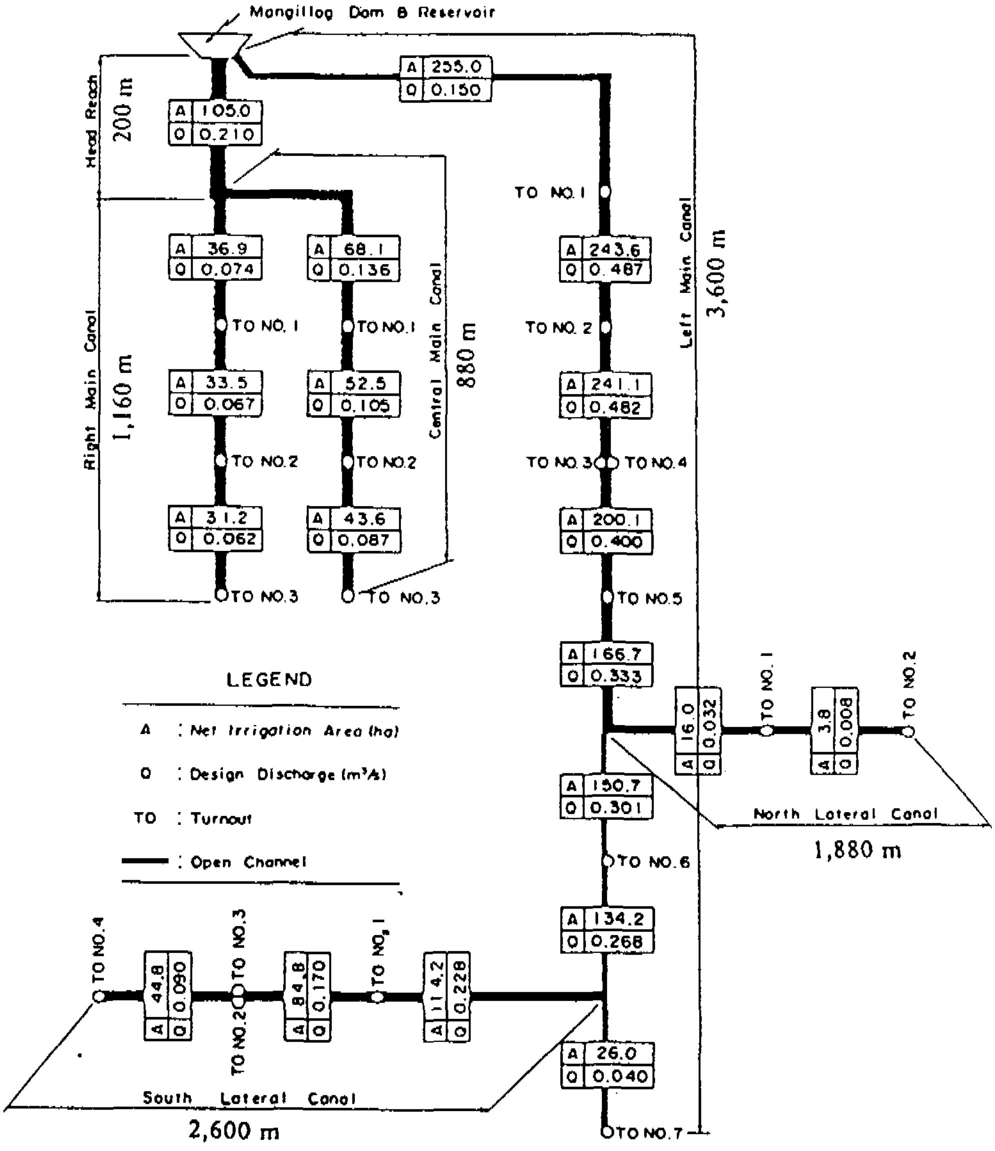


Fig.5.3.1 SCHEMATIC DIAGRAM OF MANGILLOG IRRIGATION SYSTEM

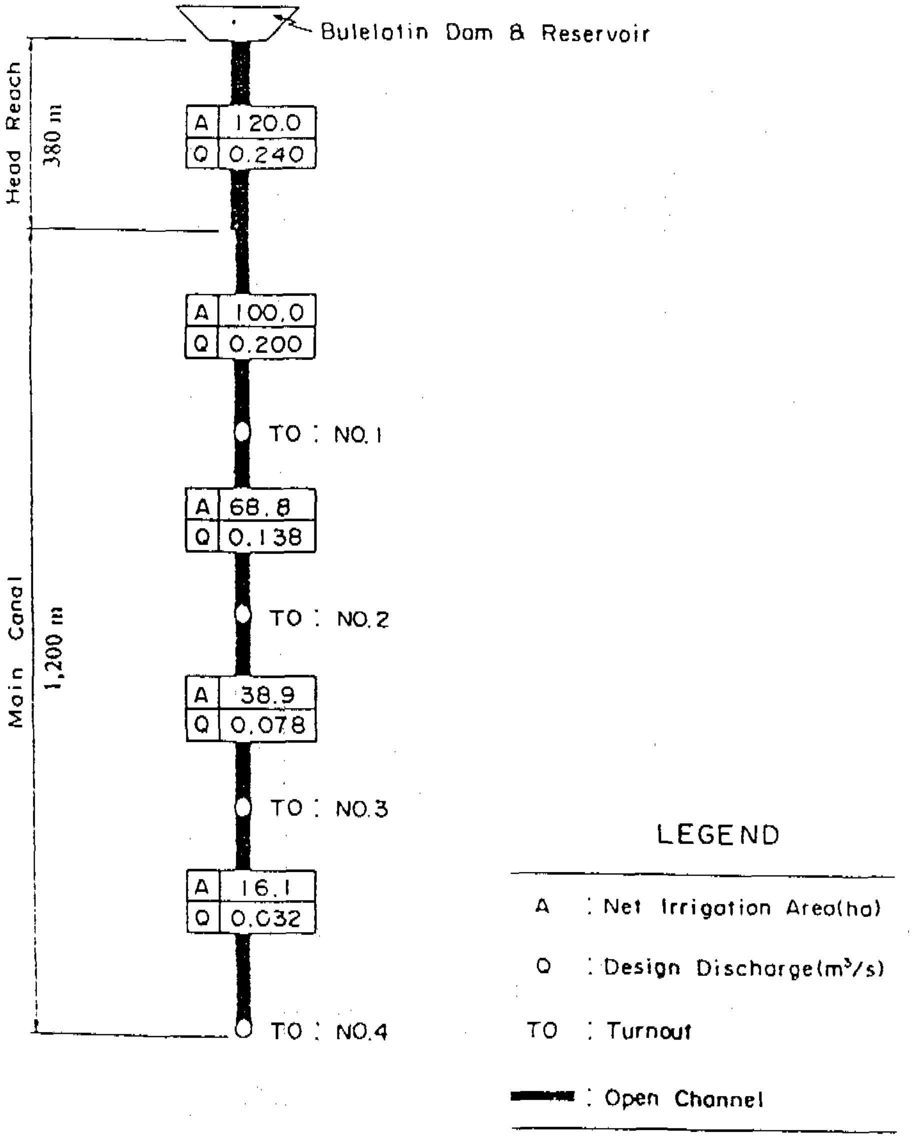


Fig.5.3.2 SCHEMATIC DIAGRAM OF BULELATIN IRRIGATION SYSTEM

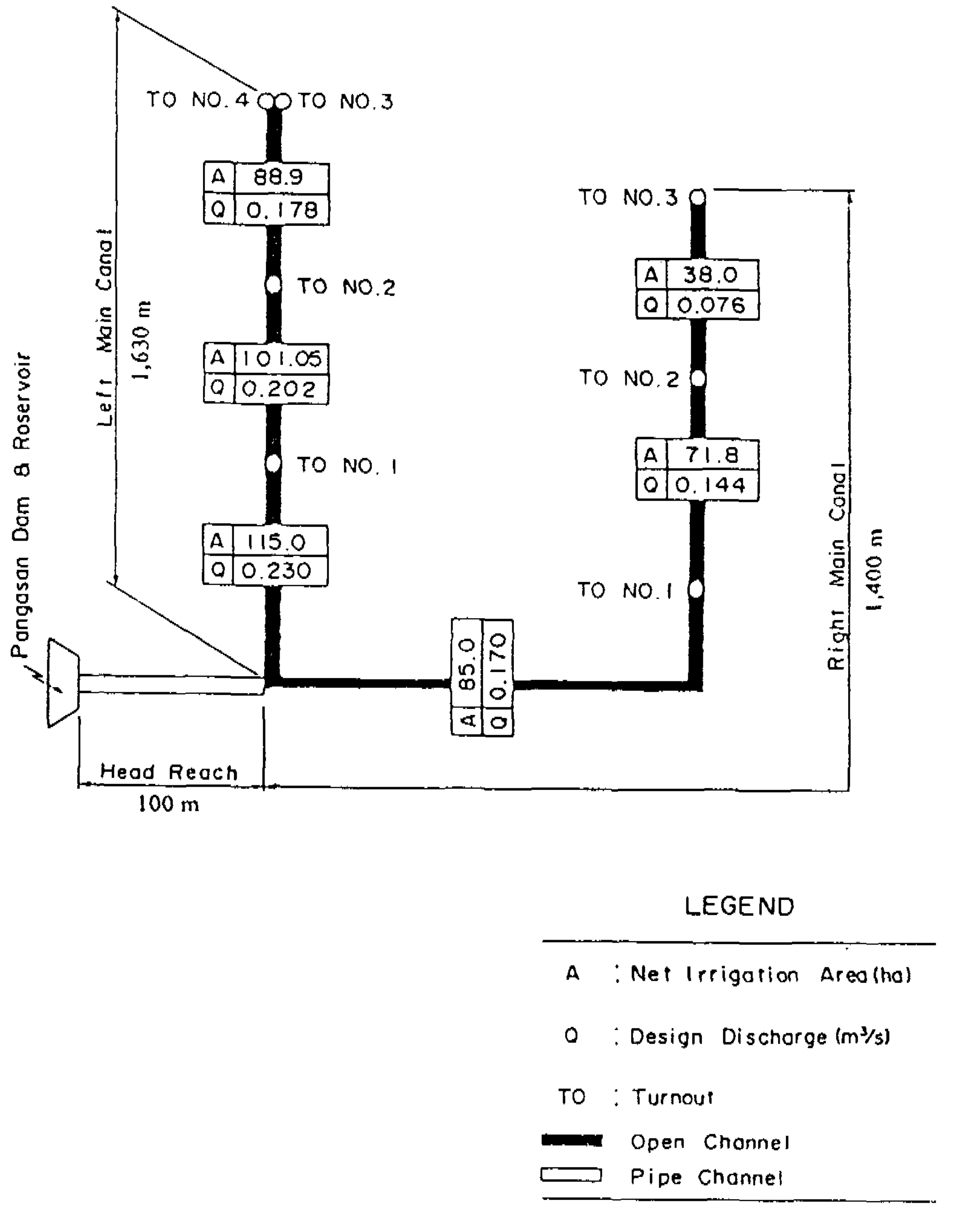


Fig.5.3.3 SCHEMATIC DIAGRAM OF PANGASAN IRRIGATION SYSTEM

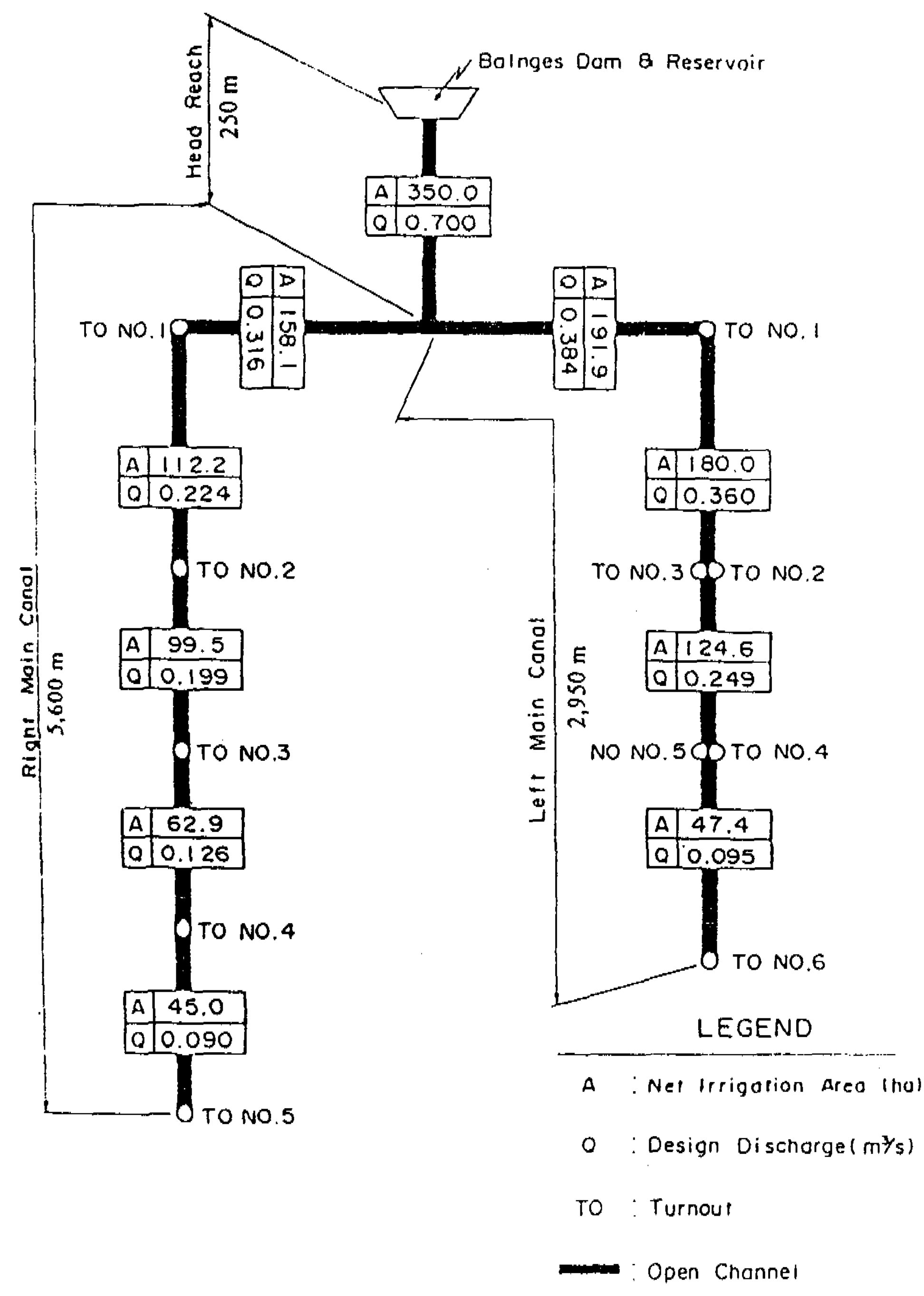


Fig.5.3.4 SCHEMATIC DIAGRAM OF BALNGES IRRIGATION SYSTEM

RAIN WATER CATCHMENT PONDS FOR IRRIGATION IN TAOYUAN AND SHIHNEN DISTRICTS, TAIWAN

Wen-Jung Hu*, Ching-Ho Kuo**

ABSTRACT

Both the Taoyuan and Shihmen Canals take water from the Shihmen Dam to irrigate farm lands amounting to 37,000ha.in the Taoyuan and Hsinchu counties of northern Taiwan.According the definite plan of the Shihmen Dam Project and the actual irrigation operation, the dam can only provides a portion or about 50%-60% of the total amount of irrigation water, and the rest is to be supplied by the regulation of irrigation farm ponds and the flow catched by local diversion weirs. The topographic conditions and soil types in these areas are generally suitable for farm pond construction and operation. Totally 686 farm ponds with capacity of 45,160,000m^3 were constructed as rain water catchment facitities and have been operated by the Irrigation Associations(IA)for irrigation for a long time.

Recently, owing to the environmental and socio-economic changes, the farm land has decreased because of industrialization and urbanization. Review on the capacity of the farm ponds was, therefore,considered necessary so as to keep pace with the reduction of irrigation area. A mathematical model based on the theory of linear programming has been studied for reviewing and planning to determine the necessary capacity of the farm ponds. By computer manipulation of the linear programming, the results appeared that the farm ponds still play a very important role for irrigation in this area. If the farm ponds provide 35% or more of the irrigation water, the total capacity of the farm ponds should be reduced by reducing the farm lands. As the result of the study, the purpose of effective utilization of land and water resources in Shihmen Dam service area can be realized.

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1 . INTRODUCTION

There are tremendous terraced tableland totalling about 53,000ha. located in the Taoyuan and Hsinchu counties of northern Taiwan. With an elevation from 240m. to the sea level and an average land slope of one hundredth declining towards the Taiwan Strait, this area is one of the important rice production districts in Taiwan. The soil type in this area is mainly latozolic soil with low permeability.Owing to the timely uneven-distribution of rainfall in this area, irrigation is indespensable for rice production. Of course,irrigation performance depends on the availability of water sources and facilities as well as good management practices. The topographic conditions and soil types in this area are suitable for pond construction and operation. Before construction of the Taoyuan and Shihmen Canal irrigation systems, thousands of farm ponds were already built and used by the local farmers themselves like "rain water cisterns" for irrigation. Most of the farm ponds were small in size, irregularly located, and privately owned, it was very difficult for the farmers to store enough rain water to carry out irrigation. Therefore, water shortage for irrigation occurred very often until the completion of the Shihmen Dam Project, which may supplement the deficit to the ponds in addition to the collected rain water.

The Shihmen Dam, located on the upper reach of the Tahan River (Figure 1), about 50 km.southwest of Taipei, is the first multi-purpose project completed in 1964 for irrigation, power generation, water supply and flood control.The dam has an effective capacity of about 251,000,000m^3. Irrigation is one of the major function of the dam. The Taoyuan and Shihmen Canals are the two main irrigation water supply systems of the dam (Figure 1). The irrigation area of the dam originally planned was 56,318ha.scattered in the Taipei, Taoyuan and Hsinchu counties, among which 21,926ha. of the farm land in the southern part located in elevation from 240m. to 100m. are irrigated by the newly built Shihmen Canal System, about 29,500ha. of farm land in northern part located in elevation from 100m to the sea level are irrigated by the existing Taoyuan Canal System, and the rest is irrigated by the other small systems.

According to the definite plan report of the Shihmen Dam project, the dam can only provide 48% and 50% of the total irrigation water to the Shihmen Canal system and the Taoyuan Canal System respectively. Therefore,the deficit of the irrigation water for the canal systems amounting to about 50% should still be supplied with rain water and local return flow collected and regulated by the farm ponds (TPWCB,1964;Taoyuan 1984). The farm ponds, hence composed a series of small dams and play a very important role for irrigation in this area even after the completion of the Shihmen Dam.Owing to the recent environmental and socio-economic changes, the farm land has been largely decreased because of industrialization and urbanization. Review on the number of farm ponds was considered necessary and some improvement works to consolidate the ponds also has been carried out (Shihmen IA,1978 & 1981).

2 . DESCRIPTION OF FARM PONDS IN TAOYUAN AND SHIHMEN DISTRICTS

2.1 Farm ponds in the Taoyuan Canal irrigation area.

The Taoyuan Canal Irrigation System, which originally took water from the Tahan River directly after its completion in 1936, takes water from the afterbay weir after the completion of the Shihmen Dam. Before completion of the canal system, there were already about 8,000 private farm ponds with area totalling about 7,600ha. in the area (Taoyuan IA,1984). They were used and operated as the main irrigation water source. Because these farm ponds were all rainfed, the water source for irrigation was very unstable and water shortage happened very often at that time. In order to effectively regulate rain water for increasing land use, the privately owned small farm ponds were consolidated and remodeled during construction of the system. As the result, the numerous small ponds were reduced and enlarged to 241 and the ownership was truned over to the Taoyuan A for better operation and management of the ponds. These farm ponds each with an area from 27ha. to 3ha,water depth from 7.5m.to 1.2m,and capacity from 643,000m^3 to 21,200m^3 were well planned and located within the irrigated area(Figure2).With the socio-economic changes in the area and steady water supply from the Dam, the 241 farm ponds were later reduced to 226.The numbers,areas and capacities of the ponds located in the individual laterals are listed in Table1.

2.2 Farm ponds in the shihmen Canal irrigation area.

Similar to those in the Taoyuan area, originally there were 3,179 farm ponds with total area of 3,115ha. and capacity of 27,000,000m3(Shihmem IA,1988)in the area. They were owned and used by the local framers themselves also as rain water catchment facilities for irrigation before completion of the Shihmen Canal System in 1964. The number of the ponds were too many for the IA to carry out irrigation operation and management, especially these farm

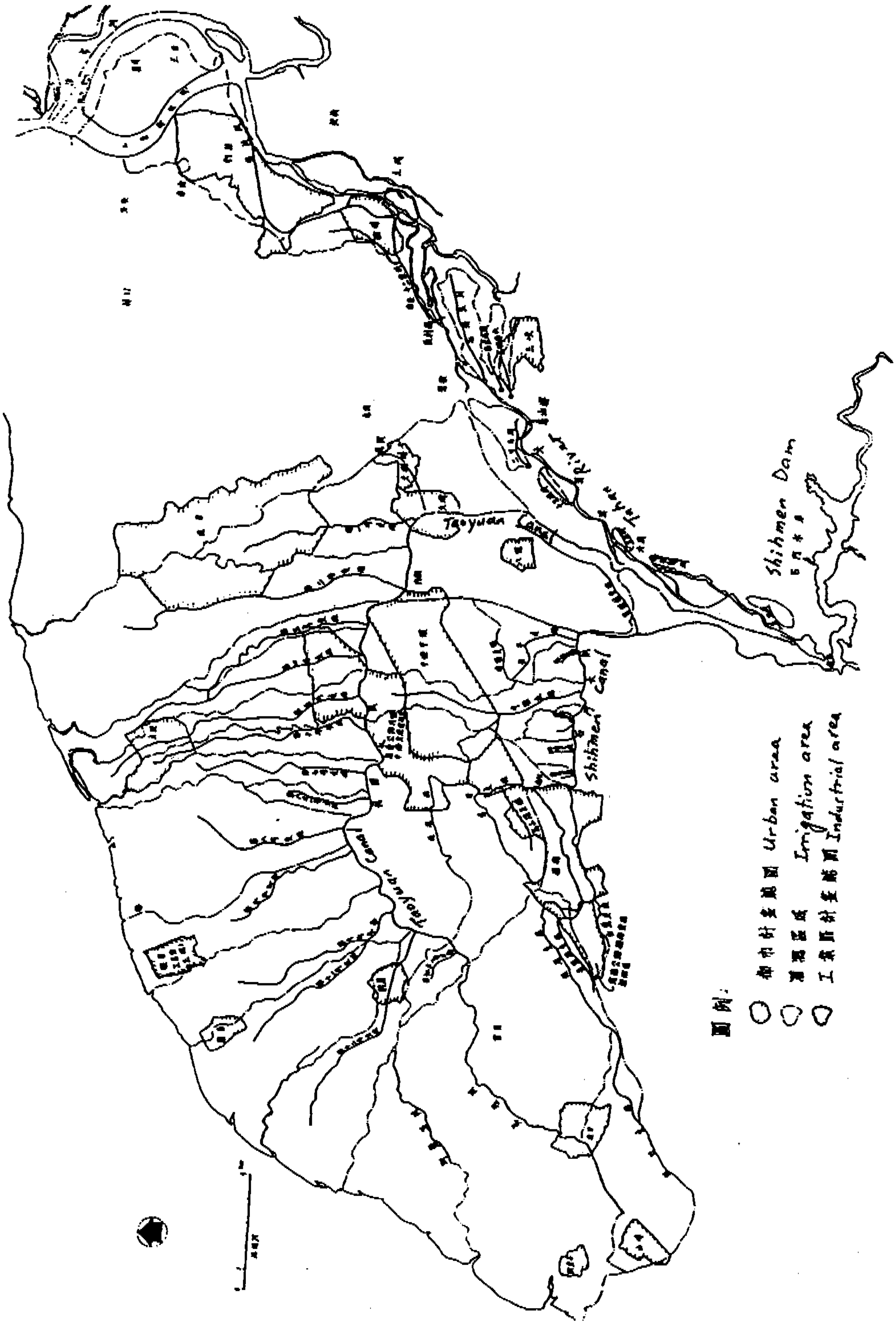

Figure 1. Shihmen Dam and its two irrigation canal systems.

Table 1 Farm ponds in Taoyuan Canal System

Lateral No.	Number of ponds	Pond area(ha)	Effective capacity (10 m3)
1	9	76	1,150
2	33	318	4,610
3	6	24	340
4	14	113	1,960
5	14	124	2,030
6	14	90	1,600
7	11	99	1,920
8	32	276	4,890
8-1	5	34	670
9	17	135	2,880
10 and 11	36	471	6,210
12	16	175	2,980
12-1	4	21	320
Kokokung canal	15	106	2,140
Total	226	2,062	33,690

ponds were very difficult to put into conjunction use together with the canal system due to their irregular locations and poor connection facilities. An improvement project for the farm ponds was proposed after the completion of the canal system. A total farm pond capacity of 25,000,000m3 was originally planned by the Taiwan Provincial Water Conservancy Bureau (TPWCB) in 1964(TPWCB,1964), and 850 farm ponds were selected from the existing 3,179 for improvement to meet the required/planned capacity(TPWCB,1964). However, recently the number and the total capacity of the farm ponds were further studied and reduced. Based on the existing irrigation area of 12,513ha, the originally planned farm pond capacity of 25,000,000m3 for the irrigation area of 21,926ha. was revised to 12,000,000m3 and the number of farm ponds was reduced accordingly from 850 to 460(Shihmem IA, 1978&1981).Their individual areas and capacities of each lateral are listed in Table 2.

2.3 Engineering features of the farm ponds.

Since a farm pond is like a small reservoir surrounded by an earth dike to impound and store water for irrigation use (Figure 3). Besides, stone pitching is needed to protect the earth embankment, and a spillway is also constructed to spill out the excess water in ponds (Figure 4,5). Four types of outlet gates are used to release water from the pond. Their typical drawings are shown in Figure 6.

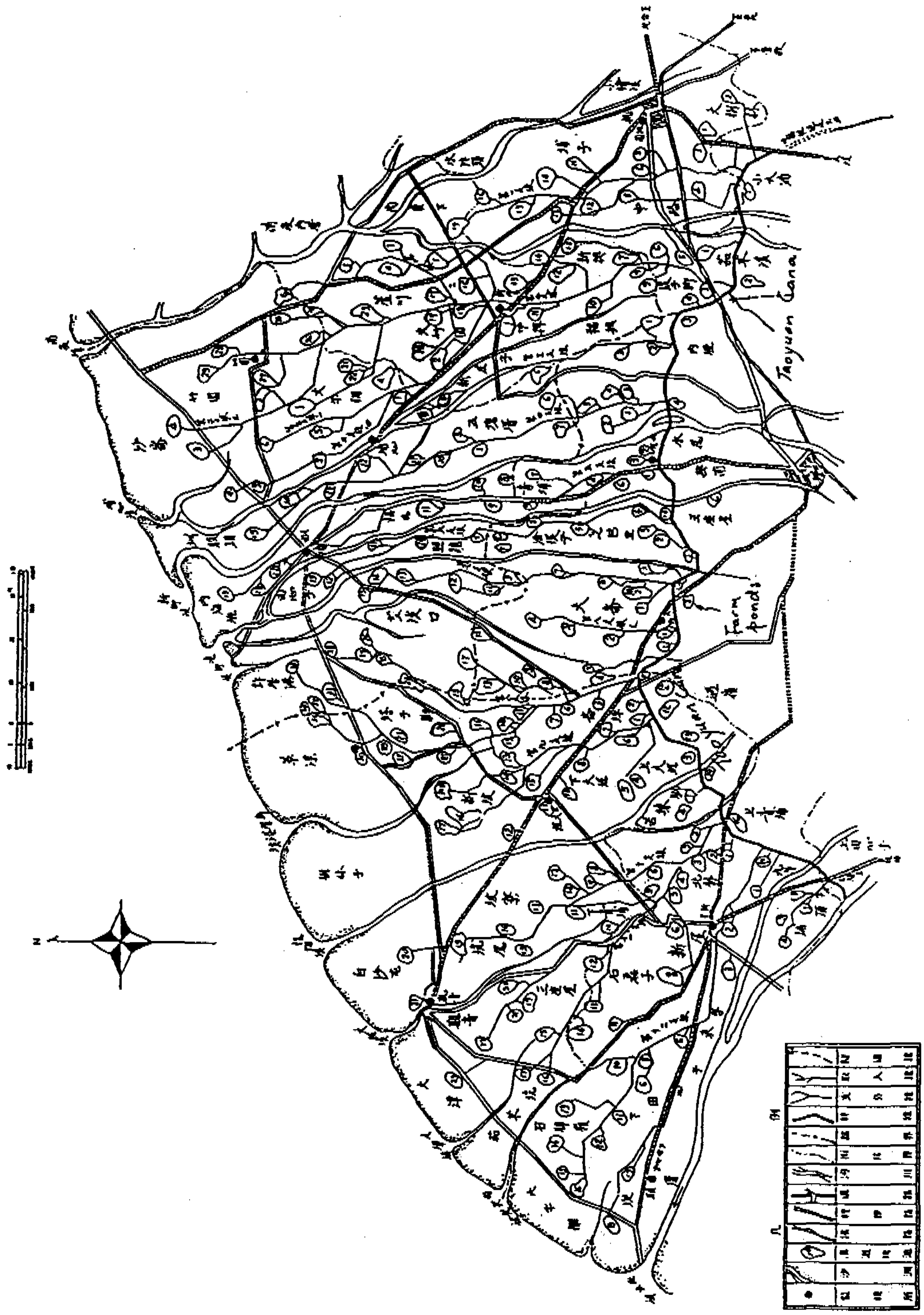

Figure 2. General location of farm ponds in Taoyuan irrigated area.

Table 2. Farm ponds in Shihmen Canal System

Laterals	Number of ponds	Pond area(ha)	Effective capacity(10 m3)
Yuan-su-lin	84	229	1,616
Pu-tin	27	75	559
Chung-lee	21	54	183
Tong-shu	6	9	37
Nung-shu	5	8	39
Sir-tzu	6	19	218
Ping-tsen	5	8	51
Kuo-lin	91	296	2,372
Kao-shan-tin	9	11	79
Shan-see	2	6	46
Shan-do	15	12	76
Kuan-tin	61	130	1,284
Raw-lin	89	252	3,712
Tsang-kang-lin	9	4	34
Hu-kuo	30	103	1,163
Total	460	1,216	11,470

3. FARM POND OPERATION

3.1 Operation rules

Since the irrigation water in this area comes from the Shihmen Dam, farm ponds and diversion weirs as mentioned above, the irrigation water conveyance system is depicted in Figure 7. Due to the complexity and diversity of distribution systems and different water sources, a set of operation rules has been drawn up as follows:

(1).The farm ponds which take water from diversion weirs shall store stream water as much as possible in order to save the water to be released from the Shihmen Dam.

(2).The farm ponds shall collect surface run off as much as possible from their respective catchment area.

(3).When additional water beyound irrigation can be delivered from the Shihmen Dam, the larger farm ponds or those which do not take water from local streams shall be first priority to store the water released from the Dam.

(4).When the rice irrigation season is over, canals shall continuously convey the water from the Dam and diversion weirs to fill up all the farm ponds as much as possible, except those

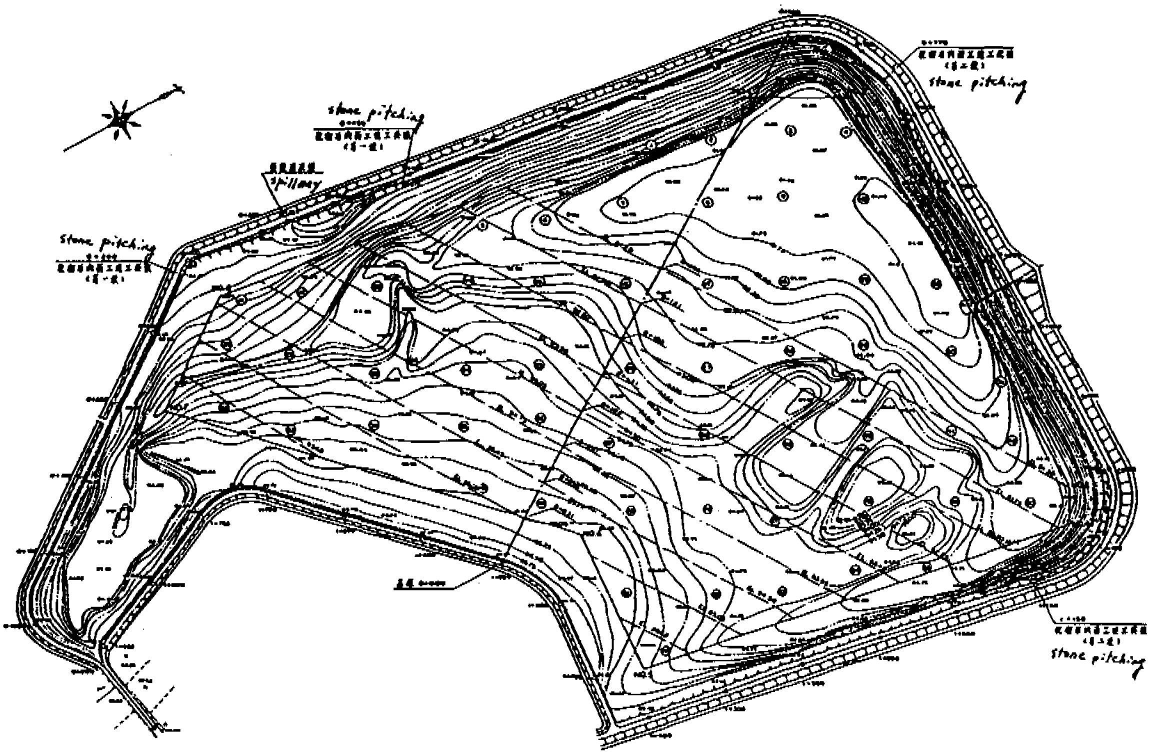

Figure 3. Typical farm pond.

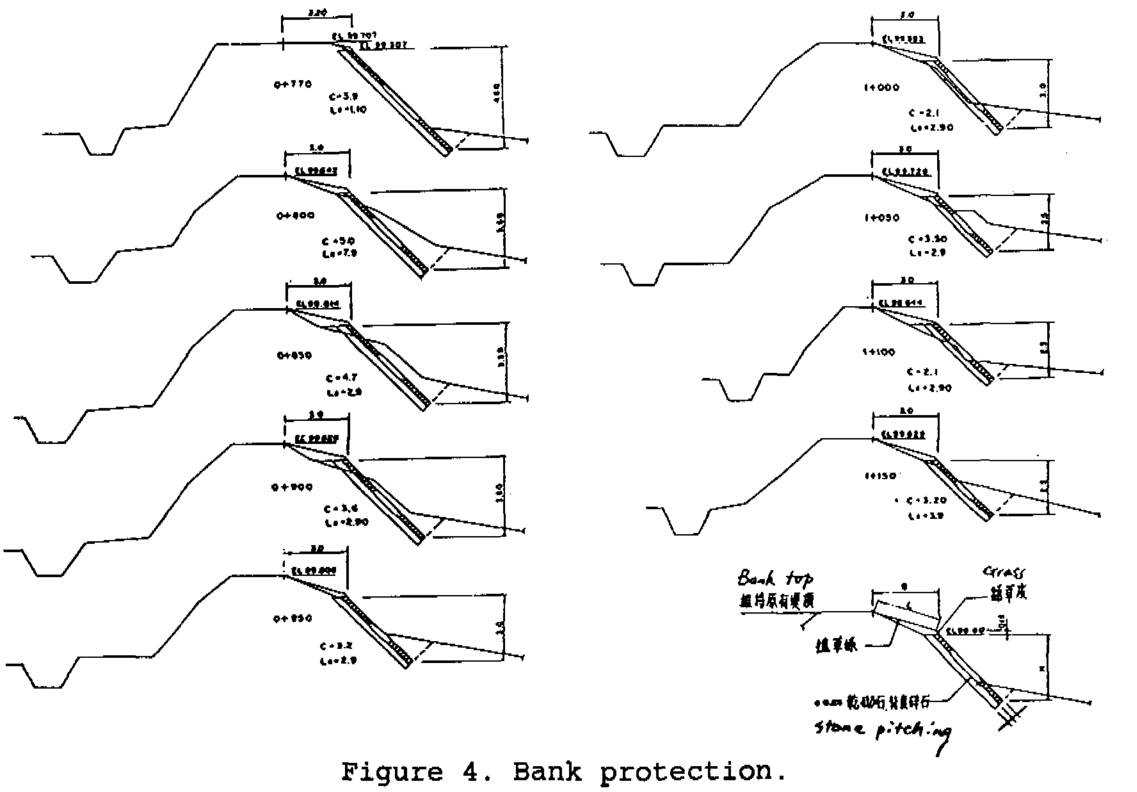

Figure 4. Bank protection.

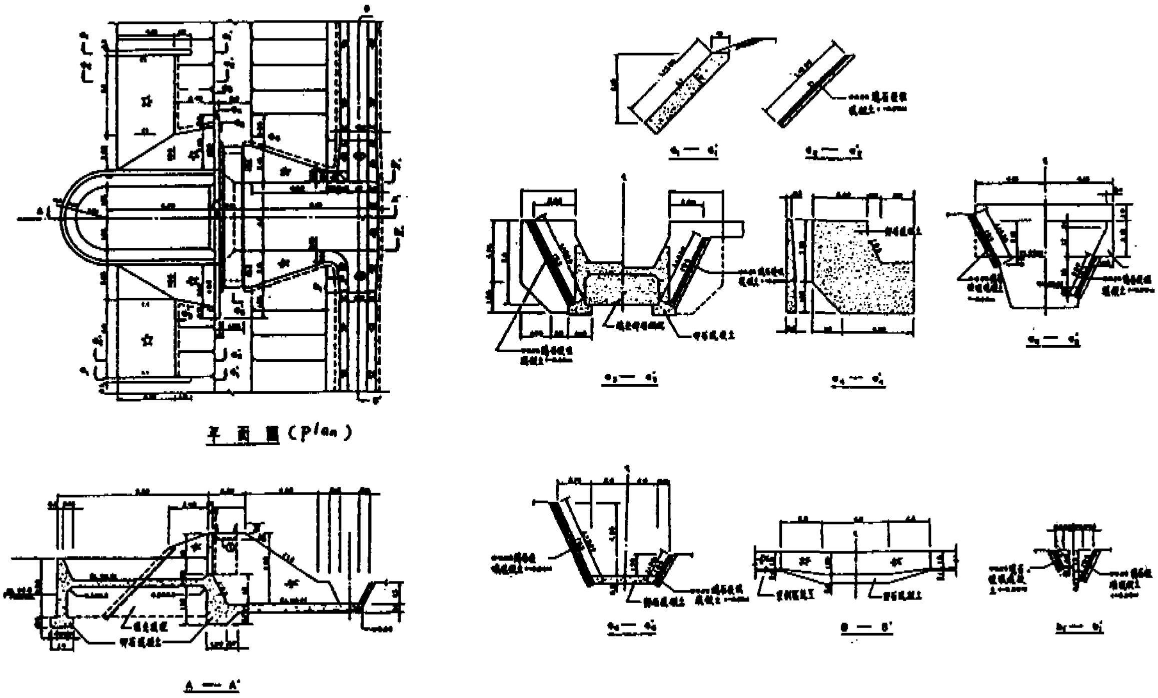

Figure 5. Standard design of spilway.

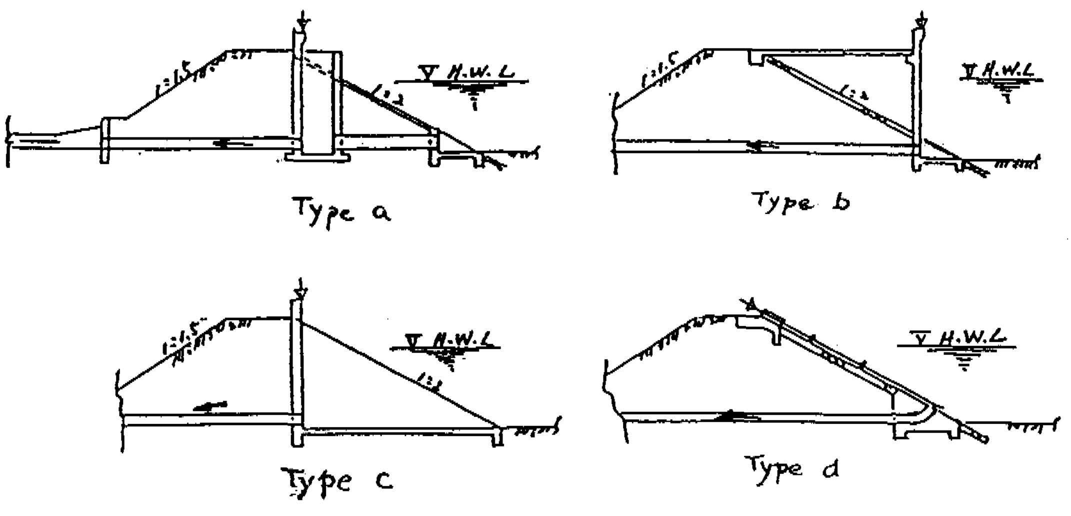

Figure 6. Types of outlet gate.

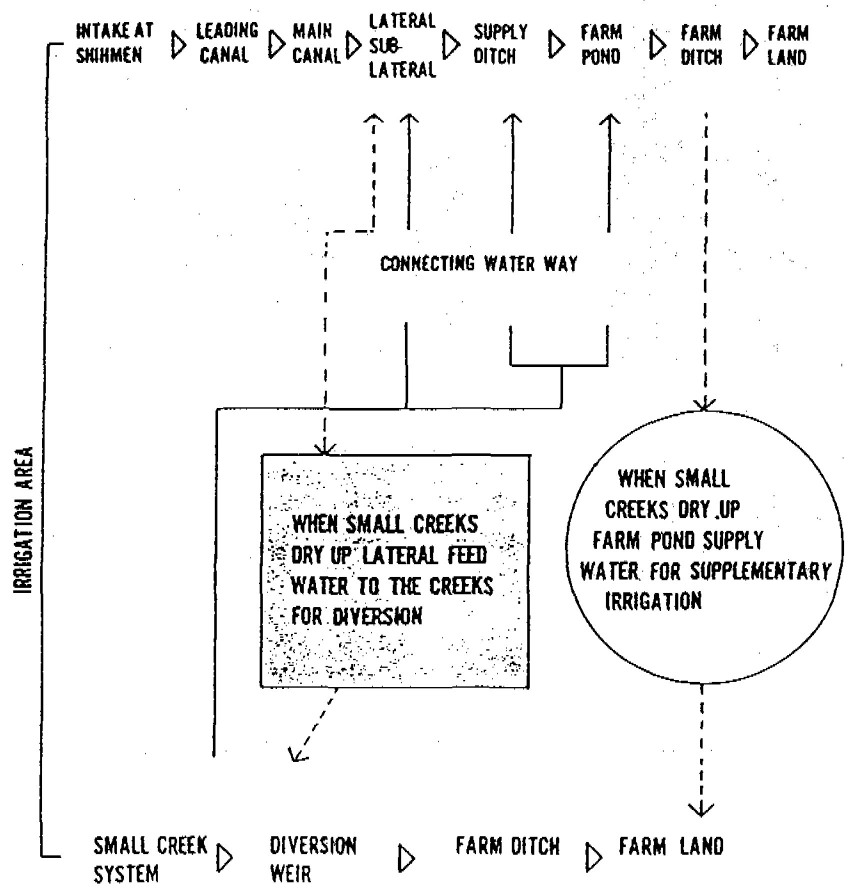

Figure 7. Irrigation Water Conveyance System in Taoyuan.

facilities need to be repaired.

(5).All the outlet gates of the farm ponds have to be closed during non-rice irrigation season except those for irrigating upland crops.

(6).Possible measures must be made to obtain the maximum storage by collecting run-off due to rainfall in the streams/the catchment areas. This in turn will save more water in the Dam for release in dry season or other uses.

3.2 Actual operation

Based on the above operation rules, an illustrative example of irrigation practices being undertaken by the Taoyuan and Shihmen IAs in 1986 id listed in the following Table 3.

Table 3. Irrigation practices of Taoyuan & Shihmen IAs in 1986

Irrigation District	Irrigation area (ha.)	Farm irrigation requirement (10 m3)	Gross irrigation requirement (10 m3)	Supplied by weirs and ponds (10 m3)	Supplied by canal (10 m3)	Percentge (%) Weir	Canal
Taoyuan IA	21,181	340,780	397,871	140,577	257,294	35	65
Shihmen IA	11,167	139,861	163,579	40,994	122,585	25	75

The original irrigation areas served by the Taoyuan and Shihmen Canal System were 29,500ha. and 21,926ha. respectively. Actually,the irrigation water released from the Shihmen Dam has been reduced in accordance with the decrease of the irrigation area as shown in Table 3.Although irrigation is the major purpose of the Shihmen Dam Project,the two IAs can only obtain about the original percentage of irrigation water for actual operation according to the so-called"M5 water allocation rule", which was set up in the definite plan report of the project. This means that less water is released from the Dam by proportion of the area.

The " M5 water allocation rule " is a water distribution guidance for the Dam to supply water to different water users. It was established on the basis of the normal operation under the normal inflow of the Dam. However, actual amount of water to be released for irrigation depends on availability of storage in the Dam and climate condition of the year.

Because the Taoyuan and Shihmen Canals still cannot take sufficient amount of water from the Dam to meet the irrigation requirement, and for effective utilization of all the water sources, it is necessary to maintain certain number of farm ponds to collect rain water and to regulate local stream flow for supplementary supply.

4. MODEL FOR FARM POND IMPROVEMENT

As mentioned above, there are so many existing farm ponds, especially in the Shihmen district.They are difficult for the IA to carry out irrigation operation and management. An improvement project of the farm ponds was proposed after the completion of the Shihmen Dam Project. A planning model with Rippl Diagram method was applied by the TPWCB in 1964(TPWCB,1964). Further review with a mathematical model based on the theory of linear programming was also conducted in 1978 and 1989(shihmen IA,1978&1981).

4.1 Model formulation (Hu and Wen,1987)
The parameters included in the farm pond operation are shown in Figure 8.

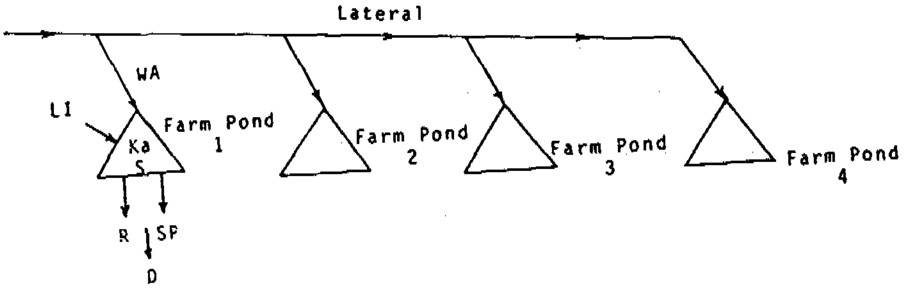

Figure 8. Farm pond operation parameters

where

WA is the amount of water allocated from dam into individual farm pond.

LI is amount of water diverted from river into individual farm pond.

Ka is the farm pond capacity.

S is the farm pond storage.

R is the amount of water released from the farm pond.

SP is the spillage from the farm pond.

D is the irrigation water requirement.

For determining an optimal farm pond capacity, the following two assumptions are made:

(1).The farm pond capacity (Ka) is fixed to the possible existing farm pond capacity for finding the minimum water allocation from the dam (WA).

(2). The water allocation from the dam (WA) is given according to the M5 water allocation rule for finding the minimum farm pond capacity(Ka).

4.2 Mathematical models

From the above assumptions, two optimization models with the objective function of minimized dam allocation and that of minimized farm pond capacity are then formulated separately by applying the linear programming theory. For the actual field irrigation practices, the " yearly use method "and "ten-day time interval "are usually used in the farm pond operation. It means that no water is left to next year for use, and that there are 36 intervals in a year. The proposed two mathematical models are as follows:

(1) Model A

a. objective function

minimize $\sum_{t=1}^{36} WA(t)$

b. constraints

$S(t+1)-S(t)=WA(t)+LI(t)-R(t)-SP(t)$

$R(t)\geqq D(t)$

$S(1)=S(37)$

$S(t)\leqq Ka \qquad t=1,\cdots\cdots,36$

(2) Model B

a. objective function

minimize Ka

b. constraints

$S(t+1)-S(t)=WA(t)+LI(t)-R(t)-SP(t)$

$R(t)\geqq D(t)$

$S(1)=S(37)$

$S(t)\leqq Ka \qquad t=1,\cdots\cdots,36$

where:

t denotes the number of sequential ten-day intervals.

S(37) is the farm pond storage of the first time interval of the next year, which equals to S(1).

4.3 Model application and discussions

According to the irrigation areas, soil properties, cropping patterns, catchment areas, rainfall data, etc, the amount of irrigation water and the diversion water can be determined.By running a computer with linear programming, the desirable results from both two models are obtained as follows:

(1). The farm pond capacity determined by Model A is larger than Model B.

(2). The yearly water allocation of Model B from the Dam is larger than Model A.

(3). If Model B is adopted and the water allocation from the Dam to the two Canal Systems is according to the original "M5 water allocation rule ", the capacity of the farm ponds will be reduced in accordance with the reduced irrigation area, and more farm lands can be obtained from the abolished farm ponds for agricultural use.

(4). In the Shihmen Canal irrigation area, the yearly water allocated from the Dam is reduced from 90 cms-month to 55.6cms-month in accordance with the existing irrigation area of 12,513ha. since 1988, and the total pond capacity is revised from 25,000,000m3 to 10,000,000m3 by using Model B to fit the present situation.

(5). According to the present situation, the yearly irrigation water requirement in the Shihmen Canal is 237,950,000m3 of which 144,370,000m3(equivalent to 55.6cms-month) is supplied by the Dam and the rest of 93,580,000m3 or 39% is provided by the farm ponds.

(6). Till now, there are 89 farm ponds with total capacity 5,936,930m3 have been improved in the Shihmen Canal irrigation area. Totalling 48,228,370m3 of irrigation water have been regulated by the improved farm ponds yearly. It means that an average frequency of using the farm ponds reaches 8.12 times annually. In other words, these improved farm ponds have been effectively put into good function.

5. COUSLUSION

The irrigation farm ponds in the Shihmen Dam irrigated area are the rain water catchment facilities and the important farm infra-structures. The capacity of the farm ponds should be reviewed periodically owing to the reduction of the irrigated lands resulted from industrialization and urbanization. Although the two IAs may request the Dam Administration Bureau to release enough irrigation water according to the "M5 water allocation rule " and to abolish some of the farm ponds, actually most of the irrigation water are firstly released from the farm ponds in order to save the water stored in the Dam for effective use.

Because the farm ponds provide 35% or more of the total irrigation water, they are very important in this area. Their capacities should be adjusted or reduced according to the reduced irrigation area. A mathematical model based on the theory of linear programming could be applied for checking. By computer manipulation of the linear programming,the total farm pond capacities of individual pond can also be determined for engineering improvement. In this way, effective utilization of land and water resources could also be achieved.

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THE MERITS OF SMOOTHING IRRIGATION FURROWS TO IMPROVE THE UNIFORMITY AND REDUCE THE TOTAL APPLICATION OF IRRIGATION WATER

Ebrahim Hejrati*

Summary

The infiltration rate changes with time. It is a fairly high value when the soil is first wetted, then it quickly decreases to a much smaller, but stable, rate known as the basic infiltration rate. There are many factors which will change the initial part of the infiltration curve, the two major factors are the soil moisture content before irrigating and the surface roughness. Smoothing the roughness in a furrow acts to speed up the furrow advance and the recession so that for a given inflow time the opportunity time remains nearly constant. The accumulated infiltration is a function of the opportunity time and the infiltration rate curve for the particular soil. The uniformity of the water which is infiltrated into a soil is dependent on the uniformity of the opportunity time along the length of the furrow being irrigated.

The data reported were collected during the third irrigation in a field planted to corn on a silty loam soil in Eastern Nabras. Two basic ditching treatments, using a conventional ditcher and using a Haw kins ditcher, were each compared with and without an additional smoothing operation.

Smoothing the furrows increased the uniformity coefficients for the opportunity times along the furrow in both ditching methods. No test of significance was conducted on the data due to the lack of replications.

Reducing the roughness coefficient by smoothing the furrows speeded up the furrow stream advance which would have allowed a shorter set time, thereby reducing the total application of water. The objective of applying 2 inches of water could have been achieved if the well had been shut off sooner. This would not have adversely affected the uniformity of water application.

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EXPERIMENTAL PROCEDURE

Treatment Layout

The experimental plots used in this study were located on the Agricultural Engineering test site at the University of Nebraska Field Laboratory at Mead, Nebraska. The soil was a Sharpsburg silty clay loam that had been graded ten years before to a slope of approximately 0.2 percent. The field was planted to corn. There had been two irrigations prior to the tests reported.

Four treatments were applied to the field. Two ditching or furrowing machines were used, a conventional ditcher with a shovel and two disk openers and a new type ditcher made by Hawkins manufacturing incorporated which uses a blade and bedding rails to push the soil into the row horizontally. In each of the plots which were ditched by one of these machines, half of the furrows were also smoothed by a packer wheel which was attached to the ditcher. The packer wheel followed the ditcher unit at a distance of about 3.5 feet crushing the clods which rolled into the furrow after the ditcher passed by. Thus the four treatments were:
Conventional Ditcher, Conventional Ditcher plus Smoothing, Hawkins Ditcher, Hawkins Ditcher plus Smoothing.

The layout of the plots in the field is shown in figure 5. Not shown in the plot layout is the discard area which is directly to the west of the plot area.

At the time of ditching, two sets of furrows were marked in each of the plots, as shown in Figure 6. A wheel track furrow and an adjacent soft or untraveled furrow were flagged in each half of the plot. The plots were also marked at each one hundred foot station down the length of the field. To prevent confusion later on, furrows were chosen so that the wheel furrow, in each pair of furrows, was always on the west and the soft furrow on the east.

One of the pairs of furrows in each plot was designated for the furrow stream advance and recession. The other pair of furrows were those furrows which ran on either side of the moisture block stations.

The furrows were chosen so that they were located in the central portion of each six row half of the plot with at least one ditched furrow on each side of the instrumented furrows. This was required since the Hawkins ditcher only ditched the central five furrows out of each six rows.

Eight furrows per plot were irrigated at the time of the experiment. The two pairs of furrows already mentioned, and the two furrows adjacent to each of these pairs.

The total water applied to the field was measured using Sparling in-line water meters on the main well and on the reuse pump. The well output was 1050 gallons per minute with 6.5 pounds pressure. The gates were adjusted using flumes placed in the furrows so that 25 gallons per minute entered each furrow. All treatments were irrigated at the same time, using 800 of the 1050 gallons per minute output of the well. The remaining water was used on the discard area to the west of the plots.

FURROW STREAM ADVANCE AND RECESSION

A wheel track and a soft furrow were selected in each treatment as previously described. The advance and recession times were recorded for each designated furrow at every hundred foot station. The advance was defined as the time the first visible surface water reached the point in question. The recession was said to occur at a point when the water stopped moving at that point. To check the recession, the water was stirred slightly, this caused it to become a little cloudy. If the cloudiness moved downstream, the recession had not, by definition, reached the point.

ADJUSTING THE STREAM SIZE

The furrow stream size was adjusted using 60° V-notch trapezoidal flumes placed twenty feet downstream from the gated pipe. The furrows in which the advance and recession data were taken and the furrows between which the moisture block stations were located were adjusted to 25 gallons per minute as were the furrows adjacent to these furrows.

The flumes were installed in the advance and recession furrows and left in place throughout the irrigation. The other furrows were checked using a portable flume which was carried from furrow to furrow.

SOIL MOISTURE MEASUREMENTS

Soil moisture blocks were buried in the soil at each foot from one to five feet at each moisture block station. There were three stations in each treatment, at two hundred, five hundred, and one thousand feet downstream from the head of the field. The change in the soil moisture content was calculated from the block readings by correlating them with the moisture retention characteristics of the Sharpsburg soil, and the resistance versus tension characteristics of the gypsum moisture blocks.

DATA PRESENTATION

Furrow Stream Advance and Recession

The furrow stream advance and recession was observed, as described in the procedure, for a wheel track furrow and an untraveled or soft furrow in each of the four treatments. The accumulated times for each furrow were recorded as they reached the various stations and are presented in the form of advance and recession curves in the following figures.

Figure 7 shows the advance and recession curves for treatments using a conventional ditcher with the times recorded for a wheel furrow. Figure 8 is also for the conventional ditcher only the times are for a soft or untraveled furrow. Figures 9 & 10 show the same things as figures 7 & 8 except these are for the treatments using a Hawkins ditcher. In all four figures the solid line represents the ditching without smoothing treatment and the dashed line represents the ditching plus smoothing treatments.

Opportunity Times

As stated in the review of literature, the opportunity time for any station can be calculated by finding the time elapsed between the furrow stream advance and the recession. Table 1 shows the opportunity times at the various stations in the four treatments. The average opportunity time is weighted average since, in each set of six rows which are ditched at each pass through the field, two furrows are traveled by the tractor wheels and three furrows remain untraveled. Therefore the average values were calculated using the equation:

$$\text{Average} = \frac{2\,(\text{wheel}) + 3\,(\text{soft})}{5}$$

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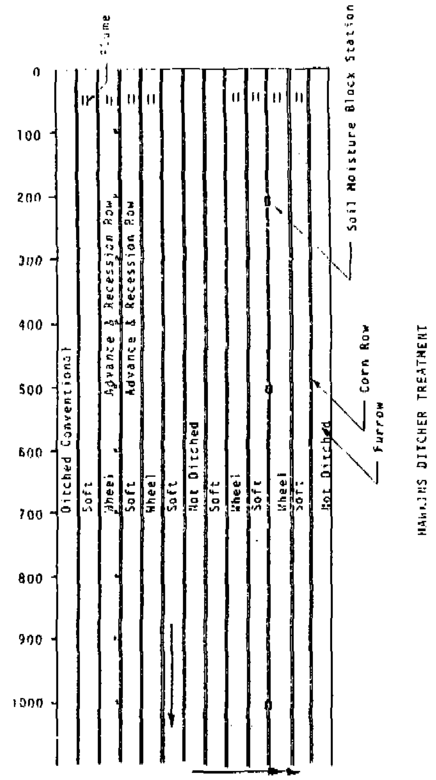

FIGURE 6. Plot layout showing flumes, station flags, and moisture block stations.

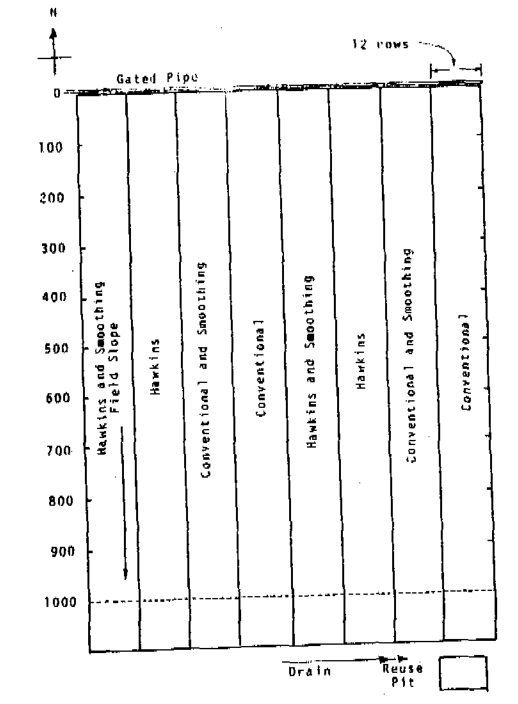

FIGURE 5. Experimental plot layout.

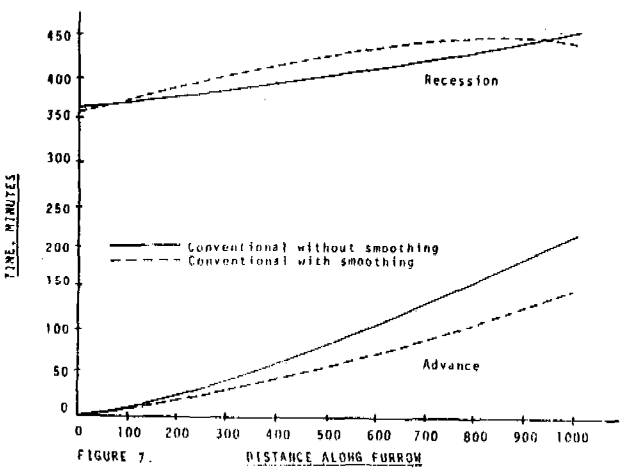

FIGURE 7.

Advance and recession curves for treatments using a conventional ditcher, wheel furrows.

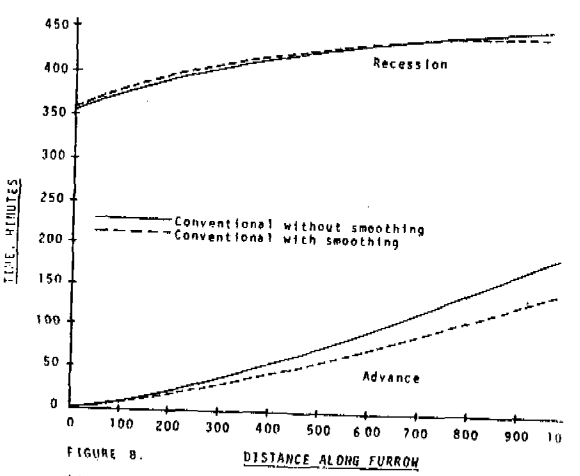

FIGURE 8.

Advance and recession curves for treatments using a convent ditcher, soft furrows.

Figure 11 represents the average opportunity times fur the four treatments in graphical form, while Figures 12 & 13 show the average opportunity times for the conventional and Hawkins ditchers respectively.

Soil Moisture Determinations

As stated in the procedure, moisture block stations were located in each treatment at the two hundred, five hundred, and one thousand foot stations. Readings were taken before, and two days after the irrigation at increments of one foot down to and including five feet.

Table 2 shows soil moisture status before and after the irrigation and the estimated depth of water stored in the root zone at each station in the four treatments. The estimated depth of water stored was calculated using Figure 14 which was derived by using Figure 15 and 16 in the appendix.

Table 1. Opportunity times and Uniformity Coefficients for the treatments using a conventional ditcher

CONVENTIONAL

Sta.	Wheel	Soft	Ave.
	min.	min.	min.
0	358	358	358
1	372	372	372
2	363	367	365
3	346	351	349
4	329	358	346
5	316	324	321
6	305	315	311
7	292	304	299
8	275	293	286
9	262	293	281
10	248	290	267

Cu = 1 - y / d

Cu = 1 - 31.7 / 323.2

Cu = 0.90

CONVENTIONAL and SMOOTHING

Sta.	Wheel	Soft	Ave.
	min.	min.	min.
0	358	358	358
1	377	375	376
2	378	370	373
3	380	371	356
4	368	376	373
5	379	369	373
6	365	360	362
7	352	346	348
8	345	339	341
9	329	322	325
10	325	310	316

Cu = 1 - y / d

Cu = 1 - 16.1 / 354.6

Cu = 0.95

Table 1 (continued). Opportunity times and Uniformity Coefficients for the treatments using a Hawkins ditcher

HAWKINS

Sta.	Wheel	Soft	Ave.
	min.	min.	min.
0	358	358	358
1	364	362	364
2	366	362	364
3	361	358	361
4	368	364	366
5	360	357	358
6	342	338	340
7	323	321	322
8	305	301	303
9	291	283	286
10	266	266	266

Cu = 1 - y / d

Cu = 1 - 29.8 / 335.2

Cu = 0.91

HAWKINS and SMOOTHING

Sta.	Wheel	Soft	Ave.
	min.	min.	min.
0	358	358	358
1	367	367	367
2	379	371	374
3	372	367	369
4	370	347	356
5	364	355	359
6	352	343	347
7	344	333	337
8	328	315	320
9	320	305	311
10	302	300	301

Cu = 1 - y / d

Cu = 1 - 20.4 / 345.4

Cu = 0.94

Table 2. Moisture stored in the soil at various stations in the furrow for the four treatments.

Treatment and Station	Available moisture in the soil before the irrigation	Available moisture in the soil after the irrigation		Moisture stored by the irrigation
Conventional ditcher				
200 ft.	6.3 in.	8.95 in.		2.65 in.
500 ft.	7.65 in.	12.60 in.		4.35 in.
1000 ft.	11.15 in.	13.00 in.		1.85 in.
			Mean	2.95 in.
Conventional ditcher plus Smoothing				
200 ft.	6.72 in.	10.20 in.		3.48 in.
500 ft.	7.60 in.	11.00 in.		3.40 in.
1000 ft.	7.05 in.	11.40 in.		4.35 in.
			Mean	3.74 in.
Hawkins ditcher				
200 ft.	7.55 in.	9.30 in.		1.75 in.
500 ft.	7.35 in.	11.00 in.		3.65 in.
1000 ft.	10.70 in.	12.40 in.		1.70 in.
			Mean	2.37 in.
Hawkins ditcher plus Smoothing				
200 ft.	6.80 in.	10.30 in.		3.50 in.
500 ft.	9.32 in.	12.50 in.		3.18 in.
1000 ft.	5.32 in.	7.65 in.		2.33 in.
			Mean	3.00 in.
			Grand Mean	3.02 Inches

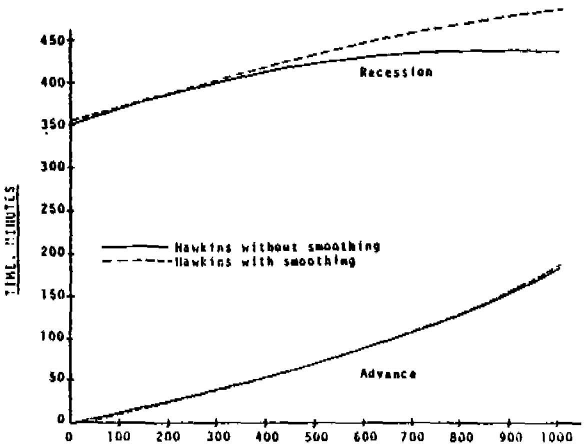

FIGURE 9. DISTANCE ALONG FURROW

Advance and recession curves for treatments using a Hawkins ditcher wheel furrows.

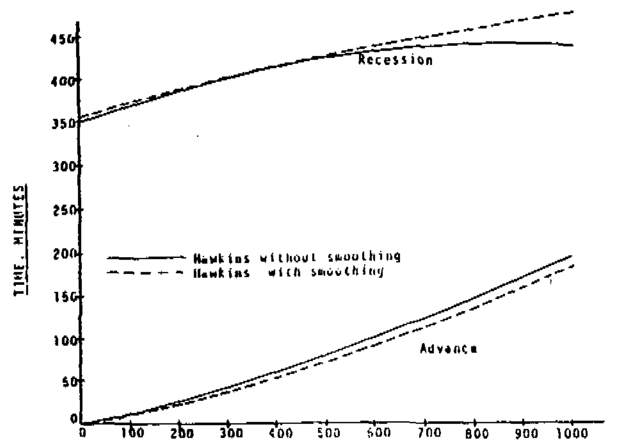

FIGURE 10. DISTANCE ALONG FURROW

Advance and recession curves for treatments using a Hawkings ditcher, soft furrows.

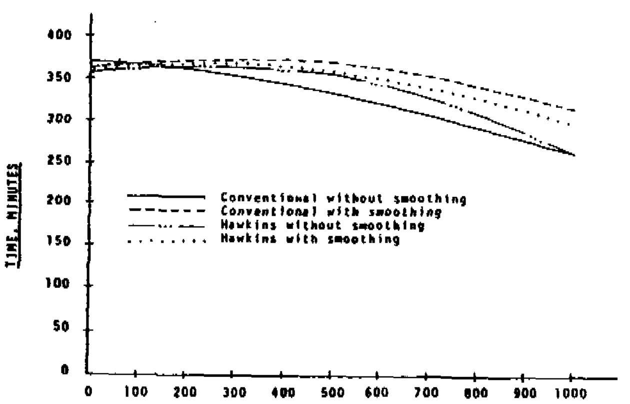

FIGURE 11, DISTANCE ALONG FURROW

Average opportunity time curves.

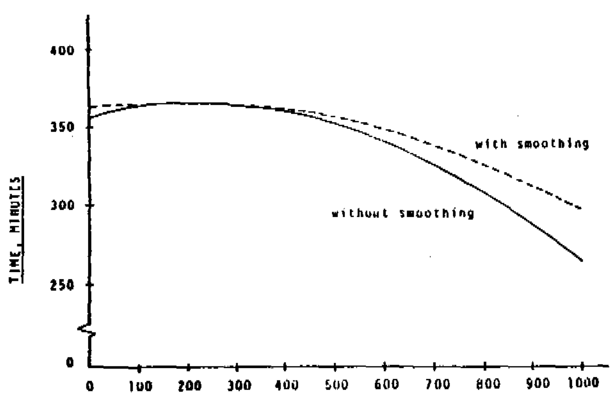

FIGURE 13. DISTANCE ALONG FURROW

Average opportunity time curves, Hawkins ditcher.

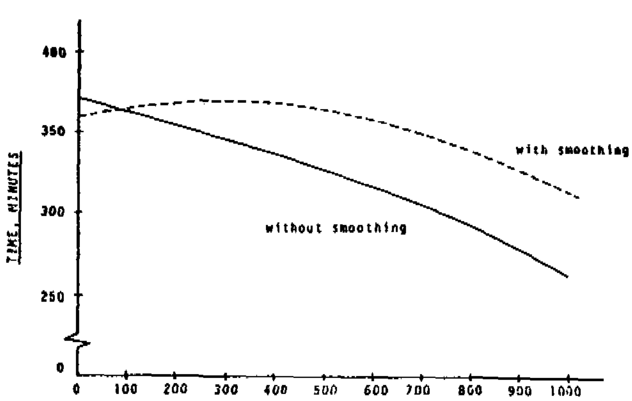

FIGURE 12. DISTANCE ALONG FURROW

Average opportunity time curves, conventional ditcher.

DISCUSSION OF THE RESULTS

Uniformity of the Opportunity Times

It was pointed out in the review of literature that the depth of water infiltrated into a soil is directly related to the time that water remains on the soil surface; the opportunity time. This relationship is not proportional due to the characteristics of the infiltration curve. However, it follows that the more uniform the opportunity time along a furrow the more uniform will be the depth of water infiltrated along that furrow.

With the conventional ditcher, smoothing the furrow improved the coefficient of uniformity by 0.05, from 0.90 to 0.95 even as late in the season as the third irrigation. Smoothing also increased the uniformity of the opportunity times in the Hawkins treatments. The increase was not as great as the increase in the conventionally ditched treatments but it did show an increase from 0.91 to 0.94. The reason smoothing the furrow had less effect on the treatments using a Hawkins ditcher could be that there were fewer clods made while ditching with the Hawkins or that the clods were more easily disolved by the previous irrigations that those made by the conventional ditcher.

No test of significance was performed on the data because too few replications of the experiment have been run.

Using Soil Moisture Blocks to Measure Moisture Stored

Soil moisture blocks were used to measure the soil moisture in inches of available moisture both before and after the irrigation. The results of these measurements can be seen in Table 2.

In order to use blocks to measure the soil moisture on the basis of inches of available moisture in the soil profile several conversions had to be made. The first step was to convert the delmhorst moisture tester reading into a value for soil moisture tension in bars. This has been done by Watts using a pressure plate apparatus and is shown in the Appendix, Figure 15, Next, the moisture tension had to be converted to percent moisture, dry weight basis, by using a moisture retension curve for the soil. This curve for the Sharpsburg silty clay loam soil is shown in the Appendix in Figure 16. Then using an average bulk density of 1.3 the percent moisture was converted to a total moisture, inches per foot. The available moisture was calculated by subtracting the moisture above 15 bars tension from the total moisture.

An interesting and unexpected result was observed from inspection of the data concerning total water stored. Smoothing the furrows increased the mean depth of water stored in the soil in those treatments which received the smoothing operation.

The reason for this increase in the total average depth of water stored in the root zone seems to be due to drier soil conditions at the start of the irrigation in those furrows which were smoothed. It must be assumed that the drier conditions resulted from less water being infiltrated during the previous irrigations. If that is true, then some compaction of the soil must have occurred during the smoothing operation. The compaction would have slowed the rate of infiltration of water into the soil resulting in less water applied. The wetting and drying cycles of the first two irrigations would have reduced the compaction allowing a higher infiltration rate during this, the third, irrigation. Therefore, late in the season, the furrows which were smoothed using a packer wheel at the time of ditching took in more water than those which had not been smoothed.

Reducing the Total Water Application

The total application of water during this irrigation was higher than the objective had called for. The reason the extra water was applied was because some other experiments were being run on the field which required more time to run than the optimum irrigation time would have called for.

In Nienaber's work with a Sharpsburg soil, he found the basic intake to be about 0.5 inches per hour. This basic infiltration rate occurred after approximately 130 minutes irrigation time.

Using the conventional ditcher without smoothing, (Figure 7, page 23), as typical furrow stream advance and recession curves, it can be seen that the advance reached the end of the field at approximately 210 minutes. If the water had been allowed to run out of the furrow for 30 minutes instead of 140 minutes before the well was shut off the opportunity time could have been reduced by 110 minutes. Since 210 minutes is beyond the 130 minutes required for the soil to reach the basic infiltration rate, the water would have been infiltrating at the basic rate of 0.5 inches per hour. Therefore, 0.5 x 2.17 = 1.09 inches less water could have been applied to the field. This would have reduced the total average depth of water applied to the field to 3.26 - 1.09 = 2.17 inches of water. Thus meeting the objective of putting on appromixately 2.0 inches of water with the irrigation.

CONCLUSIONS

The following conclusions were drawn from the study on the merits of smoothing the furrows to attain more uniform water distribution and to apply less water per irrigation.

1. Smoothing the furrows increased the uniformity coefficient of the opportunity times in both ditching methods tested.
2. Reducing the roughness in the furrows by smoothing with a packer wheel speeded up the furrow stream advance so that a shorter set time could be used, that would allow a smaller application of water.
3. The data presented in this thesis were taken on the third irrigation of the year. Greater differences would be expected on the first irrigation than on the third, since much of the roughness had been smoothed out by the previous irrigations.

RECOMMENDATIONS

The following recommendations are offered for further study in this field:

1. More measurements should be taken.
   - A. Instantaneous infiltration rate measurements should be taken.
   - B. Bulk density measurements should be taken.
     1. To see if smoothing the furrows also compacts the soil.
     2. To see if the bulk density changes over the growing season.
   - C. Penetrometer measurements should be taken in the furrows for the same reasons as B.
   - D. Neutron scattering moisture analysis should be used to check on the block method of determining moisture stored.

2. More replications should be run.
   - A. More replications each irrigation to see if statistical differences exist between treatments.
   - B. Study should include other soil types.

3. Study should be run over the entire irrigation season especially during the first irrigation since it is the one where the most benefits would probably be derived from smoothing.

MULTIOBJECTIVE RAIN WATER CISTERN SYSTEMS

Show-Chyuan Chu*, Yu-Si Fok**

ABSTRACT

Rain water cistern systems can serve multiobjectives. Although they are traditionally used for domestic water supply, however they have been used for other purposes. From an economic view point, if a rain water cistern system (RWCS) can serve multiobjective uses, it could afford a higher initial and operation/maintenance costs. Therefore, planners of rain water cistern systems should seek multiobjective uses to enhance the feasibility of their applicability. Examples of rain water cister systems multiobjective uses are presented in this paper, Readers are encouraged to report their experience related to this subject.

INTRODUCTION

Multiobjective use of rain water cistern systems (RWCS) may help their users to gain a better justification for selecting their development other than just consider their traditional use for domestic water supply as a single objective water resources development. The reasons for users and planners to view rain water cistern systems in multiobjective use are based on economic and institutional consideration. This consideration is originated from the generally excercised two objectives water resources planning principle: (1) to enhance national economic development and (2) to protect the quality of the environment. This paper presents examples of multiobjective rain water cistern systems to encourage planners and users to develop their rain water cistern system for multiobjective use in order that appropriate attachments can be installed in the system for multiobjective use. Readers are encouraged to report their experience related to this subject.

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REDUCTION OF STORM DRAIN PEAK LOAD

Storm drainage systems' peak load capacity is limited and hard to increase which is often caused floodings due to the expansion rate of the city is greater than the enlargement rate of their storm drainage systems. This sitution is especially true when the city is developed from low laying valley land and progressively upward to the foothills of the valley. Although a city may have a development plan but it is rare to have the farsight to project and plan for the distant future. There are many uncertainties involved in the projection of the future, it is very rare for planner to plan for more than two phases of the city's expansion plan. As a result, a scenario is set for the city's department of public works and its drainage section to illustrate this rationale.

Supposely the drainage section has followed the city's development plan to permit a subdivision to construct their storm drainage system to carry not only this subdivision's storm peak discharge but also requested the developer to construct the storm drainage system with additional capacity to carry the second phase's peak storm discharge before they can grant the developer with the building permit. Definitely, this is the result of a compromise because the developer has to pay for the cost of the storm drainage system's extra capacity and at the same time the city drainage section would like to have the drainage system with the capacity to carry the third phase's storm discharge, which is much larger than the carrying capacity of the second phase's. Owing to the uncertainty of the city expansion rate, the city granted the developer a permit to construct the subdivision's storm drainage system with the projected city expansion phase two designed peak discharge load capacity. At this point, the scenaio is at the stage that matters concerned have been settled for the time being. However, by the time of completion of the subdivision project, perhaps due to the success of the subdivision's development or due to the unexpected upswing of the city's expansion rate, the phase two expansion has been started for sometime. Because the subdivision's constructed storm drain has the capacity to carry the phase two peak discharge load, no building permit is denied. This happy time may or may not last long and sooner or later some building permit applicants may found that their building permits have been denied because their subdivision's storm drainage system's system's capacity have already been subscribed.

The scenario is now turned to a scene at the mayor's office. A group of angry and protesting residents demand an explaination from the mayor for their building permits denial. Definitely the mayor will ask the director of the pubic works for an explaination; and the director of the public works will hear the section head of his department's drainage section to report that the phase three development area is located upstream of the phase two. However, the phase two's storm drainage systems have already constructed and connected to the phase one's storm drains according to the city expansion plan ,and those protesting applicants' properties are located in the phase three city expansion areas, the city has no provision to allow the connection of the phase three storm drainage systems to be connected to the existing phases one and two's storm drains. For the future of the city, the mayor is surely demand a solution of the phase three subdivision expansion's storm drainage problem.

This is a difficult assignment for the city drainage section because the development of a new storm drainage system for the phase three development involves a lot of unsolvable problem. For example to obtain the right-of-way passing through developed areas of phases two and one in down streams is almost impôssible, because on one can tolerate their newly established lawn, sidewalks and roadway being dig up again. The cost of buying right of way from developed areas are much higher than undeveloped areas. If the right of way problem is solved, time required for the construction of the phase three storm drain would take sometime to complete and most of the property owners in the phase three area can not wait because their building loans have been approved and have to pay interest regardless their properties are under construction or not. Therefore these properties' owners will press for an immediate granting of their building permit. The best management program for the drainage section would be to require residents of the phase three area to retain their properties' runoff water during the storm and to release their retained storm water during the fair weather days into the storm drains that connected to the phase two storm drains. In other words, the existing phase two storm drain will not be overloaded during a storm causing flooding problem within it service area and during the fair weather days, it will provide unused carrying capacity to transport the retained storm water from phase three area downstream through phases two and one's areas without causing flooding problems.

In view of this storm water management scenario, rain water cistern systems multiobjective use can provide an effective solution. The city's department of public works can demand the developer of the phase three area to retain all the storm runoff water in their rain water catchment cisterns and house owners must agree to release those retained storm water into the drainage system only during the fair weather days. With this agreement submitted, the building permits are then permitted to be issued to the phase three area property owners. From water conservation view point, rain water cistern systems owners in the phase three subdivision area are encourage to use their retained storm water within their own property. Thus the multiobjective use of the rain water cistern systems can be attended.

The scenario of multiobjective rain water cistern systems application has a real world case. Denver is the biggest city of the Colorado State, U.S.A. Due to rapid expansion of the city during the 1970's, some of the city's storm drainage systems could not accommodate runoffs from the ever increasing urbanizing of the foothills of the valley. Floodings of the valley lower lands in Denver had been reported more frequently. To address this problem, the city demand each new development project to retain their project runoff within their property boundary so that existing storm drains will not be overloaded and causing floodings. Rain water catchment cisterns were used to store storm runoff waters in the basement of the highrise buildings or in the lower floor of underground parking lot. The retained storm water were being used for lawn irrigation, car washing or other uses other than for human consumption. From this example, the major objective of the rain water cistern system is for the reduction of the storm drain peak load the second objective is for out-door water uses. Therefore, the justification of the rain water cistern systems in this Denver city case is very different from the traditional rain water cistern systems single objective for domestic water supply which serve only a few users. For the building of a highrise office and hotel complex structure, the very high cost to build the rain water cistern system to retain storm runoff water of the project site is much easier to bear by the multi-million dollar project. Therefore the analysis of the benefit and cost of the rainwater cistern systems showed multiobjective rain water cistern systems can afford a much higher initial cost and operation/maintenance cost. Especially the major objective of the system is not for domestic water supply. With this concept in mind, planners can have a wider range to think of the multiobjective use of the rain water cistern systems.

WATER FOR FIRE FIGHTING

The use of water to fight fire is the common method. Definitely, public water supply systems in cities and in rural areas are the main source of water for fire fighting. In cities, there are fire stations to house fire engines and fire fighters as a public safety service. In rural areas where public water supply systems are not available, individual households have to develop their own water supply sources not only for domestic water supply but also for fire fighting.

A real world example of using rain water cistern systems to provide water for fire fighting is cited herein. The suburb of Los Angeles, California, U.S.A. has resort housing areas nested in forest lands. Although the environment is very desirable for residents of these resort areas, however, forest fires are the greatest threat. Therefore, the city has imposed a special requirement on the building permit, requiring house builders to include a water storage tank of specified capacity to store water for fire fighting. Although some of the houses use swimming pools to fulfill this requirement and disregard the well known fact that the operation/maintenance of a swimming pool in those forest areas is costly and difficult; most of these resort households chose to use rain water cisterns to meet the building permit requirement. Because they had also decided to use rain water cistern systems to provide their water supply due to the fact that there were no public water supply systems nearby their properties or there had no other sources of water for them to get their water supply.

From the above real world example, planners of rain water cistern systems can realized that rain water cistern systems have multiobjectives. Again, the example problem has two objectives that are conflicting to each other to some extent. For fire fighting, a required volume of water must be kept in storage all the time while for domestic water supply, a definite amount of water must be withdrawn everyday. Fortunately, textbooks of multiobjective water resources systems analysis had chapters presented the solutions of conflicting in water use. Interested readers are encouraged to find these solutions in those textbooks.

From the view point of public safety, providing alternative sources of water for fire fighting is the better management program (BMP). If alternative water sources were available, firefighters can perform their duty much effectively and the fire insurance company can lower their premium based on added safety on their insured properties.

Modern highrise buildings are required by law to install automatic sprinkler system for fire fighting. This is because the ladder of a fire engine can reach to a limited height, and the automatic sprinklers can douse a fire at its initial stage. However, automatic sprinklers may loss their effectiveness if there is a power failure, without electricity to maintain water pressure in the sprinkler system, no water can be spreaded to fight fire. The installation of roof-top rain water cistern system to the highrise building can provide alternative water source to fight highrise building's fire, this is because fire fighting water source has been stored at the highest floor of the building and this water can keep the sprinkler system working by means of gravitation force.

DISCUSSIONS

In this paper, the subject of multiobjective rain water cistern systems has been presented with two real examples of application.

The first example of application is for the reduction of storm drain peak load. The use of the rain water cistern system is to retain runoff of a new subdivision area during the storm so that the existing storm drainage system will not be over loaded and causing flooding. This application can help the user of the rain water cistern system to fulfill the institutional requirement of the building permit of the subdivision as the major objective. Subsequently, the use of the retained storm water for non-human consumption uses is the secondary objective. Therefore, the cost of the rain water cistern system can be set much higher because the investment of a subdivision is in million dollars units.

The second example of application is for fire fighting in the forest resort housing development. Again, the rain water cistern systems are used to collect and store rain water for fire fighting to fulfill the building permit requirement and at the same time to provide domestic water supply as the other objective. Conflicting in water use for these two objectives is identified. Perhaps the solution can be settled in a simple manner by keeping two tanks. One for the storage of the required volume of fire fighting water and the other is used for domestic water supply. This simple arrangement do not require readers to consult a textbook of multiobjective water resources systems analysis to find solutions of conflicting water uses.

The use of rain water cistern systems on top of highrise buildings to provide alternative fire fighting water source needs an example. Readers are encouraged to contribute their experience of this application.

CONCLUSIONS

Multiobjective rain water cistern systems can afford a higher initial and operation/maintenance costs; in addition, it can help development project to fulfill building permit requirements and perhaps can lower insurance premium cost. The two application examples presented in this paper can only serve as an introductory of the multiobjective rain water cistern systems' potential of applications. Planners are encouraged to report their own experience of this subject to promote a board future of the rain water cistern systems.

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THE WATER HARVESTING/AQUACULTURE PROJECT:PVO/UNIVERSITY COLLABORATION*

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ABSTRACT

The Water Harvesting/Aquaculture Project (WHAP) was a five-year project funded by the U.S. Agency for International Development (USAID). The principal goal was to "improve the quality of rural life in selected developing countries through the introduction of improved technology in ways that would balance local capacity for development with total community needs and potentials."

WHAP involved collaboration with six private and voluntary organizations (PVO's) in 41 countries during the project period. The project provided technical training and assistance on water harvesting and aquaculture technology to field staff working with local organizations, communities and individuals. Training participants acquired background knowledge to make preliminary project designs and assessments. Technical assistance was provided to those who initiated projects but lacked the skills and knowledge necessary to go beyond preplanning and site assessment.

The paper provides overview of WHAP, and discusses the water harvesting concept and authors' experiences under arid and semi-arid conditions.

INTRODUCTION

The Water Harvesting/Aquaculture Project (WHAP) was a five-year project funded by the U.S. Agency for International Development

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(USAID). The principal project holder was the Joint PVO/University Rural Development Center at Western Carolina University. The International Center for Aquaculture (ICA) at Auburn University was subcontracted to provide technical assistance to the involved PVO's. Principal goal of the project was to improve the quality of rural life in selected developing countries through the introduction of improved technology in ways that would balance the local capacity for development with the total community needs and potentials. Assumptions in the project were that water was a basic human need, and technology providing water or improving water availability would receive broad acceptance by rural dwellers.

The objectives of this paper is to discuss the concept and authors' experiences on water harvesting technology under arid and semi-arid climatic conditions in several countries in Africa, Asia and South America.

RAINWATER HARVESTING AND AQUACULTURE

Frasier and Myers (1983) defined water harvesting as "the process of collecting and storing water from an area that has been treated to increase precipitation runoff." Runoff is the portion of rainfall that runs off slopes before it evaporates or infiltrates into the soil. A broader definition was used in the WHAP project to describe water harvesting technologies suited to the needs of the project participants. For project purposes, water harvesing was the collection and storage of water from a variety of sources for beneficial uses.

The National Academy of Sciences-National Research Council (1981) stated that falling water tables and increasing ground water salinity in the South-west United States was forcing capital-intensive approaches to water harvesting, such as chemical treatments to the soil; wax, plastic, asphalt or other materials. Few developing countries can afford such costly technology. However, other water harvesting technologies are practical, relatively inexpensive and quite useful in many developing countries. In many developing countries, water resources remain under-utilized. Temporary ponds formed during rainy season often serve as water sources for domestic and agricultural uses. However, much rainwater runs off the land without being harvested for future uses.

Beneficial uses of harvested water include household needs, such as washing cloths and dishes, drinking, bathing, livestock watering, irrigation and aquaculture. Fishpond can be built on swampy or saline soils which are often unsuitable for other forms of agriculture. Hilly land which is difficult to farm or is easily eroded can be utilized to construct relatively inexpensive fishpond.

Aquaculture is usually profitable for family scale operations when integrated with other agricultural commodities. Stickney (1979) defined aquaculture as "the rearing of aquatic organisms under controlled or semi-controlled conditions." Control requires knowledge and skill by the practitioner. Little and Muir (1987) described several agricultural practices that integrated well with aquaculture. Such integrated systems provide more productive nutrient recycling, and improve the utilization of land, water, labor, equipment and other limited resources.

RAINWATER HARVESTING UNDER ARID AND SEMI-ARID CONDITIONS

This section will cover rainwater harvesting systems suitable for arid and semi-arid areas where no other alternative water sources are economically available. The concepts were used by the authors during water harvesting technical assistance visits in arid and semi-arid regions under the WHAP project.

Rainwater harvesting is practiced in most arid and semi-arid regions. In the Negev desert of Israel which has annual precipitation of less than 6 inches, rainwater harvesting systems existed 4,000 years ago (Evenari et al., 1982). Hillsides were cleared to increase runoff. and contour ditches collected runoff water for crop irrigation. Rainwater harvesting from the roofs of houses is still practiced in many regions (Pacey, 1986). Development of roaded catchment systems by the Public Works Department of Western Australia (1956) highly contributed to rainwater harvesting. In this system, graded parallel roadways drain into conveyance ditches, and the harvested water is used for crops or stored in tanks for later use. Research for large scale rainwater harvesting is mostly conducted in Israel, Australia and the United states, where treatments with chemicals or plastic membranes to increase runoff are investigated. These methods are often technically feasible and successful in developed countries but impractical for many developing countries.

Most rainwater is lost by infiltration into soil or runoff unless it is captured and stored. Though rain falls infrequently in arid and semi-arid areas, it often occurs in high intensity. One cm of rainfall on 10 m^2 of impervious catchment area would yield a maximum of 100 liters. Important components to be considered in preparing a rainwater harvesting system are catchment areas (size, soil, cover and slope), collection and conveyance. storage, and water use. Without an adequate storage system, most rainwater harvesting systems will fail during drought. Type and size of storage systems for the harvested water are determined by the uses of the water. When harvested rainwater is used for runoff farming, the storage system is the soil itself. Harvested water can be directly stored in soil with certain augmentations. An impervious catchment area of 100 m receiving 1 cm of rain can supply 10 cm of water to 10 m^2 land assuming 100% runoff rate. A catchment area of compacted bare soil would yield a high rate of runoff from rainwater.

When water is to be used for livestock watering, fish production, irrigation, or human consumption, a storage facility has to be provided. Dug-out ponds or impoundments built at the lower end of a catchment area are usually suitable for storage. Concrete-walled underground cisterns are also used to store harvested water in mildly sloped areas.

Harvested water at the end of a rain season should be stored for use during the dry season. Size of a storage system should be determined by the use rate of the water until the next rainy season. Use of this water should be prioritized for needs such as household (drinking, cooking, washing and bathing), animal watering, small scale irrigation or fish culture. However, due to the cost to collect and store large volumes of rainwater in arid and semi-arid areas, large scale crop irrigation with harvested water may be infeasible. If harvested water is used to irrigate plants, localized precision irrigation should be practiced for maximum efficiency.

In developing a rainwater harvesting system, care should be taken to minimize soil erosion, sedimentation and local flooding. Runoff from catchment areas becomes concentrated and carries enough kinetic energy to erode the field. The eroded soils are delivered into the conveyance and storage areas and cause sedimentation problems which will reduce their capacity. The system should be occasionally maintained to obtain the maximum benefit and to prevent further problems. Maintenance should include repairing damaged structures, cleaning sediments in the conveyance and storage systems, replanting dead vegetation and cleaning the inlet intake systems and water use area.

FIELD RAINWATER HARVESTING SYSTEMS

The following discussion presents several practices recommended for field rainwater harvesting during the technical assistance of the WHAP. Harvested water may be used directly or stored for later use. Detailed descriptions of these methods are found in references (Pacey and Cullis, 1986; Reij et al., 1988; Frasier, 1975). Planning field rainwater harvesting systems should include determining engineering and other characteristics of the system: rainfall-runoff relationship of catchment area. physical conditions of the catchment and water use systems, type of plants to grow, construction methods, water quality due to soil erosion and trash wash-out from the catchment and economics of the system. It should be noted that rainwater harvesting systems are all site-specific in nature.

Direct Use Systems

Once runoff from rainwater has been harvested, it can be directly applied for crop production. The principles and practices of this system depend on the method of rainwater harvesting and the crops to be planted.

1. Micro-catchment farming is a system which collects runoff to a small cropping area from a catchment area which is larger than the cropping area. A large area may be divided to many micro-catchment systems. This system is most appropriate for drought resistant plants.

2. Contour catchment farming is a system which collects runoff water from catchment areas to terraced cropping areas. Broadbase level terraces or conservation bench terraces are appropriate for this system. In arid and semi-arid regions, well designed terraces can be used not only for direct use but for storing the harvested water.

3. Water-spreading farming is a system to divert flood water by a diversion weir from non-perennial streams (often called wadi) to apply the water to low level embankment-backed cropping areas by spreading. More than one embankment may be installed to effectively use any excess flow from embankments at higher elevation.

4. Micro-basin farming uses small dugout basins along crop furrows to collect and store overland flow from rainfall or irrigation. Studies showed that this system could effectively reduce runoff and soil erosion by providing longer infiltration tim

Rainwater Harvesting with Storage Systems

Harvested water may be stored in tanks for later uses. The tanks are often filled during rainy seasons for uses during dry seasons using the following water harvesting systems.

1. Roaded catchments use narrowly spaced compacted rows of bare soil (Hollick, 1975). Water is collected in the furrow and conveyed

to protected waterways, commonly vegetated waterways, and then into a storage system.

2. Roadside catchments use either paved or bare surface roads as catchment areas. Conveyance channels are built along the roadways to carry water to a storage system, The water may be contaminated by materials washed out from the road surface. For this reason, the harvested water may not be suitable for human consumption.

3. Hillside catchments use hills as a catchment area. Terraces and conveying channels are built along the contour of hills to carry water into a storage area. This system not only harvests water from the hills but controls soil erosion. The terrace channels are suitable for growing trees and forage crops.

4. Terrace catchments use a series of broadbase terraces on a catchment area to concentrate runoff water and convey it into a water storage pond through protected waterways, thus preventing soil erosion due to concentrated flow. This system can be effectively used both for rainwater harvesting and forage cropping on the catchment areas. Details of this system will be discussed later.

Considerations in Field Rainwater Harvesting Systems

Field rainwater harvesting systems are widely practiced in arid and semi-arid areas. Harvested water is often used to supply livestock watering or human consumption in remote areas where travel between home and the field is inconvenient or time consuming. The following should be considered in developing and installing a field rainwater harvesting system.

1. Care should be taken to prevent soil erosion from the catchment area, especially along the main waterway by using a combination of protected waterways and other conservation structures.

2. The area between terraces may be used for crop production, especially suitable for forage crops or trees. Domestic animals should be kept from the catchment area to prevent contamination of the water to be used for domestic purposes. If it is unavoidable to graze animals on a part of the catchment area, runoff from this area should be diverted away from the storage area.

3. In order to maximize water yield from a limited catchment area, all or part of the catchment should be bare and well compacted. However, due to the possibility of erosion, this area should be located on a mild slope. Terraces may also be narrowly spaced on a steep slope to reduce slope lengths which reduce erosion potential (Wischmeier and Smith, 1978). For maximum use of rainwater in the catchment area during the rainy season, micro-catchments may

be installed for tree cultivation, Even though this reduces the total amount of water collected from the catchment area, it will minimize the hazard of high runoff and soil erosion.

TERRACED-CATCHMENT RAINWATER HARVESTING SYSTEM

Design of a terraced-catchment rainwater harvesting system depends on methods of collection and use of the harvested water (Fig. 1). Complicated open-channel and closed conduit hydraulic systems are often needed to collect, convey, store and distribute the harvested water. A rainwater harvesting system which is used for general purposes (livestock, fishpond, irrigation and household uses) should have the following components: a) Catchment area, b) Delivery, c) Conveyance, d) Sediment settling pond, e) Tank inlet structure, f) Emergency spillway, g) Storage tank, h) Protective fencing, i) Water intake system, j) Filtration and k) Service. Each component should be carefully designed, constructed, operated and maintained for the maximum benefit. If the harvested water is for non-human consumption, some of the listed components may be omitted.

Quality of the harvested water from a catchment area is not ordinarily a problem for livestock or irrigation uses, but it should be considered when the water is used for human consumption or for aquaculture. Water harvested from disturbed bare soil usually contains high level of suspended sediment and colloidal materials. Animal traffic and grazing in the catchment area, common practices in arid and semi-arid regions, will result in contamination of the water with fecal materials. A rainwater harvesting system for human use should be fenced to limit animal activities and should include a filtration device.

The following items should receive attention in future research to achieve maximum benefit from a field rainwater harvesting system with storage tank under arid and semi-arid conditions. Because of the site-specific nature of rainwater harvesting systems, these items should be studied under regional conditions and guidelines developed accordingly. Economics of a considered rainwater harvesting system and environmental impact due to the system should also be considered.

1. Design and Construction
   a) Rainfall-runoff relationship
   b) Location of system
   c) Type of catchment area and method of water collection
   d) Type of waterway

e) Materials and methods of construction
f) Shape and size of sediment settling ponds
g) Emergency spillway and use of overflow
h) Ratio among depth, surface area and volume of storage tank
i) Bank erosion prevention
j) Tank inlet and water intake
k) Water use system

2. Operation and Maintenance
   a) Priority of water use
   b) Protection of harvested water from contamination by soil erosion and human and animal activities in the system
   c) Prevention of soil erosion from catchment area, especially from the concentrated flow area
   d) Use or protection of catchment area
   e) Removal of sediment from delivery and storage systems
   f) Protection of water use system from contamination and damage
   g) Tank inlet and water intake
   h) Water use

3. Socio-economic implications
   a) Cost-benefit ratio
   b) Availability of resources for implementation; finance, labor, land and construction materials
   a) Impacts on habits, customs and local tradition
   b) Integrated water use system for domestic use, agriculture and aquaculture

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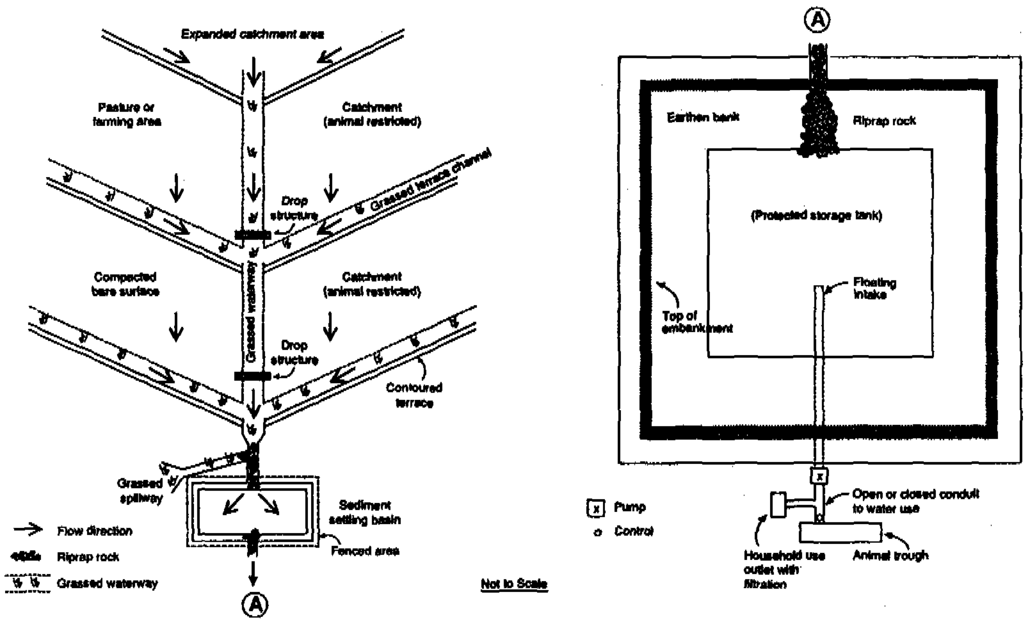
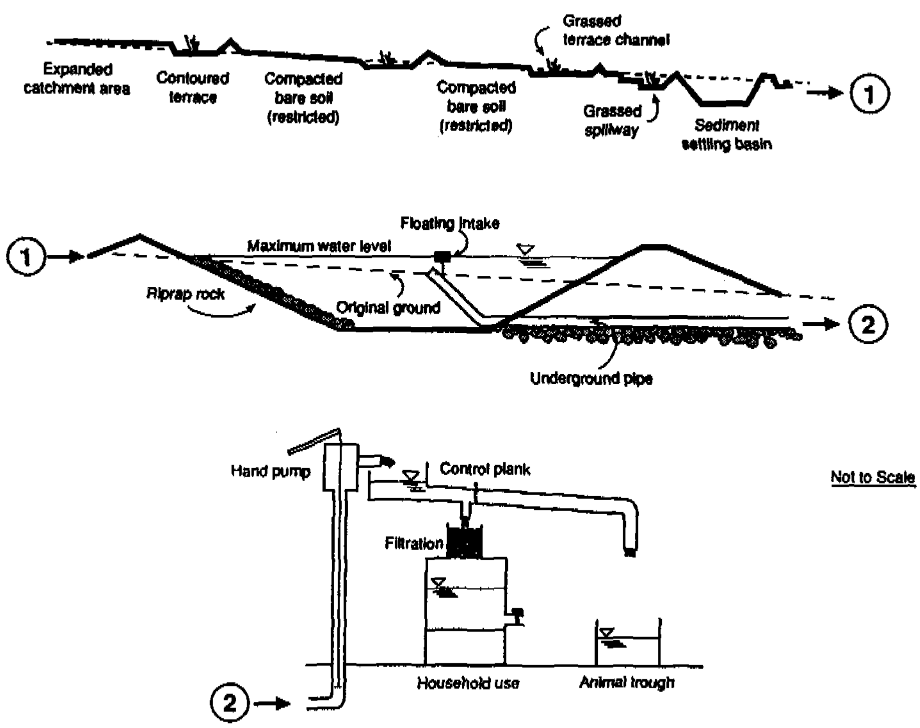
Figure 1. Terraced-Catchment Rainwater Harvesting System with a Storage Tank and Pumped Water Use; a) Plan View and b: Section View along the Center Line.



a) Plan View



b) Section View along the center line

Rainwater Catchment Using Farm Pond in Southwestern Taiwan

Chien. P.W.* Yuan, Y.H.** and Wan, H.Y.***

ABSTRACT

Farm ponds are primarily designed and constructed for storing rain water and providing water supply for the township of Tos-cheng, Yu-Ching, and Nan-Hua in Tainan county. Tien-Liao, and Yen-Tso inkaohsiung County where water shortage is a serious problem. In the past 20 years, from 1970 to 1990, a total of 58 farm ponds were constructed with a total volume of 2,745,200 m. Using farm ponds to collect rainwater is an unique feature in Southwestern Taiwan.

Rivers and streams in Taiwan are short and steep. Water flows swiftly to the ocean. Although the rainfall is abundant, water supply in Taiwan is limited. The average annual rainfall on the island is about 2,510 mm with large spatial variability, rainwater is a valuable water resource in mudstone areas with unavailable groundwater resource and insufficient surface water source. Since 1965, the Taiwan Procincial Soil and Water Conservation Bureau initiated a policy to construct a lot of farm ponds for storing rain water and supplying water to satisfy people's domestic needs, agri-culture and livestock raising. The cost for farm pond construction is higher than tap water. However, it is necessary to improve people's living environment, and to upgrade farm production. Farm ponds can also control gully erosion and landslide in mudstone areas.

A lot of effort have been spent in conducting reconnaissance survey, planning and design of earth enbankment and farm ponds using impermeable mudstone materials. So far, no dam failure has been reported. When farm pond is filled with sediments, the sludge has to be dredged out. The sludge has been used to cultivate crops such as dates and guava to increase farmer's income. This technology has been trasferred to local governments to assist in planning and design of more farm ponds and rainwater catchment systems.

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The design technology of farm pond has initially been proven successful. However, a number of problems still exists that requires further studies. These include the seepage of mudstone dam, the appropriate slope of the dam structure, and the construction cost reduction. These problems need to be addressed before anticipating more effective use of rain water resource.

I. INTRODUCTION

Taiwan is an island situated in the west coast of Pacific Ocean, and is rather young in terms of geologic time. Taiwan is a mountainous island. Plains and gently sloping land are on the west, and comprises about 30% of the total land area.

In early times, the mountain areas are densely covered and are not being exploited. Soil and water conservation practices are not necessary. About 30% of the rainfall through natural filtration process is stored in groundwater aquifer. People liveing in this area use groundwater or steam water for their everyday water needs but few are willing to collect and use rain water from rooftop.

In recent years, population in Taiwan increases drastically. Economic prosperity. Living condition improvement, and tap water supply convenience, have resulted in increasing water requirement. Yet water resources have not been proportionally increased. In fact, it is slowly depleting due to deforestation measures. This has created imbalance in the natural storing capacity of rain water. The southwestern part of Taiwan often are subject to attack of northeast monsoon. Rainfall becomes scarce during October to April every year. This area is made up of mudstone where groundwater is always unavailable. Whenever the rainfall falls below normal, people often worry about drinking water. This is also the same time water is badly needed for agricultural cropproduction. In hope to solve the problem of drinking water in mudstone areas, farm ponds have been constructed for rain water storage and water supply system.

II. FARM POND

Rainfall in Taiwan is abundant. However, it is unevenly distributed in time and space. Rivers and streams are short and flow quickly into the sea. In dry season, all river and streamflow diminishes. Therefore, The available surface water source is limited. To satisfy people's requirement and to keep pace with the population and economic development, many dams are constructed to store water and to regulate the water resources. There are altogether thirty reservoirs, natural lakes and ponds which are used for storage and to regulate water supply on this densely populated island. However, the problem of water shortage still exists during dry seasons. This situation is more critical in the hillslopes of the southwestern mudstone areas. The bare mudstone usually is impermeable and restrictive to wate penetration. The groundwater source is almost non-existence. Most rainfall becomes surface runoff and flows down rivers and streams causing flooding. During drought periods rivers and streams are completely dry. The thin mudstone soils are unable to retain any rainwater, and much less to store water underground. Shortage of water has prompted serious problems for farmers who rely solely on rainwater for their cropproduction. As a result, agriculture development is very slow. People have to walk miles to obtain domestic water during dry periods, wasting lots of valuable resources.

In recent years, the provincial Government has constructed many farm ponds using impermeable mudstone for effective rainwater storage and water supply. As the demand for water quality grows, people requesting construction of farm pond increases and are willing to provide land areas for dam building. Aside from providing irrigation water, simple filtration systems are also installed to provide for domestic drinking water use.

III. CONSTRUCTION OF EARTH DAM

Earth dam has existed for a long time. The oldest earth dam was not constructed by man. It was naturally formed by landslide on mountain slope blocking up streamflow in valley bottom. Some of these earth dams are very large and may exist for a long time but most are only temporary in nature.

To construct dam with earth is very contradictive. When soaked in water, earth becomes soft. If excessive water is added it even becomes liquefied. Theoretically, earth is not be best material to store water. However, adequate combination of earth and rock would produce desirable stability. Therefore, dams are still constructed with earth, besides, earth are easily available and cheap. It can be easily treated during construction.

The foundation requirement is low, can be constructed on earth foundation. Selection of suitable siting is very easy. The base of the earth dam is usually very broad. This can distribute the horizontal hydraulic pressure over a large area. With small unit foundation load and large frictional area, the risk of foundation failure may be reduced. Broad-based foundation may also reduce the possibility of water seepage through the foundation bottom. The con-struction cost of earth dam is much lower than other type of enbankment. Therefore, it is often used to construct farm ponds for rainwater catchment purposes.

If the impermeable clay layer is not present, it would be necessary to extend the impermeable layer from the dam center downward until it reach the bottom impermeable layer, and thus increase the construction cost. Construction of farm ponds in mudstone areas using impermeable mudstone materials is very economical and appropriate since groundwater cannot soak through them. This type of dam is also single-layered which is ideal for small dam construc-tion.

The upstream slope of the farm pond is usually covered with pebbles in order to control wave actions and to minimze damage due to water level drop. The pebble layer should extend from the highest water level to the lowest water level. The dam top and downstream slope should be covered with grass to protect from raindrop splash. Same ponds are covered with pebbles for the same purpose, but the cost is much higher. The grass cover not only is economical and effective in conserving soil and water, it can also be used for beautification purpose. Cheap construction cost is important in the promotior of the rainwater storing system. Furthermore, 5 m wide road on top of the dam can serve as farm road, which in turn may improve the living conditions in this area.

IV. PLANNING AND DESIGN OF FARM POND

It is not easy to design a farm pond because factors and parameters very greatly with locations and must be taken into consideration. Design can be conducted with the aid of a computer. However, all factors concerned need to be analyze based on designer's personal experience, value judgement and self perception. A perfect design should be safe and economically viable like many other important engineering structures.

(A) Farm pond planning

Planning of farm pond includes:

1. The initial planning is conducted at farmer's request that is submitted to local government based to their actual needs. The Provincial Soil and Water Conservation Bureau then make field survey, and to propose a project for action.

2. Since farm pond is primarily used by farmers, the land used for water collection and dam site must be provided by the farmers.

Farmers are required to organize a committee to raise funds for construction (about 15% of the total construction cost). The government is responsible for selecting qualified contractor to build the farm pond. After completion, the water supply facilities including the pump house, cisterns, and water pipe-line should be installed by farmers themselves according to the their own requirement.

(B) Farm pond site survey

Field survey of the farm pond site includes:

1. To select the most appropriate dam site or farm pond location, the water storing site topography, topsoil, drainage, groundwater, erosion, vegetation and soil property in the vicinity are studied.

2. The data obtained from the field survey are analyzed. The water storage area, dam site, spillway and topography of nearby structures are surveyed with the planimetry method. The angle between dam axis and the spillway is also measured by tansect. The dam axis and the stream vertical cross section is measured with a levelling devise. The profile maps are prepared and provided for the designers.

(C) Flood volume design

Design of flood volume is an important task to enhance the quality of farm pond construction. Under-estimation of flood volume may jeopadize safety of the structure, whereas over-estimation may waste the construction funds. Flood volume is usually determined according to the flood volume measured in the past. Farm ponds used for rainwater storage and water supply are considered small dam construction. For a free-falling type spillyway, flood volume should be designed for 50 years. For an open-ditch emergency type spillway, flood volume should bedesigned for 10 years.

If the emergency spillway cannot be built due to topographic limitation, area of the vertical section should be enlarged, and the design should be for 100 years. An open ditch-like spillway can be used and should be designed for 50 years.

The ditch cross section is designed in accordance, to hydraulic principle of optimum flow cross section (ie. ditch with the same cross section which allow maximum flow).

(D) Dam body design

In determining the width of the dam body, the dam material and the dam base conditions must be considered. In principle, the following conditions should be met:

1. The seepage line should be within the outer slope of the dam body.

2. The inner and outer slope of the should, depending on the dam material dam, be absolutely safe and stable.

3. The seepage water should flow within the dam base and should not cause soil particle movement. The stability of dam body is directly related to the safety of farm pond. The side-slope should, depending on the material, be designed according to the soil dynamics landslide theory. The slope should not exceed the following standard:

Earth dam height	<2.5m	2.5 to 5 m	> 5 m
Dam slope	1 : 2	1 : 2.5	1 : 3

4. The slope of the dam, in general, is quite long. To avoid erosion damage, diversion ditches should be construced at appropriate in-tervals to safely dispose of the surface runoff. The diversion ditches may be made out of pre-cast ditches, bricks or grass.

V.DISCUSSIONS

(A) Protection of farm pond side slope

The side-slope of the earthdam should not be too steep for easy maintenance. Above the maximum water level, some vegetation should be planted to protect the slope. At present, Bahia grass is the most common grass used. The planting space is about 20 to 30 cm. Because mudstone is very erodible, the dam side-slope should be covered with straw until the Bahia grass grows up. Bahia grass is a perennial grass and not sensitive to alkalinity. After the side-slope is com-pletely covered, runoff water can still infiltrate through and cause gully erosion on the slope facr. Mice can also destroy the slope face with cave digging. After completion and turning over to farmers, the farmers are responsible for the maintenance of the pond. They are required to conduct periodic grass mowing, mouse control, fertilization, filling in erosion gullies and grass re-planting for earth dam protection. These are necessary to prolong its service life.

(B) Operation sediment discharge gate

The sediment discharge gate is usually open during the rainy seasons (form June to August) so that the sludge and sediment from landslide can be removed along with flood water. It should be closed some time before the end the rainy period. Some observations of sediment discharge at Yueh-Ching and Tien-Liao farm pond are summarized here: (Please refer to The experimental report on explitation and protection of mudstone in southwestern Taiwan for detailed information)

1. Yueh-Ching farm pond

The water catchment area of this farm pond is about 29 ha. The initial storage amount is around 50,000 tons. The upstresam surface cover is about 25% During the 8 months gate closing period, total rainfall received is about 950 mm. Out of the total sediment of 15,000 cubic meter, 10,000 cubic meters are discharged. After ten years of operation, this area has completely lost its agricultural value because near by mudstone area is enlarging. Sediment discharge and maintenance have been stopped. The entire pond is filled with sediment and resembles the scenery at the "Moon World". Kaohsiung Country.

2. Tien-Liao farm Pond

The water catchment area of this farm pond is about 30 ha. The upstream surface cover is estimated to be 65% During the 2 years gate closing period, total rainfall is about 4,000 mm. The total storage is around 45,000 tons. The total sediment amounts to about 21,000 cubic meters, sediment discharge quantity is about 12,000 cubic meters.

(C) Runoff coefficient in mudstone areas

The runoff coefficient is usually between 0.83 and 0.87 The soil loss is about 6 to 8 cm per years. Studies have shown an amount of 314 cubic meters of sediment was accumulated on each hectaare of watershed area per year at the Ahkungtien reservoir Therefore, farm pond can also generate large amount of sediment. According to the two farm ponds, sediment and sludge cannot be completely removed from the sediment discharge gate. The sludge accumulated near the gate can come cut easily along with the flood water. Sediment discharge conducted every year with the flood water during rainy seasons is better than sediment removal once every two years. Usually the sediment discharge gate removes opproximately 50 to 60% of the total sediment. The gate design is limited by the vertical and horizontal pipes, and the hydraulic pressure. It is extremely difficult to open large gate. Therefore, the gate is usually constructed with 1 x 1 m cross sectional area. It is opened and closed by means of bolt-operated handle.

(D) Relationship between upstream cover and pond life

The upstream cover is found to be inversely proportional to the sediment yield. Because of poor upstream cover, annual production of sediment for the Yueh-Ching farm pond is about 15,000 cubic meters, with normal discharge practice, 5,000 cubic meters of sediment remain in the pond each year. The service life of this farm pond, with a storage capacity of 50,000 tons is then limited to ten years. The Hou-Kan farm pond in Yu-Ching Hsiang has good upstream cover. Both soil and water are well conserved, sixtheen years later, it still performs well in water storing. Its service life should be able to extend much longer. Therefore, the pond life, is closely related to the upstream cover.

(E) Economic feasibility of sediment removal

The Chiao-Kan farm pond is constructed at a cost of NT $2,593,500. The average water storage is about 314,000 tons/years. The unit cost of stored water is about NT$83 per ton. The cost for removing and transporting sediment is estimated at NT$65 per cubic meter excluding the charge at the landfill, from the soil and water conservation point of view, farm pond filled with sediments is same as a functional check dam. Therefore, it is not advisable to remove all the sediment because it has other uses. A drainage ditch can be constructed from the spillway outlet to the upstream area to control water flow. Between the earth dikes and slope foot, reclaimed land would be formed. Another dug-out type farm pond can be built at a suitable location. The dredged up sediment can be scattered on new reclaimed land behind the earth dike for agricultural crop production. This practice can also satisfy local residents drinking water needs at the same time.

(F) Safety inspection of farm pond

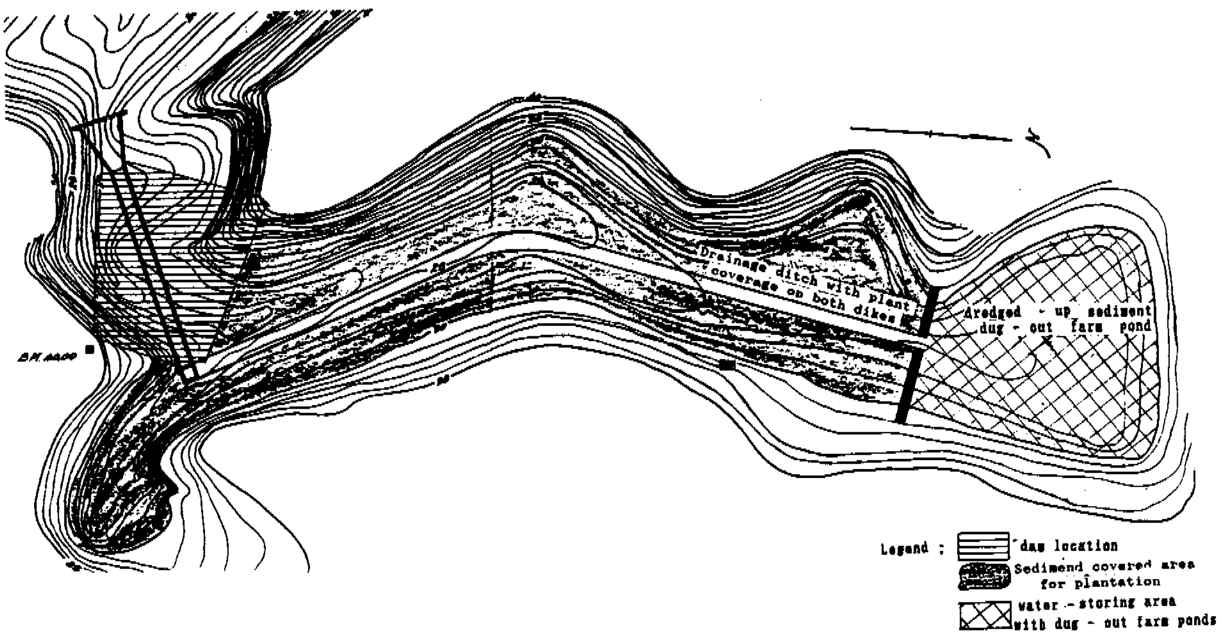
Periodic safety inspection is essential in earth dam maintenance. Damage to farm pond is a gradual process. If the failure precursor becomes obvious, positive remedial measures can be taken to avoid possible damage or disaster. Safety inspection should be conducted twice a year. The first inspection should be conducted after the rainy season when the farm pond is full of water. The second inspection should be performed when the water level drops to the lowest position in the dry season. The following items should be checked during a safety inspection.

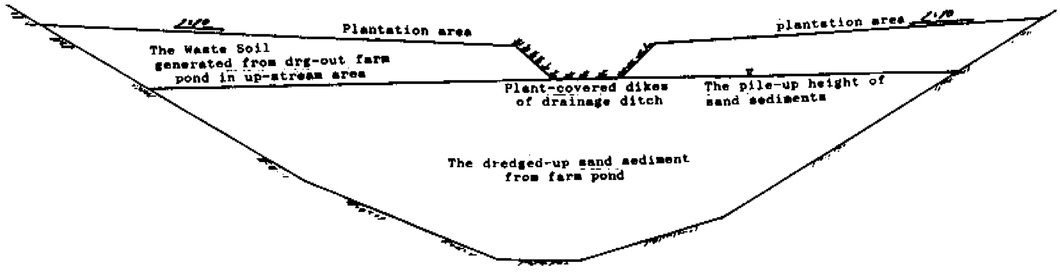
1. Structural condition of earth dam top.
2. Base line of dam axis.
3. Cracks on dam top, and the original crevices on the upper part of slope face.
4. Bulges on dam downstream slope face and near dam base.
5. Wet area of downstream slope face and near dam base.
6. Water seepage in downstream slope.

(G) General maintenance of farm pond

Since farm pond uses earth dam to retain large quantity of water, great care should be exercised during construction of earth

Figure 1. Utilization of dredged up sediment from farm pond.





dam to prevent dam failure and disaster. After heavy rain, prompt action must be taken to restore the eroded dam body and the damaged plant cover.

The maintenance of farm pond usually includes:

1. Grass on side-slope around farm pond should be mowed periodically. Proper actions are needed to prevent mouse damage, and the enlargment of erosion ditch.
2. Gate and side-bridge should be periodically painted for protection. Side-bridge needs constant safety inspection.
3. Prior to gate closing, the debr is left in the gate grooves should be removed after sediment discharge to avoid bolt bent and the incident of water leakage.
4. Warning signs should be placed around the farm pond to prevent children from swimming in pond. 5. The height of the earth dam and the vertical pipes should not be altered.

(H) Economic analysis

The main objectives of farm ponds construction are to solve the problem of drinking water for the people living in hillslopes, to enhance the sceneries, to irrigate field crops, to improve agriculture development, and to increase farmer's income. Farm ponds can provide multiple benefits. For example, the dredged-up sediment can be used to protect slope foot; an positive benefit to hillslope conservation. The farm pond located upstream of a water dam will be able to reduce thesediment in dam. Thus, in turn, extend the service life of the reservoir dam. This benefit is hard to predict. In Taiwan, water costs only NT$9 a ton. The minimum cost for constructing farm pond would be around NT$33/ton. The average cost for storing water is about NT$31/ton. In some cases, it may be as high as NT$254/ton. However, construction of farm pond is the only solution to the problem of drinking water for farmers living in mudstone areas. The construction cost is needed only during the first year. A farm pond with poor cover can be used for the years. With good cover and management, the farm pond is still in good con-dition after more than 16 years of operation. Its profit, of cource, is greatly increased.

Baside water storage, a farm pond can also regulate ditch flow. The Hsin-Hsin farm pond located in Tien-Liao Hsiang, Kaohsiung County is specially designed to collect rainwater for drinking purposes only. The earth dam of the pond is 9 m high, 110 m long, with a total storage of about 11,500 cubic meter. Rain is its only water source. The estimated service life is about 20 years. The cost for water storage is about NT$11/ton. This indicates that construction of farm ponds to collect and store rainwater to alleviate water shortage in dry season is beneficial and advisable. If more farmers participate in water collection and storage using farm ponds during rainy season, more benefit would be obtained from rainwater catchment.

VI. CONCLUSIONS

Both Yueh-Ching and Tien-Liao farm ponds, with a total storage of 95,000 cubic meters, have actually benefited local people by providing adequate drinking and irrigation water. However, 23 years later, they now are filled with sediment due to lack of proper maintenance and timely sediment removal. The Yueh-Ching farm, pond has converted to a scenic spot in the mudstone areas. Some farm ponds such as Chou-Me-Lai farm pond are managed with multiple purposes. It has been developed into a tourism attraction in addition to its normal agricultural irrigation function.

The construction of farm pond to collect and store rainwater seems unacceptable to the people enjoying tap water convenience. This does not mean a complete halt in the promotion of rainwater catchment systems on the island. In Taiwan, mountain occupies more area than plain. Water required both for drinking and irrigation is in short supply in hillslopes, if high cash crops cannot be planted and production cannot be increased due to water shortage, farmers' living standard, environment and economic conditions cannot be improved. Rainwater catchment and water supply system would be directly beneficial and therefore required further development and promotion efforts. According to previous records of rainwater catchment construction, farmer's needs for earth dam dug-out, cistern type farm pons are increasing indicating the necessity to construct more rainwater catchment systems.

Finally, integrated efforts from specialists, experts and scholars are needed in order to construct more effective rainwater catchment systems, for the solution of water shortage problems on the island.

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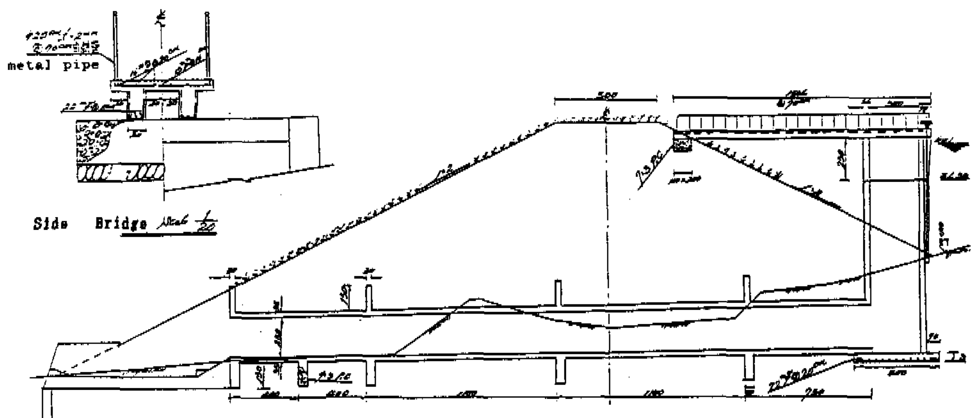
1987 green resources investgation project -- air survey on the

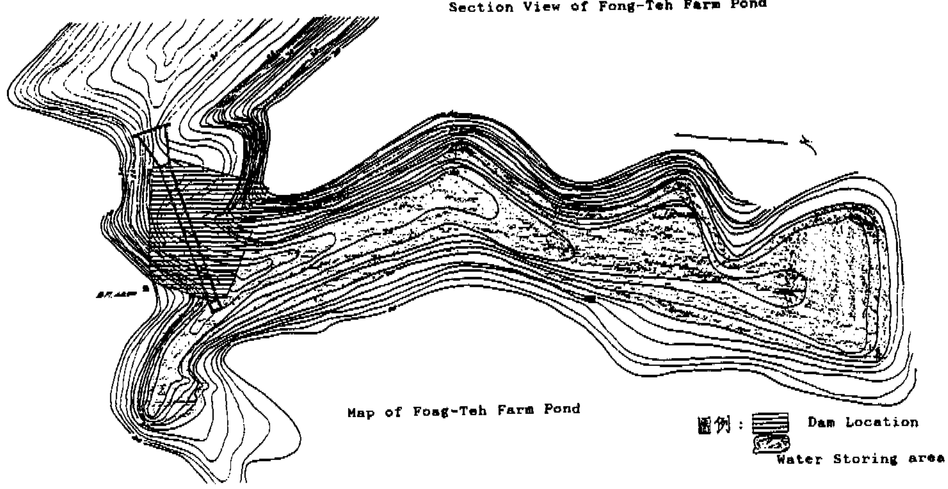
bare mudstone areas in southwestern Taiwan.

I. APPENDIX

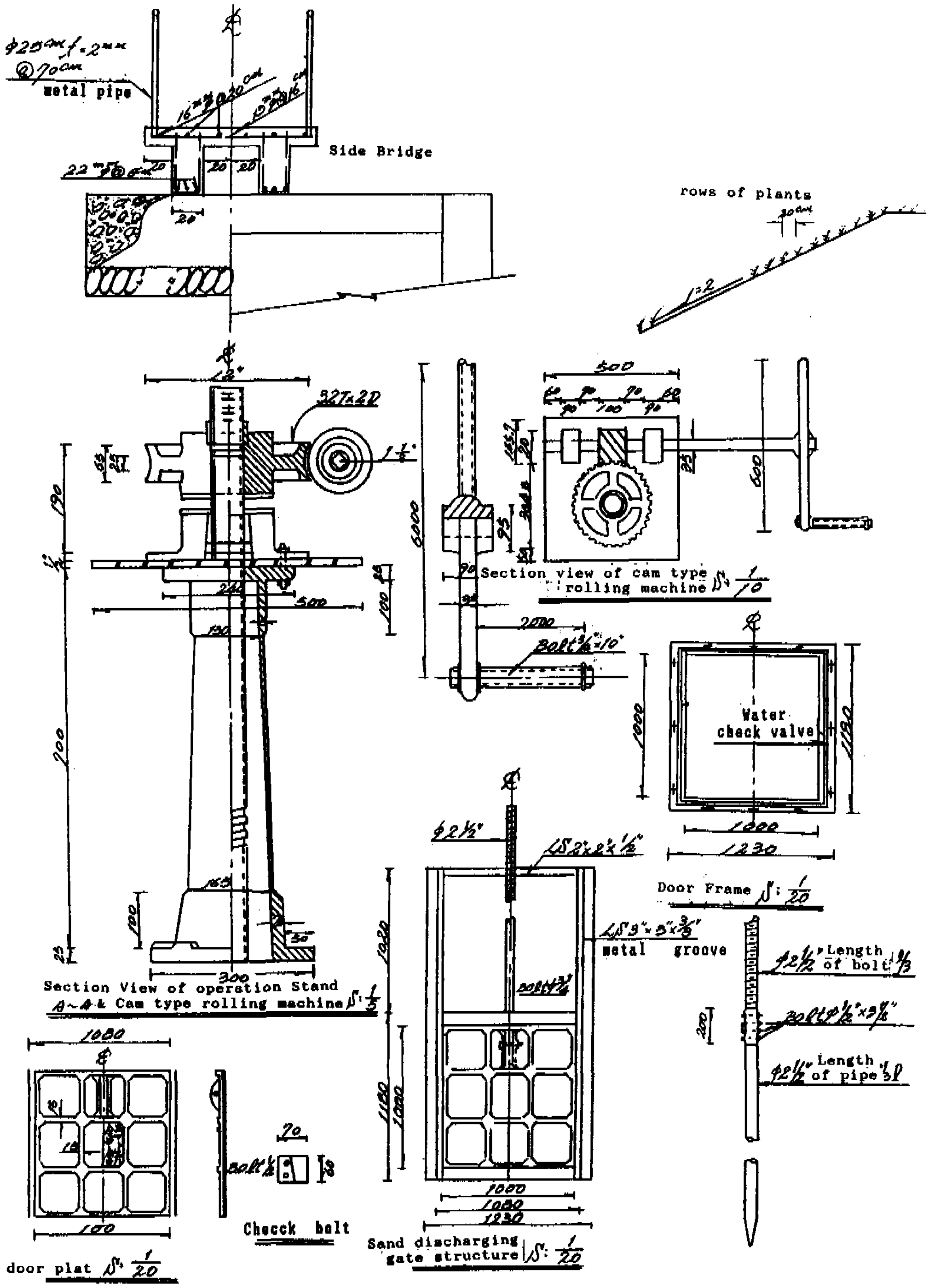
1. Schmatic of farm pond design.



Section View of Fong-Teh Farm Pond



2. Design of side bridge, gate, gate operation stand, and vegetation on slope of dam.



3. Farm pond photos.

WATER USE PROBLEMS IN MUDSTONE AREAS OF SOUTHWESTERN TAIWAN

J. F. Hsiao*, C. H. Wu**

ABSTRACT

The hilly areas of southwestern Taiwan is dominated by mudstone. Under normal conditions, these areas have adequate but unevenly distributed rainfall. Many small gullies are found on steep slopes. Mudstone soils are usually shallow and impermeable. Even with abundan, rainfall at times, water shortage problems often occur during dry seasons due to poor water holding capacity. The agricultural water use in these areas is characterized by growing first crop of rice in river valley and flatland using rainfed. The field-collected rainwater is used to grow a second crop of rice from June to October. In recent years, increasing number of farm ponds has been constructed to provide water for hillslope orchard farming. Besides irrigation and pest control purposes, the collected water has been used domestically. This paper briefly introduces this water utilization method and its use in a natural setting.

I. Distribution of Mudstone Areas, Land Use, and Population

A. Distribution of mudstone areas

The major mudstone area is located in Tainan County. Its southeastern boundary reaches the border of Kaohsiung County covering an area of about 73,600 ha. Within this hilly area, elevation ranges between 50 to 799 m. Most lie below 100 m. The geology of mudstone is mainly pliocene Rocks and its closely related rock materials. The dominant group is the mudstone series. The mudstone layer is approximately 5,000 m deep. Interlayers or bands of gray sandstone are found in the massive mudstone body. This sandstone interlayers also contain large amount of clay and usually turn into mudstone. It is not surprising to find thick layer of exposed sandstone in isolated areas in Nanhua. This exposed sandstone layer often form cliff of several to 10 m high that wedges

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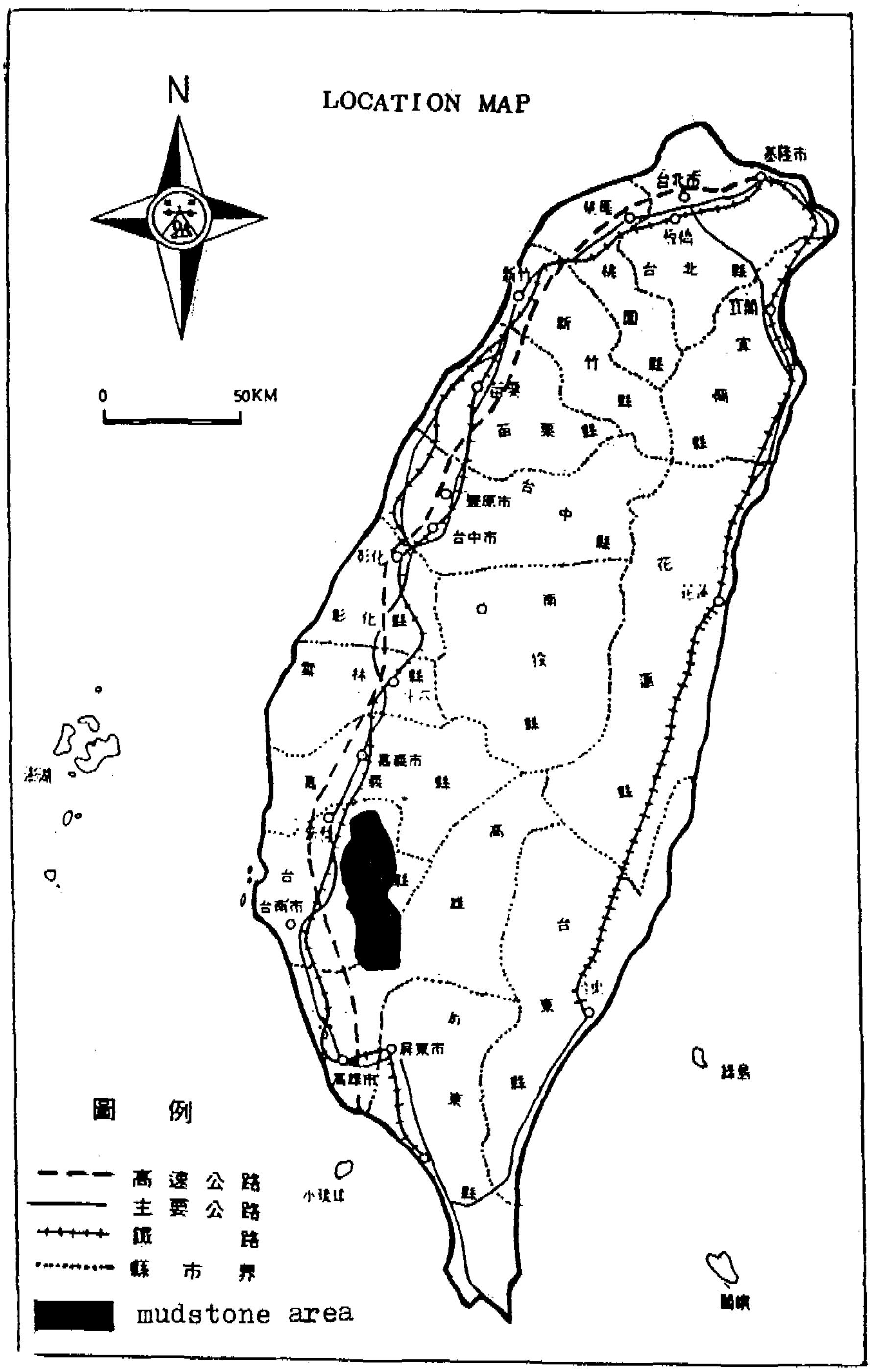

Figure 1. Location map of mudstone areas in Taiwan

out at both ends but not persistence. Most mudstone horizons, except where sandstone interlayers are observed, are not clear due to its monotonous lithology. Mudstone in this area is derived from deep ocean sediment. It is fine-textured, compact, impermeable and has high salinity characteristics. Distribution of mudstone areas is shown in Figure 1.

B. Land use

1. Major type of land use

According to a survey conducted in 1984 by the Agricultural and Forestry Aerial Survey Institute of the Taiwan Forestry Bureau, mudstone areas amount to about 73,613 ha. Of these, 3,836 ha (5.2%) remains barren; 65,157 ha (38.5%) is vegetated, 1,840 ha (2.5% is urbanized; and 2,780 ha (3.8%) is submerged in water. In 1967, a survey completed by the Mountain Agricultural Resources Development Bureau (MARDB) estimated the bare mudstone area of about 2,533 ha. Minor discrepancies might exist due to the different base maps used by both surveys (Aerial Survey used 1:5,000 topographic maps, whereas MARDB used 1:25,000 maps). However, the fact that the bare mudstone area has increased about 52% over the last twenty years cannot be challenged. Its boundary is in fact enlarging at a very rapid pace.

2. Farmland use

Farmlands are located in alluvial valleys and hillslopes. Bench terraces are built on alluvial valleys to grow short-term crops such as rice and sugarcane, and long-term crops such as citrus and Indian jujubes. Long-term crops such as longan and mango are grown in hillslopes. White popinac, thorny bamboo and other shrub are grown in steeper hillslopes.

C. Distribution of population

Since mudstone areas are situated in low undulating hills, there are widespread areas of river valleys with dense network of stream ditches. For the purpose of water needs and farming, people like to live in river valleys. As a results, densely populated urban centers are located where stream merge, and near river floodplains and basin areas.

Because the political boundaries of this mudstone areas is not

Table 1. Population growth of mudstone areas in Tainan and Kaohsiung counties.

County and village			1959		1969		1979		1984		1989	
			person	%	person	%	person	%	person	%	person	%
Tainan County	Total		808,980	100	938,692	116	969,621	120	1,003,275	124	1,015,469	126
	mudstone area	Total	55,515	100	70,893	128	60,453	109	56,834	102	53,832	97
		Nanhsi	9,116	100	17,303	199	14,100	155	13,829	152	13,152	144
		Yuching	17,884	100	21,494	120	20,112	112	19,109	107	18,601	104
		Nanhua	10,246	100	12,354	121	11,192	109	10,783	105	10,096	98
		Tsochen	9,929	100	10,698	108	8,504	86	7,262	73	6,702	68
		Lung-chi	8,340	100	9,044	108	6,545	78	5,851	70	5,281	63
Kaohsiung county			638,549	100	850,581	133	1,018,063	159	1,080,197	169	1,105,369	173
	mudstone area	Total	35,059	100	39,818	114	33,321	95	30,501	87	29,075	83
		Ner men	18,217	100	21,916	120	20,647	133	19,488	107	18,711	103
		Tienliao	16,842	100	17,902	106	12,674	75	11,013	65	10,364	61
Total	Two county		1,447,529	100	1,789,273	124	1,987,684	137	2,083,472	144	2,120,838	147
	Mudstone Area		90,574	100	110,711	122	93,774	104	87,335	96	82,907	92

well-defined, it is extremely difficult to gather accurate population distribution data. The historic population growth data for cities and villages with large mudstone areas, including Nanhsi, Yu-ching, Nanhua, Tsochen, Lung-chi of Tainan County, and Ner-men. Tien-liao of Kaohsiung County, are listed in Table 1.

Table 1 also indicates that during the last twenty eight years population has increased from 1,447,529 to 2,120,838 for both Tainan and Kaohsiung Counties, an increase of about 147%. At the same time, the total population for the entire Taiwan areas also increases by almost 180%, from 11 to 20 million. However, population decreases within the mudstone areas from 90,574 to 82,907, a decrease of about 8%. This reduction trend still persists until today.

Due to adverse natural conditions and underdevelopment of other industries, agricultural population ratio remains as high as 49.2%. This ratio is only about 22.4% in Kaohsiung County, 34.5% in Tainan County, and averages about 18.25% for the entire Taiwan areas.

II. Analysis of Water Shortage Problem in Mudstone Areas

A. Climatic factors

Mudstone areas are situated in the southwestern part of Taiwan. The climate is characterized by subtropical maritime type with high temperature and rainfall. However, rainfall is usually unevenly distributed. Summer seasons are wet while winter seasons are very dry. In this region, water shortage occurs at least six months of the year. The rainfall and evaporation pattern in the mudstone areas are listed in Tables 2 and 3.

Both tables indicate that rainfall is concentrated between May to October which accounts for about 90% of the annual total. November to April are the dry months which only adds up to 10% of the annual rainfall amount. The average annual rainfall for the entire island is shown in Figure 2.

B. Topographic and geologic factors

The thickness of the mudstone layer can reach 5,000 m and is water impermeable. Wetting may cause expansion and breakage. Drying may result in contraction and cracking. Particle size of mudstone is very fine. When wetted it remains in suspension and can be easily carried away. Once exposed it will continue to erode and slip away. It is, therefore, uncommon to observe formation of talus at the gully head, valley mouth and exposed foothill.

Table 2. Rainfall data in the mudstone areas.

Unit: mm

Month / Locality	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Leuyien	20.3	28.5	42.3	63.6	183.0	379.1	306.6	337.4	153.7	24.1	19.7	15.8	1584.6
Shinhua	16.6	24.0	36.0	58.1	201.2	393.7	343.5	454.2	161.8	35.2	16.8	7.4	1748.5
Yuijin	17.2	31.6	51.3	79.7	250.0	493.1	554.0	599.2	301.1	47.3	17.0	17.4	2454.8
Joujien	16.9	25.5	42.3	72.6	203.6	448.6	475.5	480.4	218.3	48.5	18.9	12.1	2063.2
Nanhua	17.8	33.6	46.7	79.2	262.0	490.9	517.9	636.4	298.2	62.3	18.5	15.5	2480.3
Niemen	19.0	26.1	40.8	65.0	262.9	485.6	502.0	568.4	278.7	50.9	22.9	9.9	2308.9
Tenliao	14.9	22.8	38.8	58.4	204.0	402.5	380.3	476.1	240.8	38.5	17.0	7.6	1890.8

Table 3. Evaporation data in the mudstone areas.

unit mm

Month / Locality	Jan.	Feb.	Mar	Apr.	May	Jun.	Jul	Aug.	Sep	Oct	Nov.	Dec	Total
Shinhua	108.8	137.7	163.8	153.1	173.6	190.0	199.6	191.2	133.1	153.4	140.7	110.4	1,855.4
Tainan	71.8	93.1	117.9	123.3	157.9	169.3	185.8	169.1	126.3	125.3	91.2	59.1	1,490.1
	108.4	127.5	142.6	148.9	190.6	203.0	220.0	179.3	139.4	146.8	130.1	114.5	1,851.1

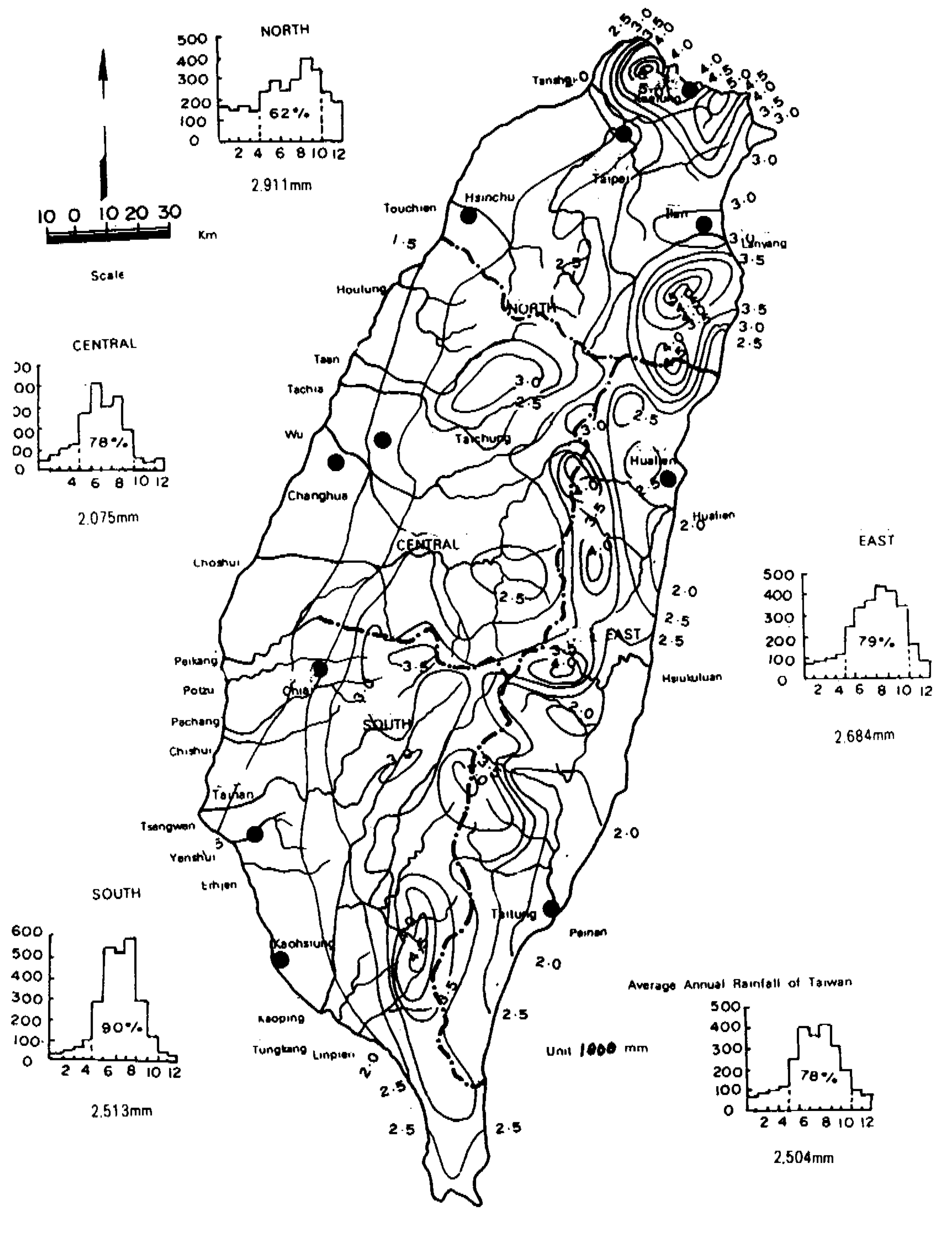

Fig.2. Annual isohyetal Map of Taiwan (1949-1986)

C. Shallow soil depth

Mudstone are derived initially from areas with deep incisions and extremely steep terrain. Soils, in general, are shallow with less than 50 cm deep. It is very fine textured, compact with poor drainage and water holding ability. The soil surface is sparsely covered with vegetation. Large areas remain fallow. Drought damage often occur with lack of water holding and storage capabilities.

D. Groundwater shortage

Because of its compactness and impervious nature, mudstone usually lacks groundwater resources. The water layer is non-existence due to deep layer of mudstone fused with thin layers of sandstone. The entire mudstone areas has insignificant amount of extractable groundwater supply, except for a small fraction of return water in the river floodplain areas. Water supply in mudstone areas is characterized by frequent drought and water shortage. This adverse environment is an unique feature of water use in the agricultural development in this area.

III. Water Supply in Mudstone Areas

A. Supply from non-mudstone areas

The Tsengwen river flows in a east-west direction dissecting the north-central region of this mudstone areas. This river originates from as far as Shui Shan, which is situated beneath Yu Shan, Chiayi County. However, due to the construction of Tsengwen reservoir, water is diverted to Wushantou reservoir and provide for irrigation and domestic uses in the Chiayi and Tainan floodplains. One of its tributary, Hou Chueh river, also originates in between Nanhua and Ta-pu villages. However, construction has been underway to build Nanhua reservoir and to utilize this water supply for domestic uses. Therefore, utilization of surface water supply in this region is restricted to areas close to the river banks and for domestic use only. Water allowable for agricultural irrigation use is very limited.

B. Diversion from small ditches

The mudstone areas have many small incision ditches. People usually prefer living close to the river valleys. In early days, people obtain domestic water use from diversion ditches and water wells located at alluvial valleys.

Table 4. Farmland acreage in mudstone areas of Tainan and Kaohsioung counties

county and village			Total acreage (ha)	cultivated area							
				cultivated acreage		upland field	paddy field				
				acreage	%		sub-total	Double Crops	1st. Crops	2nd. crop acreage	2nd. crop %
Tainan county	whole county		201601	102385	50.8	49278	53108	13932	2783	36393	685
	mudstone area	sub-total	49650	15802	31.8	13464	2339	14	7	2318	991
		Nanhsi	10963	5723	52.2	5051	672	—	—	672	100
		Yu-ching	7637	4074	53.3	3396	678	—	—	678	100
		Nan-hua	17152	3511	20.5	2976	535	14	—	521	974
		Tso-chan	7490	1532	20.5	1084	449	—	7	442	984
		Lung-chi	6408	962	15.0	957	5	—	—	5	100
Kaohsiung county	whole county		272966	56613	20.7	30472	26141	14951	856	10334	691
	mudstone area	sub-total	18830	4249	22.6	2362	1887	21	21	1845	978
		Ner-men	9562	3221	33.7	1730	1491	—	—	1491	100
		Tien-liao	9268	1028	11.1	632	396	21	21	354	894
grand total			474567	158998	33.5	79750	79249	28883	3639	46727	59.0
mud-stone area			68480	20051	29.3	15826	4226	35	28	4163	98.5

C. Rainfed paddy field

The major agricultural crop in East Asian countries is paddy rice because their main stable food is rice. These countries try very hard to grow rice paddy. In the northeastern part of Taiwan, including Taipei, Taoyuan, and Hsinchu Counties, almost one third of the total hillslope areas with slope exceeding 55% grows paddy rice on bench terraces. In the central and southern regions, since rainfall is unevenly distributed, rice paddies are grown using ridging raised to an appropriate height in order to collect direct rainfall. Timely collected rainwater are used to grow paddy rice each year during June to September. This practice is often referred to as the "rainfed paddy field". Secondary paddy rice in this area is solely grown using rainfed because there is no other available water sources.

The cultivated land areas for each city and village within the mudstone areas are listed in Table 4. Obviously, most paddy rice fields within the mudstone areas use rainfed method to store rainwater for growing a second crop of rice.

According to a paddy rice water requirement study conducted by the Taiwan Provincial Water Conservancy Bureau, daily water consumption of paddy rice in this area ranges between 7 to 10 mm. Assuming daily consumptive use of 8 mm and 100 days to grow the secondary paddy rice crop, the total amount of irrigation water needed to grow a 5,000 ha second crop of rice is about:

$$0.008 \times 100 \times 5000 \times 10000 \text{ m}^3 = 40{,}000{,}000 \text{ m}^3$$

D. Water storage in farm pond

In recent years, with the great advancement of economic growth, the government and the private sectors are better able to spend more money to improve the infrastructure facilities. Many farm ponds are built in mudstone areas to provide for adequate domestic and agricultural water uses.

IV. Construction and Management of Farm Pond

A. Farm pond construction background

1. Limited and difficult to obtain water sources Uneven distribution of rainfall creates water supply shortage in this area. Other methods to obtain water sources prove to be uneconomical.

2. Topographic and geologic conditions suitable for construction
   a. Mudstone areas are usually located in low undulating hills with many incision ditches. Stream ditches and their tributary are very complex and diffused. In general, small ditches are separated between 300 to 500 m apart. River channels are located at narrow gullies with elevation drop of about 2 to 3%, ideal siting for farm pond construction.
   b. Mudstone soils are impermeable to water. Water loss due to seepage is negligible. This material is also suitable for use in earth enbankment because when wetted it will expand and become extremely compact.
3. Abundant rainfall
   Many large storms occur during May to September of each year. Since the catchment area is very small, sufficient water may be collected in a short time. Usually the pond outlet is open during the early stages of the rainy season to allow for spillage and to clean up the sediment inside the pond. It is closed during the latter stages of the rainy season to store water. This practice can reduce sediment, maintain water storage and prolong the life of farm ponds.

B. Past years construction and uses
1. Farm pond construction
   Construction using digging method is usually performed privately. Public funding are provided to build barrier-type farm ponds. Between 1964 and 1990, the Soil and Water Conservation Bureau has assisted in constructing 97 ponds. Before 1973, a total of only 39 ponds has been built. However, the construction costs and water storage data are unavailable. Since 1974, a total of 58 ponds has been built at a total construction cost of about NT$82,342,0700. The total water storage is estimated to be about 2,745,239 m^3.
2. Farm pond use
   As far as operation and management is concerned, most farm ponds are well maintained and perform satisfactorily well. Some fail to store water due to poor workmanship. A few have been completely filled because adequate sediment clean-up devise is excluded in the original design. Farm ponds are becoming one of many infrastructure facilities that local residents cannot live without in the mudstone areas. They have been providing major domestic and agricultural water supply in hillslope farming. Some ponds have even been used for fish farming as part of the multi-objective scheme.

V. Recommendations

1. Factors such as climate, topography and geology have created many water supply problems in the mudstone areas of southwestern Taiwan. In early days, local residents practise rainfed paddy rice making use of rainwater stored during rainy seasons between June to September each year. Nowadays, the main water source is supplied by water stored in farm ponds.
2. Operation and management of farm ponds such as storage, water use and sediment removal are performing well. They have earned widespread acceptance by the local residents and have since become the most essential infrastructure facility in this area.
3. The construction of farm ponds and the available of water have initiated planting of high cash crops such as mango and orange in this region. This has improved the farmers' standard of living and contributed significantly to the development of local agriculture.
4. Emphasis on the work quality during farm pond construction and the awareness of watershed conservation problems should be able to reduce siltation problems and prolong operation life of the farm ponds.

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RAIN WATER CATCHMENT SYSTEM IN HYDRAULIC EXPERIMENT STATION

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Abstract

We has developed the rain water resources by a tameike (pond) in the laboratory of water use engineering , Kyoto University. Though we needed much water for the new laboratory of water use engineering at the remote location from Maizuru city, Kyoto Prefecture, the water was not enough to operate hydraulic experiment for 45 students and for researches of water use engineering. After several Years from the construction of new laboratory, though the Maizuru city had constructed new domestic water line with bigger diameter in this area in 1980, the water fee consumed by hydraulic experiment in the laboratory was very expensive one. Then we had introduced the facilities with rain water collection pipe line in underground and a tameike in our experiment station. The major items of facilities are as follows.

dimensions of rain water catchment system

total area of laboratory	2.5 ha
watershed area of tameike	1.0 ha
rain water collection pipe line in underground	side ditch of paved road 150m long and 6 meters width under ground drain pipe 250m

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roof area — roof of laboratory house 600 m2

tameike (pond) — area of water surface 1000m2; mean depth 3m; maximum storage 3000m3

The results of the rain water catchment system by tameike was very effective. We could saved much water fee in the hydaulic experiment. Theoretical bases for the optimum design of rain water catchment tameike has been presented in this paper from the standpoint of water utilization.

1.RAINFALL SITUATION OF MAIZURU AREA IN JAPAN

The Maizuru area exits along northern part of Japan Sea as shown in Fig.3 . Though there is much annual rainfall, there was no excess water for new hydraulic experiment for students of undergraduate and postgraduate course, and for researchers. Then we had studied how to prepare new water resources from rainfall for new laboratory of water use engineering.

After sincere study of new water resources here, we had understood that we can prepare the new rain water collection system with cheaper construction cost because of there are much rain in Maizuru city, comparing the utilization of expensive public domestic water. Before and after the construction of new laboratory, only drinking water has been prepared for the people.

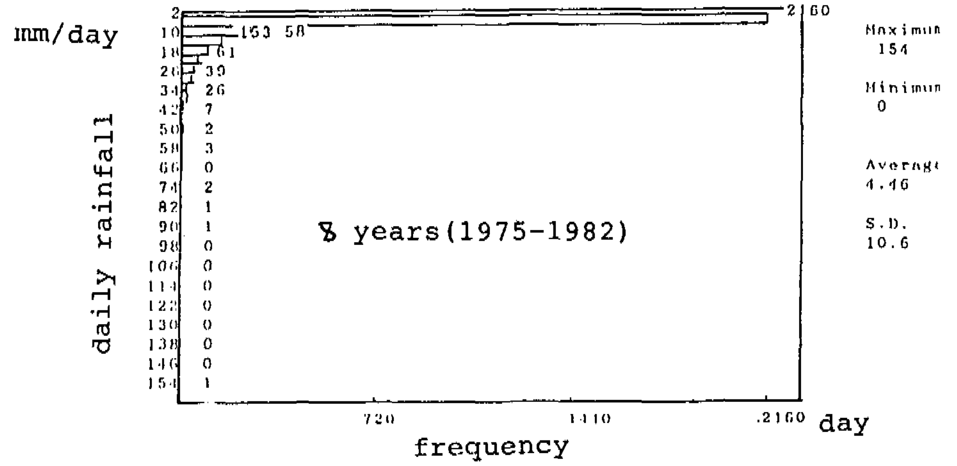

Fig.1 histogram of rainfall at Maizuru

Fig.1 is the frequency curve of daily rainfall at Maizuru city for 5 years from 1975 to 1979. Maximum daily rainfall is 154 mm/day and averages rainfall is 4.46 mm/day , and standard deviation is 10.6 mm/day.

To get more useful information for the design of rain water catchment system, the distribution of continuous no-rain day during 5 years from 1975 to 1979 is shown in Fig.2 with very meaningful data. Though Maizuru area has plenty of rainfall, the water use facility was not developed so much as other public project. Them the water should be developed by special effort for our new laboratory.

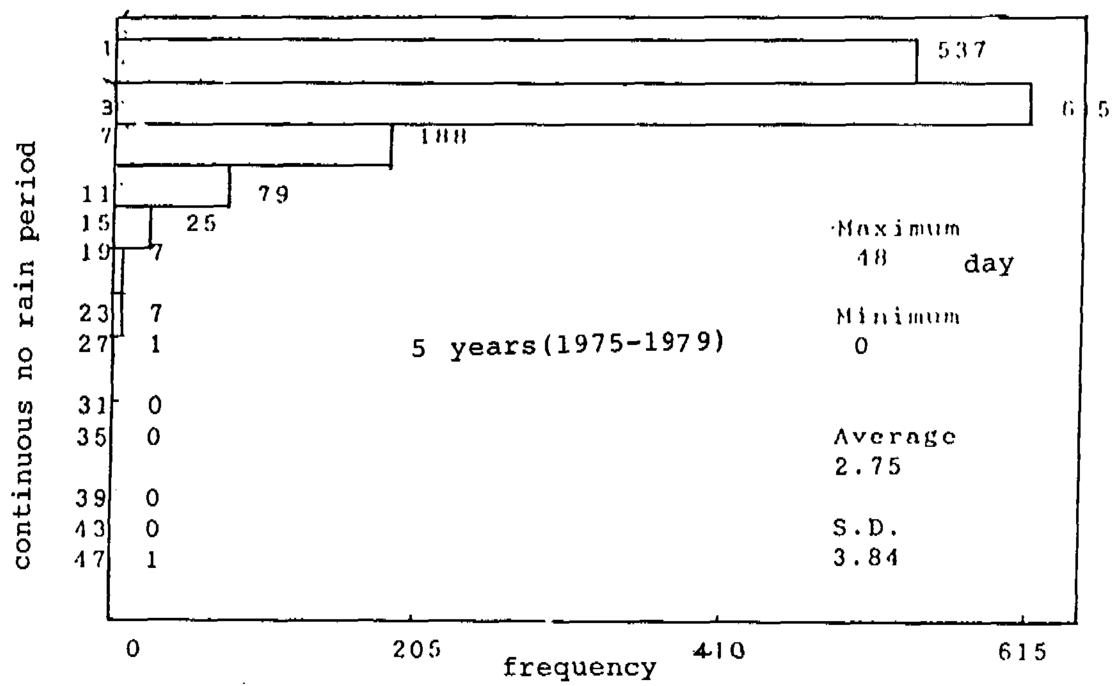

Fig.2 continuous no-rain days at Maizuru for 5 years from 1975 to 1979

In the period of 5 years the longest no-rain day was 48 days, and average continuous no-rain day was 2.75 days and the standard deviation of it was 3.84 days. The 10% probability longest continuous no-rain days is 7 days. These data show that there are rainfall frequency of once a week in Maizuru city.

Fig.3 show the Maizuru city in Japan island, and the average annual rainfall is about 1800 mm/y here , but actually the north remote area where exists outside of developed area has many places under the shortage of new water resources.

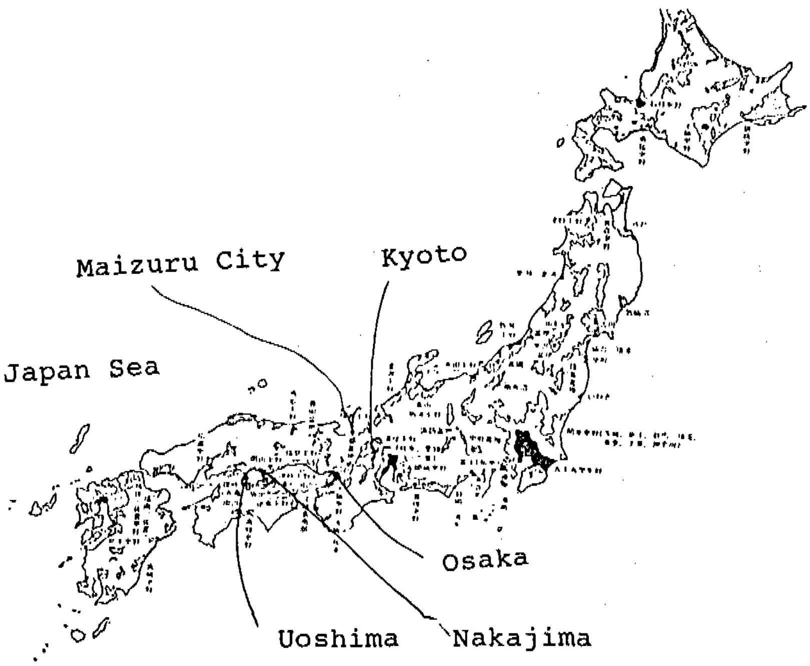

Fig.3 map of Japan island and the location of Maizuru

2. CAPACITY OF HYDRAULIC EXPERIMENT STATION OF WATER USE ENGINEERING

The location of laboratory of water use engineering lie on the north sea coast of Japan sea as shown in Fig.3.

The plan of the laboratory is shown in Fig.4 . The total area of laboratory is 2.5 ha and there are many hydaulic experiment flumes and big hydraulic models of water development projects. The upper region of laboratory is sea shore and its lower region is mountain area, and both side areas are occupied by factory. We have constructed new rain water collection pipe in underground and Tameike which has black color area as shown in Fig.4.

Fig.5 shows the trends of water utilized by the hydraulic experiment at the laboratory. We constructed new rain water collection pipe and a tameike in 1986 at the laboratory. By 1986,we has used the domestic water for hydraulic experiment, from 4600 to 2100 m3/y,but after the construction of tameike, the water from domestic water line has been decreased to less than 100 m3/y (only 3%).

For the drinking water for student and researchers ,we have continued the utilization of public domestic water ,but the water was very few.

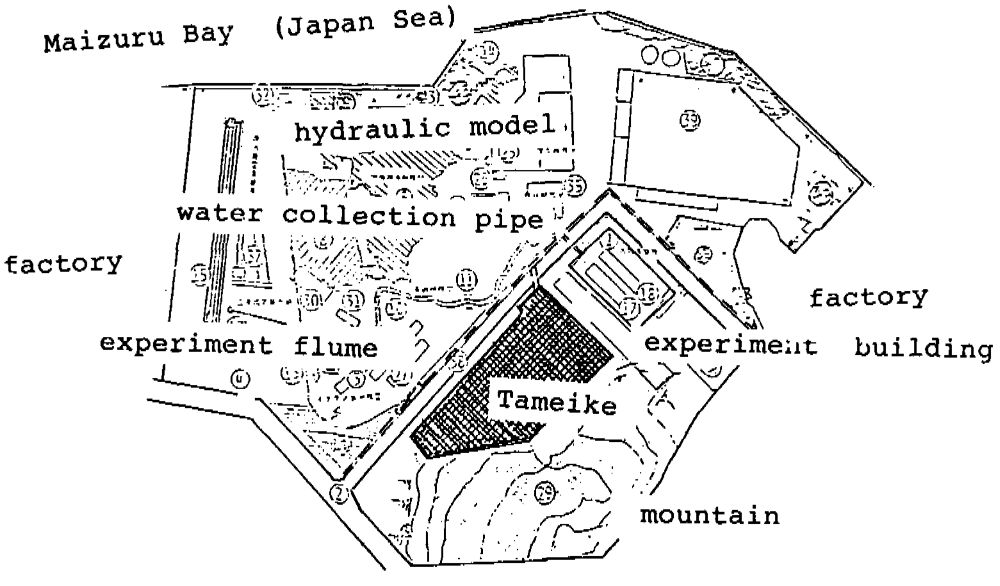

Fig.4 laboratory of water use engineering

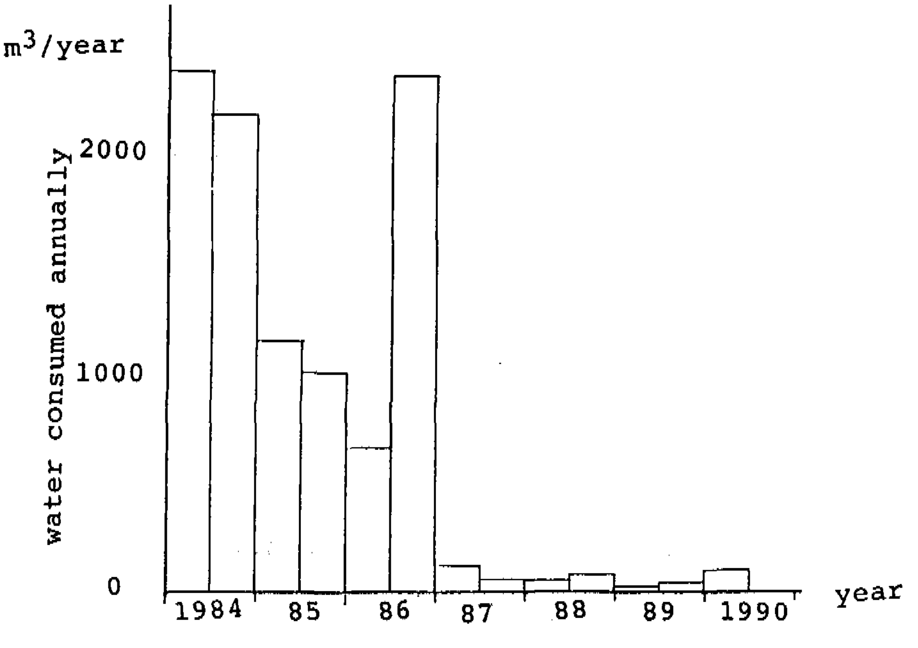

Fig.5 consumed water for hydaulic experiment in water use engineering form 1975 to 1979

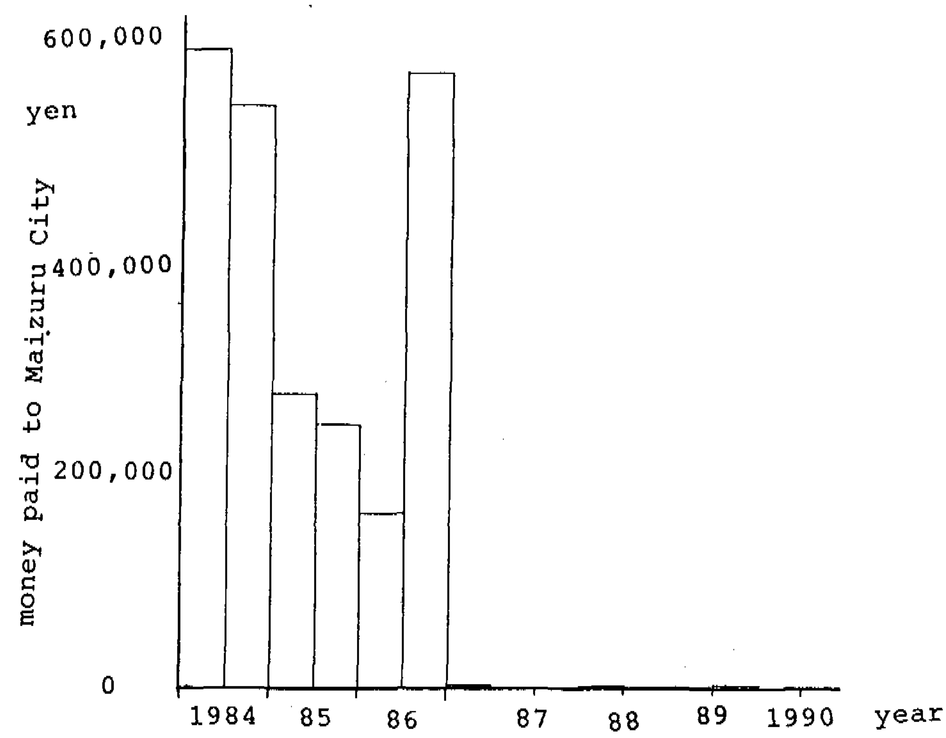

Fig.6 money saved by the introduction of Tameike water instead of public domestic water

The effect of Tameike was very effective for the saving of water quantity. But for the water quality of Tameike , there are some problem because of inflow of sewage water from paved road,we cannot drink the water of new Tameike.

Concerning the water fee of the laboratory to Maizuru city public domestic water , it was very expensive before the Tameike construction , from 580,000 to 250,000 yen/y,but after the construction of new tameike, the water fee to Maizuru has been decreased very much as shown in Fig.6, less than 30,000 yen/y,by the application of water fee calculation formula at Maizuru city.

3 Design method of rain water catchment Tameike

The curve of Fig.7 which has been calculated by the equation (2) of water balance from the daily rainfall data for average year from 1975 to 1979 shows the maximum potential of rain water potential at Maizuru city.

The potential maximum water utilization should be prepared by the construction of tameike as shown in Fig.7. The curve show the

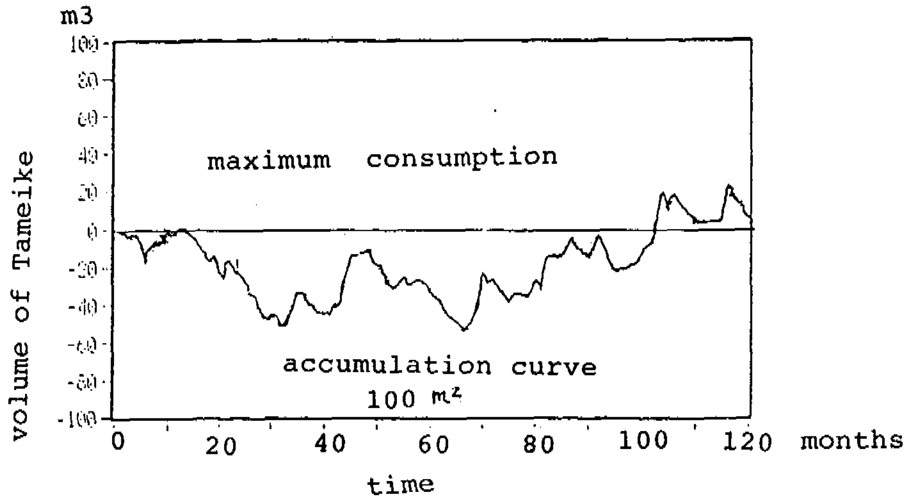

Fig.7 rain water resources potential

distribution of the balance of necessary water storage , then we can solve the reasonable volume of Tameike from the length of maximum vertical line between horizontal straight line and trends line.

There is three kinds of theoretical method for the design of optimum Tameike (pond) volume.

i. Tameike design by continuous no-rain days (preliminary method)

The design volume of Tameike can be given by the next formula.

$$V = N*Q + Ev*A \quad (1)$$

where
V:design volume of Tameike
Q:daily water demand for Tameike to do hydraulic experiment
Ev:evaporation from water surface of Tameike
A:average area of water surface of Tameike
N:continuous no-rain days

ii. design year (single year) method

$$(V(I))max = \sum_{0}^{k} (Qi(I,K) - Qm)dt \quad (2)$$

inflow by daily rainfall to tameike

$$Qi(I,K) = C*A*R\ (I,K) \quad (3)$$

T:period in a year
K:day
I:year
R:daily rain
Qi:inflow
Al:watershed area
C:run off coefficient

The calculation of equation (2) should be performed every year for n years respectively, and we can get n pieces of of tameike storages V(I) max. Then we can decided the 10% probability volume among n pieces of storages V(n) max.

iii. carry over method

$$(V)max = \sum_{0}^{I} \sum_{0}^{K} (Qi(I,K) - Qm)Dt \qquad (4)$$

The equation (4) should be calculated through first day of first year to last day of last year for n years. In this case the last storage of i-th year would be carried over to the initial value of i+1th year. Then we can select the optimum storage with 10% probability volume from the results.

The best method should be selected among three methods. The most simple one is the method described in section i and , the method described in section ii is suitable method for humid region , and the method described in section iii is suitable for water serious area in arid region.

Photo.1 Tameike

Dt:time increment
(V(I))max:maximum storage for each I year
Qm(I): maximum water utilization for each year I
Qm; maximum water utilization for Imax years

3. POTENTIAL OF WATER CATCHMENT SYSTEM IN THE FUTURE

The plan of the laboratory of water use engineering is shown in Fig.4. The area surrounded by line is the catchment area of rainfall and the black area is the rain water catchment tameike, and double doted lines itself is the under ground water collection pipe. The rain on the roof of laboratory, paved road and slop of hill flow into Tameike.

The rain water resources would be important in remote island, in rural areas and sometimes in special big city, to water use and save much natural resources.

I would like to say thank you very much for many colleagues who are studying the rain water catchment system in the world.

*annotation notes

We have developed the sanitary rainwater cistern by using special light material as shown in Fig.8 and Photo.2.

Photo.2 Photograph of rainwater cistern(2m3)

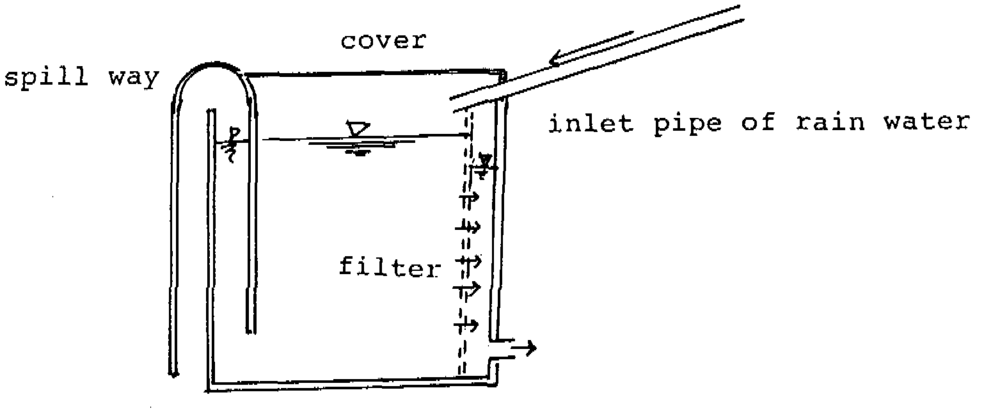

Fig.8 sanitary rain water cistern (2 m3)

Design of coastal fresh water pond for optimum use of water Resources

Lai, Chan Ji*; Pan, D. B.**; Hwung, Hwung Hweng.***

ABSTRACT

An idea of constructing a coastal fresh water pond system for reclaimed area is reported. This pond utilizes a dividing channel, initially designed to isolate the reclaimed land from the nearby urban area, as the fresh water reservoir. The completed fresh water pond system is composed of (1) Linkage, conveyance and bypass (2) Monitoring & control, MACS and, (3) pond storage, CFPW systems. System design requirement for the pond and consideration are listed.

The MACS is planned to be fully automatic and performed in both predictive and real-time modes. The linkage system uses two by-pass channels and retain most of the current environmental issues. The pond is designed to have overall storage of $21,6x10^6$ M^3 and capable for industrial water supply of two months. The overall system is being evaluated in an experimental station.

1. Introduction:

For the last decade, Taiwan has undergo a rapid development in industries. The land resources for constructing high-technology factories and other productive facilities of high standard have been requested by the investors. To fulfill their demands, several coastal land reclamation projects have been proposed. One of them located in the middle of Taiwan, as shown in Fig.1, is being constructed. However, the coastal reclaimed areas are at the lowest downstream of the catchment, sufficient water supply is one of the major factor to the success of this reclaiming project. There are some examples in Taiwan, where the reclaimed coastal lands fail to meet their design purposes due to non-sufficient issuing of fresh water.

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In recent years, environmental issues have become very important in all developing project, any further development of water resources project can have strong impact to existing urban area. On the other hand, if the water is supplied by upstream reservoir, if they are available, the channel and other hydraulic structure required to divert water are too long. This may largely increase development cost. The water supply to the coastal reclaimed area is thus important and to use water stored in coastal fresh water reservoir is one of the better approach.

The usage of coastal fresh water reservoir has been succeeded in many places, eg.. The Netherlands and Japan. The theoretical background, including the hydraulics of select withdraw, mixing, stratification, etc., are well known [1]. But the application of these theories to practice usually under large local restrictions. This paper thus just reports a planned coastal fresh water pond (CFWP afterward) for a new developing reclaimed area. The difference of present water pond to those reported in [1] is that the pond has been designed to be multiple purposes. It uses dividing waterways, not only for water storage, but also for isolating reclaimed land from the nearby already developed urban area. It provides living, recreation spaces to people and habitat to some spaces and are expected to have some contribution to environment protection.

Since water stored in pond is mainly from upstream drainages, the long dry seasons at this region and rather poor water quality promotes requirement of monitoring and control systems. The system is planned to be fully automatic in the future. The basic considerations to the overll system are given in this paper.

2. Description of overall System.

The proposed system is being evaluated in an experimental station. The system uses structures and storage area which are designed as part of the reclaimed works, and hope the construction cost can be reduced. It also retains part of the original environmental issue and cause less effects on local residents. Fig. 2 shows the preliminary design of the pond system.

The system is design to store water at suitable quality during flooding season and drainage poor quality water to sea during dry season. The overall system is composed of four subsystems as: (i) C: linkage and conveyance and bypass, (ii) M: monitoring and control, (iii) S: CFWP and, (iv) possible groundwater supply. Fig.3 shows the layouts of the overall system. From north to south, there are five drainage channels C1, C2, C3, C4 and C5 flow towards the reclaimed area. Among them, C3, C4 and C5 are larger drainage and have drainage areas of 35.6, 170.93 and 180.55 Km^2 respectively.

At dry season, normally from November to May at this region, flows in the upstream channels come from urban drainage, the amount of water is scarce and water quality are generally very poor. They should be diverted directly to the sea through the bypass system. In the meantime, tide can flow into these drainage channels so the effects to original habitat is minimized. Fresh water can also diverted from a diversion weir C0 through canal D1 and store in S1.

At flooding season, once the polluted tidal channel has been flushed, fresh water from upstream run off is diverted through the controlling wall and into the storage. Once the required water level is achieved. Excess water can discharge through the bypass channel or overflows into the sea. Details and preliminary design of the system are described in the next section.

3. System preliminary design

3.1 Meteorological, and geo-hydrological conditions.

The meteorological and hydrological conditions are required in the planning of the pond system. Some are summarized in Table.1.

Table 1 Metrological and hydrological conditions

wind	Max 52m/s NNW	av. 6.2m/s NNE
Temperature	max. 35.5°C	av. 22.3°C
Pressure	max. 759.94 mm	av. 758.52 mm
Precipation	max. 240.5mm/day	1034mm/year - 1347mm/year
Evaporation	max. 274.5mm/mon July	1279mm/year - 2336mm/year
Tide	HHT = +2.92 Storm surge=+3.83m	MT= +0.09; LT=-2.86
Groundwater elevation	EL+30.0 EAST mountain	EL-10.0 near coast

From Table 1, it is noticed that the annual evaporation in the region is about 1-1.5 times of the rainfall. The tidal range is about 4-5 meters. The ground water level is also very low due to excess groundwater withdraw.

3.2 The fresh water pond: CFWP

The CFWP is designed to store water for both industrial and domestic uses. In the year of 2000, the daily water requirement in the reclaimed areas is estimated to be 2.4×10^4 M^3. By considering on third of the stored water may evaporate or lost, it is expected that the pond should have a total capacity of 21.6×10^6 M^3 to supply water for a drought period of two months. Since water from drainage C1,C2,C3,C4,C5, as shown in Fig.3, are not reliable, the division weir C0 with a height of 15 meters is planned. Water is diverted from C0 through D1 and from C1-C6 to storage S1, S2 and S3. Gates G1,G2,G3,G4,G5 and G6 are user for storage control. Cross-section of S1, S2 and S3 are given in Fig.4 and their effective storage are given in Table II. The total effective storage of S1, S2 and S3 is 14.925×10^6 M^3. The gate T1 is mainly used for storm surge barrier but it is being considered to retain the area TS1 as part of the pond and to increase the total storage up to 21×10^6 M^3. The cross-section of TS1 is given in Fig.5. Currently the bed elevation at these ponds is around EL.0.0. The excavated bed material is used to fill the reclaimed land.

Table 2. Effective storages of Pond S., S2, S3 and TS1

Storage pond	Effective Area (Km^2)	Effective storage depth(m)	Pond storage ($m^3 \times 10^6$)
S1	0.5	5	2.0
S2	0.95	5	4.75
S3	1.635	5	8.175
		Total capacity	14.925
T1	2.00	3	6.00

3.2 The Monitoring and Control system: MACS

The monitoring and control system, MACS, is to insure water stored in the ponds satisfies the class II industrial water standard. The MACS is performed in predictive and real-time modes.

Since C1, C2, C3, C4 and C5 currently are tidal channels, the MACS decide when and where to divert fresh water of better quality into storage. The MACS thus is formed by rainfall stations, tidal and water level stations, meteorological and hydrological stations, water quality sensing stations and groundwater monitoring wells. Locations of these stations are shown by symbols "M_" in Fig. 3. M0 is the experimental station and also one of the station for metrological and hydrological data collection. Automations in sensing, data transferring and gates control are being tested in stations M0.

In predictive mode, the MACS includes a model rainfall modules. The model storms are obtained from statistical analysis on 60 rainfall stations, within and surround the catchment, each of them has records for more than 30 years. The distributive patterns of the past storms have been included in the model storms [2]. The runoff and discharges in channels then are obtained through rainfall-runoff model [3] and hydraulics computation. The gate control measures are made based on these computed results and planned select withdraw process. The inflows from the ground water are also incorporated. A knowledge based operation procedure, KBOP, is formed.

In real-time mode, the rainfall intensity at 5 self-recorded stations (currently, in future, more are planned) are reported to the control center M0. In the meantime, the water level and quality sensing data are collected from M1-M5. Data are fed into the KBOP and control operations on the gates G1,.. G6 are performed based on suggestions from KBOP. Through the MACS, it is expected that storage control operation can be performed in a 3 days or weekly bases.

3.3 Conveyance, linkage and bypass system

This system is design to divert floods and poor quality water to sea and retain the tidal function of channels C1-C5.Channels C1 and C2 have less storm runoff that bypass B1 and B2 are used. B1 and B2 are open, respectively, to sea and B3. Tide can flow into them. Channel C3 connects to B4, and C4, C5 flow directly to the sea and assure their originally functions. Moreover, during the process of select withdraw operation, gates G2, G4 and G5 may drain salt water. B3 and B4 then function as the linkage. There are some fishboats currently resident in S3 and they are to be moved to southern end of B3. The current layout has the least impact on the original environment factors.

3.4 The groundwater linkage.

The use of groundwater resource is very restricted here. However, the existing of CFWP may recharge the phreatic aquifer and hope to slow down land substance at nearby region. The sand filled in the reclaimed areas are also used as underground water storage and can refilled into the CFWP in dry seasons. This is also being evaluated in the station M0.

4. Summary

For water supply to a reclaimed area, a fresh water pond, CFWP system is proposed in Fig.2. This system is multiple purposed and has three sub-systems, namely, monitoring & control, MACS, linkage & bypass and storage. The MACS system is designed in fully automatic mode using knowledge based database. The linkage, storage systems are designed to fulfill the environmental requirements. If the system is completed, the water stored should be sufficient to provide industrial water for at least two months. The overall system is being evaluated in an experimental station within the reclaimed land.

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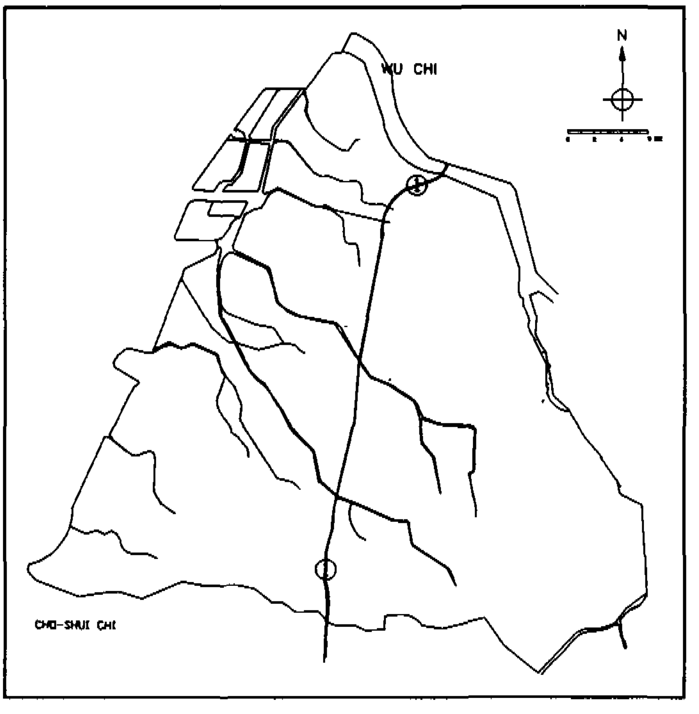

Figure 1. Overview of the Whole Catchment

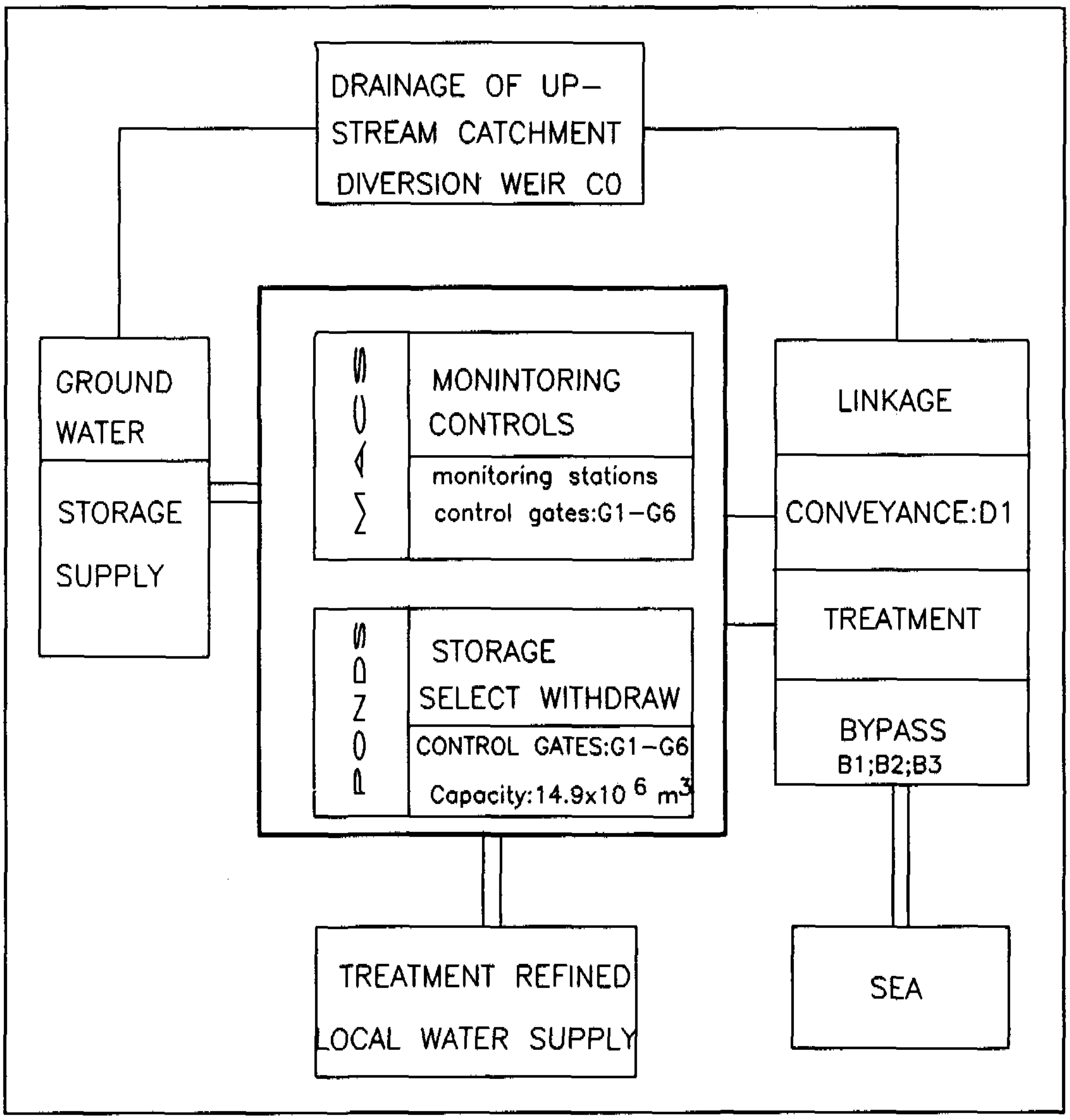

Figure 2. Block diagram for the fresh water pond system.

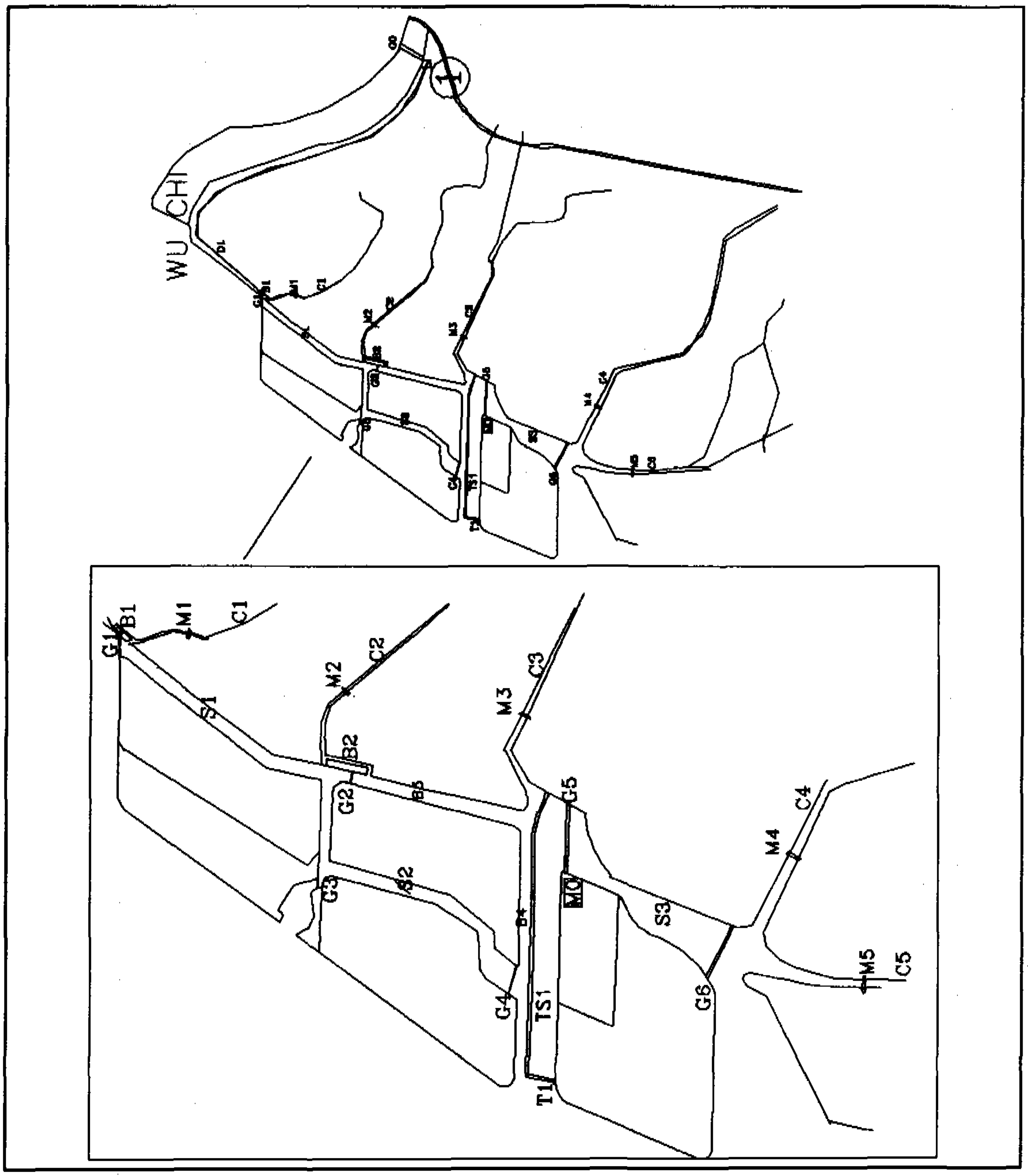

Figure 3. Layouts of the MACS and POND (C:channels; D:donveyance; C:gates; M:monitoring and Controls; S:storage)

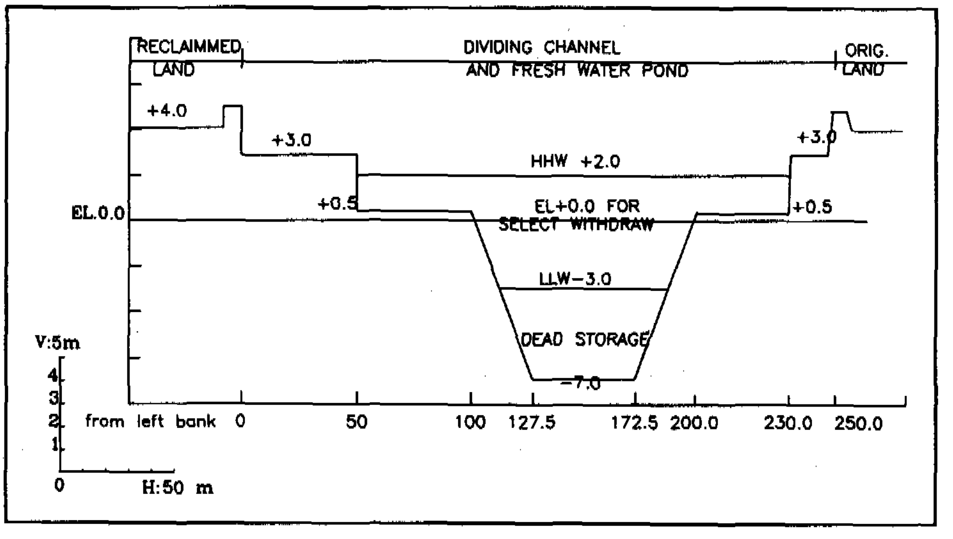

Figure 4. Preliminary design for pond storage S1, S2 and S3.

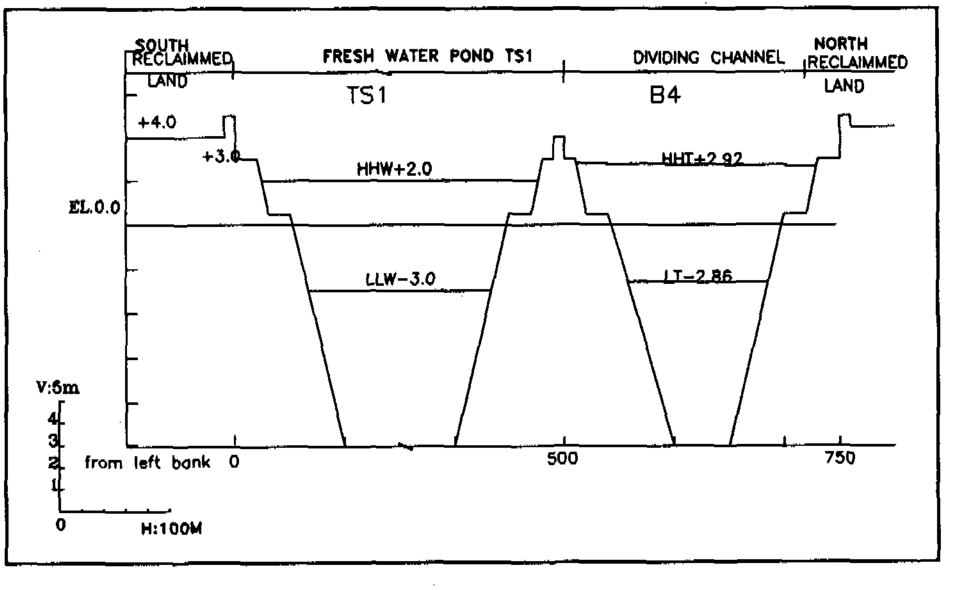

Figure 5. Cross-section of the Storage TS1 and Tidal ch annel.

THE USE OF RAIN WATER FOR W.C. FLUSHING IN THE U.K.

A Fewkes* A Jay**

ABSTRACT

The general problem concerns the use of rain water for w.c flushing. In the past there has been no financial incentive for U.K. customers to conserve water because charges were not based upon the volume used. During the next decade the metering of domestic supplies is to be introduced and water conservation devices are likely to become financially viable. The integration of rain water w.c. flushing cisterns into U.K. dwellings and their economic feasibility is evaluated. Finally the reactions of water suppliers, housebuilders and consumers in the U.K. to this method of water conservation are presented and discussed.

INTRODUCTION

In the U.K. 99% of the population are supplied with water via a mains network. Approximately 30% of the potable water supplied to the domestic sector is used for w.c. flushing, that is, the transportation of foul waste. The use of rain water for w.c. flushing is a simple and practical method of reducing the demand on both the public water supplies and waste treatment facilities.

The feasibility of a rain water w.c. flushing system to householders is related to their annual water charges. Currently the majority of domestic consumers are charged for water based on the value of their property and not the volume consumed, consequently there is no financial incentive to conserve water. Recent government legislation (Water Act, 1989) has changed both the structure of the water supply industry and the method of charging for water. The widespread metering of domestic properties is expected by the year 2000. Water conservation devices

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are likely to become financially attractive in the U.K. within the next decade.

The application of this water conservation measure is investigated by considering the ease with which two different designs of rain water w.c. supply system can be integrated within domestic properties. The reactions of the water supply industry, housebuilders and consumers in the U.K. to this method of water conservation are presented and discussed. Finally the economic feasibility of a typical system is analyzed by comparing both hardware and installation costs against the anticipated savings in water charges.

RAIN WATER W.C. FLUSHING CISTERN CONSTRUCTION AND OPERATION

The performance of a rain water flushing cistern is related to daily rainfall levels, catchment area and collection cistern capacity. The optimal tank size varies between different regions of the country due to variations in both rainfall level and available catchment area. A method of modeling system performance to determine optimal cistern sizes for range of catchment areas and geographic locations is discussed elsewhere (Fewkes and Ferris 1982).

The geographic location selected for this study is the East Anglian region which receives the lowest annual rainfall in the U.K. and often experiences water shortages during the summer months (Turton 1990). Water conservation is considered more seriously by water suppliers, housebuilders and consumers in this region than other areas of the country where rainfall levels are higher. However larger catchment areas and storage cisterns are required to satisfy a fixed proportion of the w.c. flushing demand which has a detrimental affect on the systems economic feasibility. It is estimated a family of five persons with a catchment area of $100m^2$ will require a rain water cistern of 1200 litres capacity to supply 75% of the w.c. flushing demand (Jay 1991).

The rain water is collected in gutters of a self cleansing velocity type to reduce sediment accumulation and minimize gutter surcharge. Rain water is fed into the storage tank via a silt trap to remove larger particulate pollutants. The silt trap requires periodic cleaning but obviates the installation of flow diverter.

The design of the house influences the location of the main storage, cisterns located below ground level keep the water cool and inhibit bacterial growths. Alternatively a vessel positioned at the first or ground floor obviates excavation work and alterations to the below ground drainage system. Irrespective of location all cisterns must be fitted with lids to reduce evaporation and discourage algal growths. The bases should slope slightly up at the outlet to allow settling particles to accumulate at the opposite end. The larger cisterns can be fabricated from GRP or a smaller polypropylene vessels connected together to provide an equivalent capacity, both of these materials are light, durable and economical.

Two different system arrangements are possible, a single or dual cistern system. The single cistern system is simple in design but all the rain water storage is located in one cistern which because of its volume may be difficult to integrate within a house or require excessive excavation if located below ground level. The pump is also activated each time the w.c. is flushed which could be a source of annoyance to the occupants of the house.

A dual cistern arrangement (Fig.1) has a second cistern located in the roof space enabling the w.c. to be gravity fed. This system reduces the pump duty and minimizes the number of pump operations which is activated by a float switch fitted in the roof cistern. The total storage is shared between two cisterns, this will assist the integration of the system into the building because both excavation and alterations to the drainage at ground level are reduced. To optimize system efficiency the ideal capacity of the roof cistern is between 200-500 litres (Jay 1991). A 225 litre roof store is convenient because this is the capacity of a standard plastic cold water storage cistern. Frost protection is essential and the cistern must be well insulated and fitted with a close fitting lid.

Excess rain water overflows from the ground cistern to the household drain via an overflow. A float switch de-activates the pump at a pre-defined level to prevent wastage of water from the roof store. The emptying of the ground store is also prevented by a float switch. System failure is prevented by supplying the roof store with mains water via a delayed action ball valve. To comply with design guidelines (Mays and White, 1989) the ball valve is fitted with a double check valve to prevent contamination of the mains supply by back siphonage.

Rain water w.c. flushing cisterns can be integrated into new dwellings along with other utility services at the construction stage. The most difficult item to integrate is the ground store, the ideal solution is an underground store located under the garage floor. The integration of rain water cisterns into existing dwellings is more difficult because of the necessary structural alterations and associated cost implications. The present study is limited to considering the feasibility of system installation into new houses.

THE WATER SUPPLIERS REACTION TO RAIN WATER SYSTEMS

The widespread incorporation of rain water cisterns into new houses will have a significant affect upon the growth of water demand and the rate of developing new water supplies. In addition the systems must comply with the design guidelines administered by the water suppliers. A series of interviews with the water companies supplying the East Anglian region were undertaken to assess the initial feasibility of the system. Three broad areas were investigated;

(i) system design and compliance with design guidelines,
(ii) contribution of the system to water conservation, and
(iii) suppliers general attitudes and opinions to the system.

The main concern of the water companies in relation to system design was the contamination of mains supplies with rain water by back siphonage. The pipework and cisterns must also be resistant to corrosion by acidic rain water. These requirements are satisfied by the incorporation of double check valves and the use of plastic pipework and cisterns.

Water conservation is encouraged by the companies in the East Anglian region to alleviate supply difficulties encountered during the summer period. The introduction of rain water cisterns would also reduce the rate of growth in water demand. The development of new water resources to meet increases in demand are expensive and can be ecologically undesirable, moreover the capacity of sewage facilities must also be enlarged. It is generally accepted that increases in the standard of living have a greater effect on water consumption than population growth (Central Statistics 1974). Total demand on the public water supply has on average grown at 2% compound per annum and since 1945 increased 100% for a population growth of approximately 12% (Humphries 1977). In the past investment by water companies into the supply infrastructure has been inadequate and water charges have not reflected the cost of water (Kinnersley 1988); a massive investment programme is now necessary to upgrade the existing supply network and develop new resources. The introduction of rain water cisterns therefore offers an additional method of tackling the problems currently encountered by the water suppliers.

The main problem perceived by the water companies relates to consumer education. Historically water has been a low cost commodity charges on a basis which does not encourage water conservation by the consumer. The introduction of water metering may change this attitude in the future and encourage the use of water conservation devices.

THE HOUSEBUILDERS REACTION TO RAIN WATER SYSTEMS

The views of thirty companies of varying size were surveyed to assess the housebuilding industries general attitudes the system. The survey was structured to assess the companies views on three broad aims;

(i) general attitudes
(ii) technical feasibility of the system, and
(iii) economic feasibility of the system

Changes in water supply legislation (Water Act 1989) has affected housebuilders in a number of ways;

(i) the cost of new property connection to the mains network has increased by 300%,
(ii) all new houses are fitted with water meters, and
(iii) from 1993 7 litre w.c. flushing cisterns will replace the old 9 litre cisterns.

Approximately 50% of the developers were installing low volume flushing cisterns prior to 1993 and using this as a positive marketing feature in their sales literature. All of the housebuilders were as a consequence of the new legislation aware of the need to conserve but none had plans to introduce water saving devices into their properties other than those required by the new design guidelines. This finding corresponds with recent criticism (Hall 1990) of the housebuilding industry not funding research into developing new strategies and techniques to improve the environmental performance of domestic dwellings.

Each housebuilder incorporates various common design features in their house designs which assist both the development of a standard rain water cistern design and its integration into the dwelling. Sanitary appliances are grouped together in each house design to minimize the quantity of pipework used and the majority of developers use standard roof coverings and rain water goods capable of draining large roof areas with the minimum of down pipes.

All of the builders were prepared to consider installing rain water cisterns; their main concern related to cost. The cost of fabricating and installing a dual cistern system into a typical house is estimated at 850 pounds sterling. The pay back period for the system based entirely upon anticipated reductions in water charges is 15 years (Fig.2). The calculation assumes the cost of water to increase at the rate of inflation plus 5% until the year 2000 (as prescribed by the Water Act 1989) and subsequently at the rate of inflation. The expected rate of inflation is difficult to predict but even allowing for under estimation the pay back period is unlikely to be less than 10 years. The introduction of rain water cisterns will however reduce the rate at which new sources of water require developing. The economic feasibility of rain water cisterns could therefore become economically attractive in the U.K. if the water companies offered householders financial incentives to install systems in their properties. This idea is not new and already practiced in California (Fok 1982).

Overall the housebuilders were receptive to the concept of rain water cisterns but expressed doubts relating to the systems economic feasibility. Therefore, despite the environmental benefits of the system only 60% of developers considered it would be a marketable feature if incorporated into their properties, this was because they considered house buyers are more cost conscious than environmentally aware.

THE CONSUMERS REACTION TO RAIN WATER CISTERNS

The water companies and housebuilders had collectively criticized homeowners environmental awareness. The owners of new properties fitted with water meters on a residential development in the Kesgrave area of East Anglia were surveyed to assess their general environmental awareness and in particular their attitudes towards water conservation and rain water cisterns.

Responses to general environmental questions were encouraging, over 85% were concerned about the environment and 65% were taking positive action by the use of environmentally friendly consumer products. Similarly over 70% of the homeowners stated they would be more inclined to purchase an environmentally friendly house; this statement directly contradicts the views expressed by both the developers and water companies. The majority of those surveyed were aware of the water supply problems in the area and actively conserved water. In excess of 85% of the respondents used economy water cycle washing machines and dual flush w.c.s. This is perhaps not indicative of the national situation because the householders reside in a water sensitive area and consume metered water supplies.

The possible use of rain water cisterns was positively received, over 85% of the householders were prepared to use the proposed system as a way of reducing water charges. The initial reaction from homeowners is therefore encouraging and indicates the system is a more feasible proposition than suggested by views obtained from the water companies and housebuilders.

DISCUSSION

A rain water w.c. supply system has been designed and its economic feasibility assessed in conjunction with the water companies, housebuilders and consumers reactions to this method of water conservation. The water companies were receptive to the system provided the design complies with the relevant design guidelines. The main problem identified by the suppliers related to consumers lack of water awareness. In the past no incentives existed to encourage consumers to conserve water. During the next decade the metering of U.K. domestic supplies is to be introduced coupled with increases in water costs.

Housebuilders are prepared to consider installation of systems in their new properties but expressed concern on two specific areas, cost and user acceptance. The environmental awareness of U.K. consumers was questioned by both water suppliers and housebuilders. This study indicates U.K. consumers are both aware and prepared to act upon environmental issues. The concept of rain water cisterns was well received by this group with in excess of 85% in favor of the system. The cost of installing a system into a typical U.K. house is 850 pounds sterling with a payback period of 15 years. Rain water cisterns are therefore unlikely to become economically feasible in the U.K. unless the water companies offer householders financial incentives to install systems in their properties. This is a realistic proposition as the rate at which new water supplies would require developing is reduced.

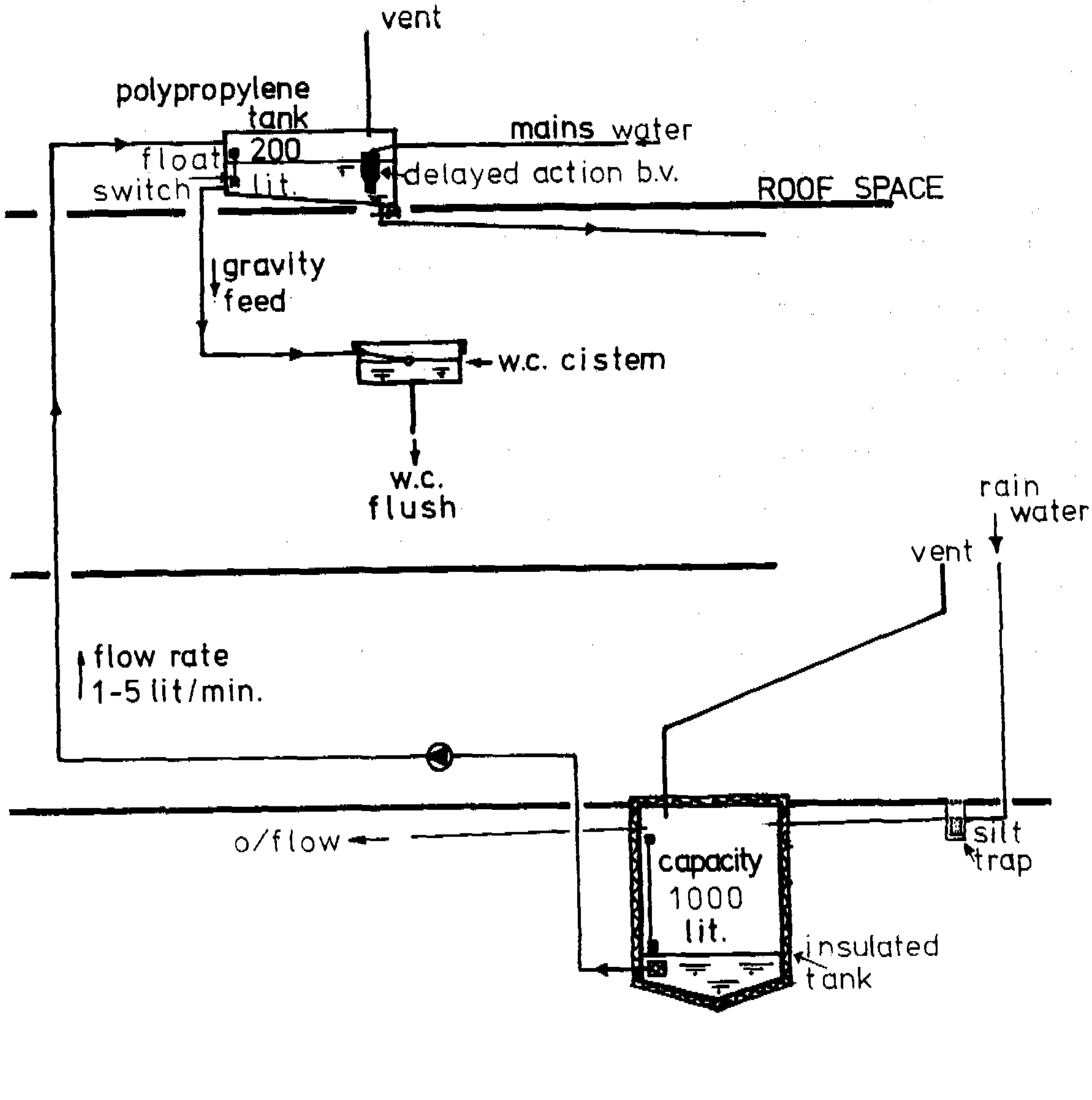

Figure 1. Dual tank rain water w.c. flushing cistern

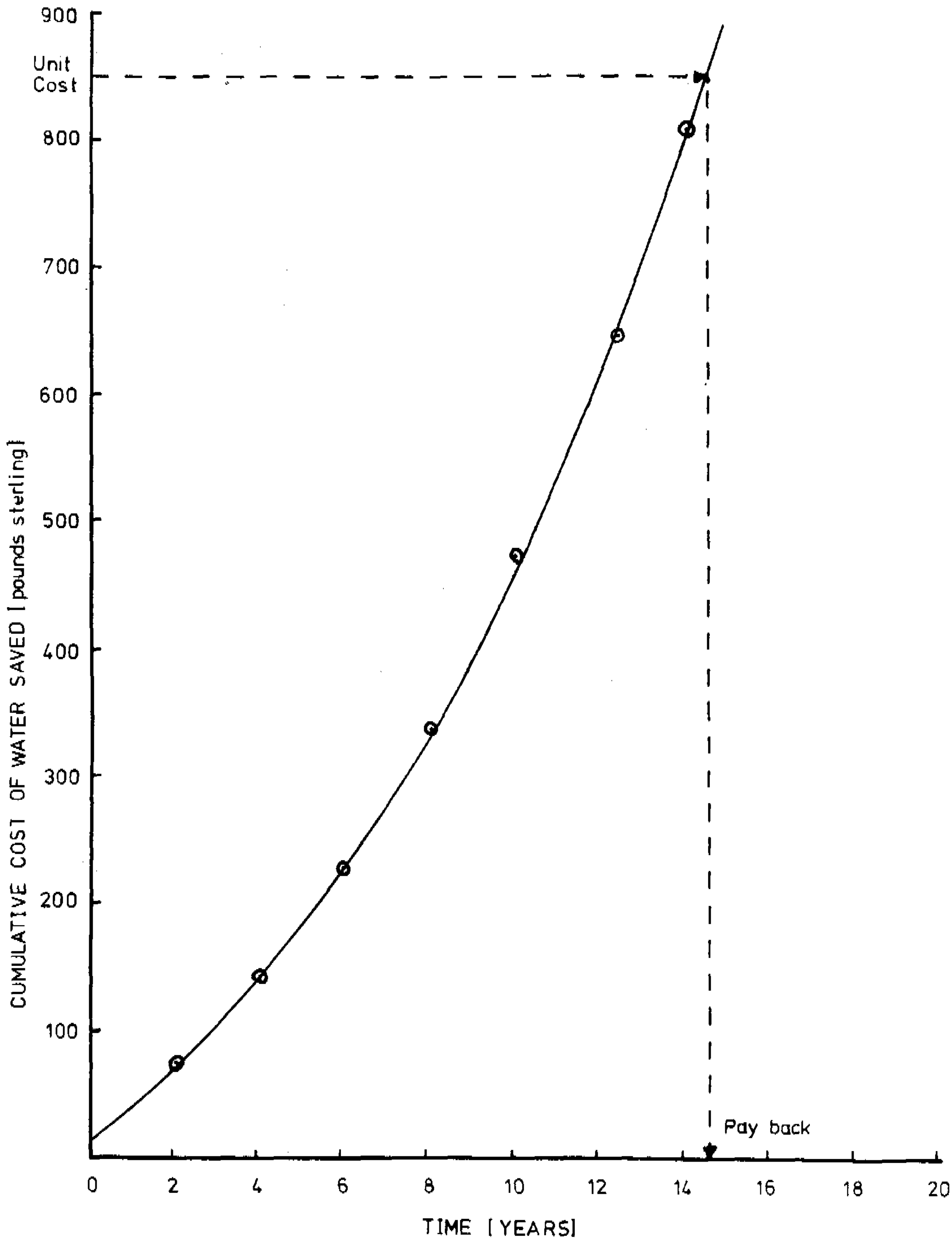

Figure 2. Pay back period for dual tank rain water cistern.

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A Simple Weir for Economical Floodwater Diversion

Ahang Kowsar*, Akbar Zargar**

ABSTRACT

Diversion dams or weirs sometimes constitute the most expensive and troublesome structures in the design and construction of floodwater spreading (FWS) systems. Many plans for construction of potentially viable FWS systems have been cancelled in the feasibility stage studies because, on occasions, the expenses involved in the design and construction of a single weir or diversion dam far outweigh the cost of the rest of the project. Thus, justification of the entire project hinges on designing a workable structure at a low cost. Gabion provides a useful material for construction of simple, inexpensive weirs which could be fitted into many designs, and may be built by unskilled laborers.

Fifteen pieces of 3.0 x 4.0 m, 3 mm diameter galvanized wire netting were used to construct a 0.60 m high weir in a 28.0 m wide ephemeral river on a debris cone to divert up to 5 m^3 s^{-1} of floodwater to a 25 ha FWS system in the Gareh Bygone Plain in southern Iran. The costs were at least 136 times lower than building a hydraulically efficient, concrete structure having the same capacity.

Although the intake structure behind this weir is located on the inside of the river bend, and at a 92° angle to it, no detectable deposition of sediments has taken place at this point during 6 years of operation. These hydraulic anomalies deserve further attention.

INTRODUCTION

Water shortage is gradually attaining the notorious status of the most crucial factor in limiting population growth and economic expansion virtually all over the world, particularly in the Middle

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East and Northeastern Africa. It has been a (if not the) cause of skirmishes between the Occupied Palestine and its neighbours since 1947 (Cooley, 1984), and will replace oil by the year 2000 as the catalyst for future armed conflicts (Starr and Stoll,1987;Linden, 1990). It is a cruel irony of the nature that while, on the worldwide basis, there is enough water for everybody, a vast disparity exists on the amount received by the inhabitants of different lands. According to the World Resources Institute (Linden, 1990), "3.4 billion of the world's 5.3 billion people must get by,on per capita basis, on only 50 L [liters] of water a day, one- seventh of the amount used by the average American". Therefore, besides the vagaries of the nature, economics play a major role in providing the required water for any one in need of it.

Water transport is a very costly undertaking, particularly in the developing countries. Although the vital nature of this precious commodity justifies the expenses involved in water-related schemes, lack of funds and multitude of projects point to the need for design and construction of durable, structures at low costs. It should be realized that not all the simple, inexpensive structure are suitable for everywhere, and every well designed, sturdy and expensive structure is objectionable. A hydraulically efficient and long lasting structure built at a considerable cost might prove more economical in the long run.

Diversion of water to floodwater spreading (FWS) systems installed in different parts of Iran since 1979 necessitated design and construction of various types of diversion dams and weirs. Site placement is usually one of the most critical points for any intake structure (IS), because many interrelated factors have to be taken into account: location and elevation of the land to be irrigated relative to the river; width of the stream bed; concentration of the suspended- and bed - loads and erodibility of the stream banks and stability of the river bed are but a few of the constraints faced by the designer.

Long, straight stretches provide suitable sites for placing diversion structures because they avoid undesirable eddy effects from bends (Zimmerman, 1966, p.60). However, abundance of meanders in most plains might force the designer to divert water in, or close to, bends. Apparently, in this case, "the ideal place is just upstream from outside of a bend" (ibid). This statement has been corroborated by Kraatz and Mahajan (1975,p.35), Silva and Makin (1987), and van Arst (1987). Higher water surface elevation and lower sediment deposition in the IS built there are two of the reasons given by these authors in support of the above instruction. Sediment deposition inside the bend makes this place the least desirable for placing an IS (ibid). However, on occasions, like the one which is the subject of this report, the designer might be forced to resort to diversion from inside of a bend. Moreover, when the water is silt-laden, as again is the case in FWS operations, the IS should be inclined towards the direction of flow, otherwise accumulation of silt and bed load at the entrance obstructs the flow (Kraatz and Mahajar, ibid).

A simple, economical and very efficient weir was built in a bend across the Bisheh Zard River (BZR), in the Gareh Bygone Plain (GBP), 200 km SE of Shiraz, Iran. The center-line of the IS, which is located inside the bend, was at 92° angle to the river axis (Fig.1). The present report discusses in detail the steps taken in building this small hydraulic structure which supplies a FWS system installed for artificial recharge of groundwater, and describes the anomalies observed during 6 years of operation.

MATERIALS AND METHODS

The study site is located in the GBP (28°38'N, 53°55'E) at an elevation of 1140 m, Characteristics of the area have been given elsewhere (Kowsar, 1989, 1990). The BZR, which is a tributary of the Shur River of Jahrom, is an ephemeral stream which flows, on the average, twice in the winter and once in the summer. The maximum observed flow during the 1982-90 period has been 300 $m^{3-1}s$ during the deluge of 1986, which, by some account, had the return period of once in 100 years.

The weir was constructed in Nov. 1985. After the foundation was levelled with a bulldozer, 7 pieces of 3.0 x 4.0 m, 3 mm diameter galvanized wire netting were laid down lengthwise across the river, immediately downstream of the IS. The adjacent sides of the pieces were tied together by wire of the same gauge, resulting in a wire netting 28.0 x 3.0 m. The width of the netting was marked at 0.60, 0.90, 1.45 and 1.72 m from the upstream side (Fig.2). The netting was bent 90° upwards along the 0.60 m marking to make the vertical upstream face of the weir. One row of 0.75 m wire pieces were tied to the base of the weir along the 0.90 m marking at 1 m intervals. This procedure was repeated with 0.35 m pieces along the 1.45 m marking.

Uncut, limestone rocks of various shapes and sizes, 0.15-0.45 m in length, were hand placed on the base, starting from the upstream face to the 1.72 m marking. The height was gradually decreased from 0.60 m on the upstream face to about 0.05 m on the downstream end. All the loose end wire pieces were kept erect during stone laying.

Subsequently, the downstream, 1.28 m end was bent along the 1.72 m marking and placed on the slanting face which would form the chute of the weir. Then the two, 28.0 m sides were tied together with wire. The loose ends of the 0.75 and 0.35 m wire pieces were securely tied to the sloping side of the netting. The bulges in the exposed netting were removed by tightening up the wires with a rod placed under them and turning it a few times (Fig.3).

Placing the bank protection was the final step in this work. One piece of 3.0 x 4.0 m netting was laid on the outside bank of the bend with its length along the vertical face of the weir. One course of 2.0 x 3.0 x 0.2 m rocks was laid on the netting which was then covered with its 3.0 x 2.0 m loose half. The ends were then tied with pieces of wire and the side adjacent to the weir was connected to it. Cross wires joined the top and bottom of the "mattress". The same procedure was followed to cover the end of an earth embankment which formed the downstream wall of the IS. It should be realized that the gabions had to the embankment shape so some overlap was inevitable. Three 3.0 x 4.0 m pieces were used for this bank protection work. Short piece cross wires were used to join the lower and upper side of the "mattresses" which protect the banks as described for the weir.

It is important to note that the weir crest was level in its entire length; moreover, its mean elevation was about 0.05 m higher than that of the beginning of the spilling sill of the conveyance-spreader channel of the FWS system which is serviced by the weir. This would ensure spillage along the length of the channel in low flows.

RESULTS AND DISCUSSION

Performance of the weir has been outstanding. This has been proved during 6 years of operation, particularly in the deluge of Dec.1986, when it safely passed a flood of over 100 m^3s^{-1} for 24 hours, before an earth embankment which had plugged the entrance to a wide, adjacent streambed gave way and the flood changed its course. Although some scours has occurred in about 2 m of the bed close to the IS, this has not caused sagging of the weir crest.

Placement of the IS inside the bend and at 92° to the centerline of the river should have caused sediment deposition there. As a rule, there is scour from outside the bend and sedimentation inside the bend (Graf, 1971, p.263-64). Moreover, obstruction of the entrance to the IS should have taken place due to its lack of inclination towards direction of the flow of the river.

Having these two points in mind, lack of sedimentation at this site is an anomaly about which we can only speculate. Apparently, resistance of the weir against scour outside the bend upsets the accepted velocity distribution across the river, resulting in the spirally moving body of water which exerts a centripetal force of such magnitude to carry the sediments, which would otherwise block the IS, inside the diversion channel and spread them onto the FWS system. The scour close to the inside of the bend downstream of the weir may be due to this phenomenon. This postulate has to be proven by precise measurement of the velocity, bid- and suspended - loads across the bend during future events.

Construction costs for the weir reported in this paper adjusted on the basis of the semi-authorized price list for 1990-91 are itemized below. Moreover, costs involved in constructing an overflow weir with an ogee spillway designed for 107 m^3s^{-1} are presented for comparison. These costs are subject to change.

Gabion weir		
3 mm galvanized netting, 3.0 x 4.0 m	@ 6000 rials each	90000 rials
Wire	@ 300 rials kg^{-1}	1800 rials
Limestone rocks	@ 1500 rials m_{-3}	19000 rials
Labor	@ 2000 rials $manday_{-1}$	22000 rials
Bulldozer rental	@ 4000 rials $hour_{-1}$	2000 rials
Total		134800 rials
Concrete weir		
Excavation	@ 445 rials m_{-3}	320000 rials
Formworks	@ 12330 rials m_{-1}	2864000 rials
Concrete	@ 9000 rials m-1	6750000 rials
Limestone rocks	@ 1500 rials m^{-3}	45000 rials
Design and supervision		1358300 rials
Total		18337300 rials

Although the economic life of the gabion weir can not be predicted, the very low initial cost and the minimum of maintenance required make this structure attractive, especially when the fund needed to construct a FWS system is considered. The 25 ha system serviced by the gabion weir may be constructed at a cost of 750000 rials; therefore, spending 18337300 rials to install a diversion weir for such a system is not justifiable.

ACKNOWLEDGMENTS

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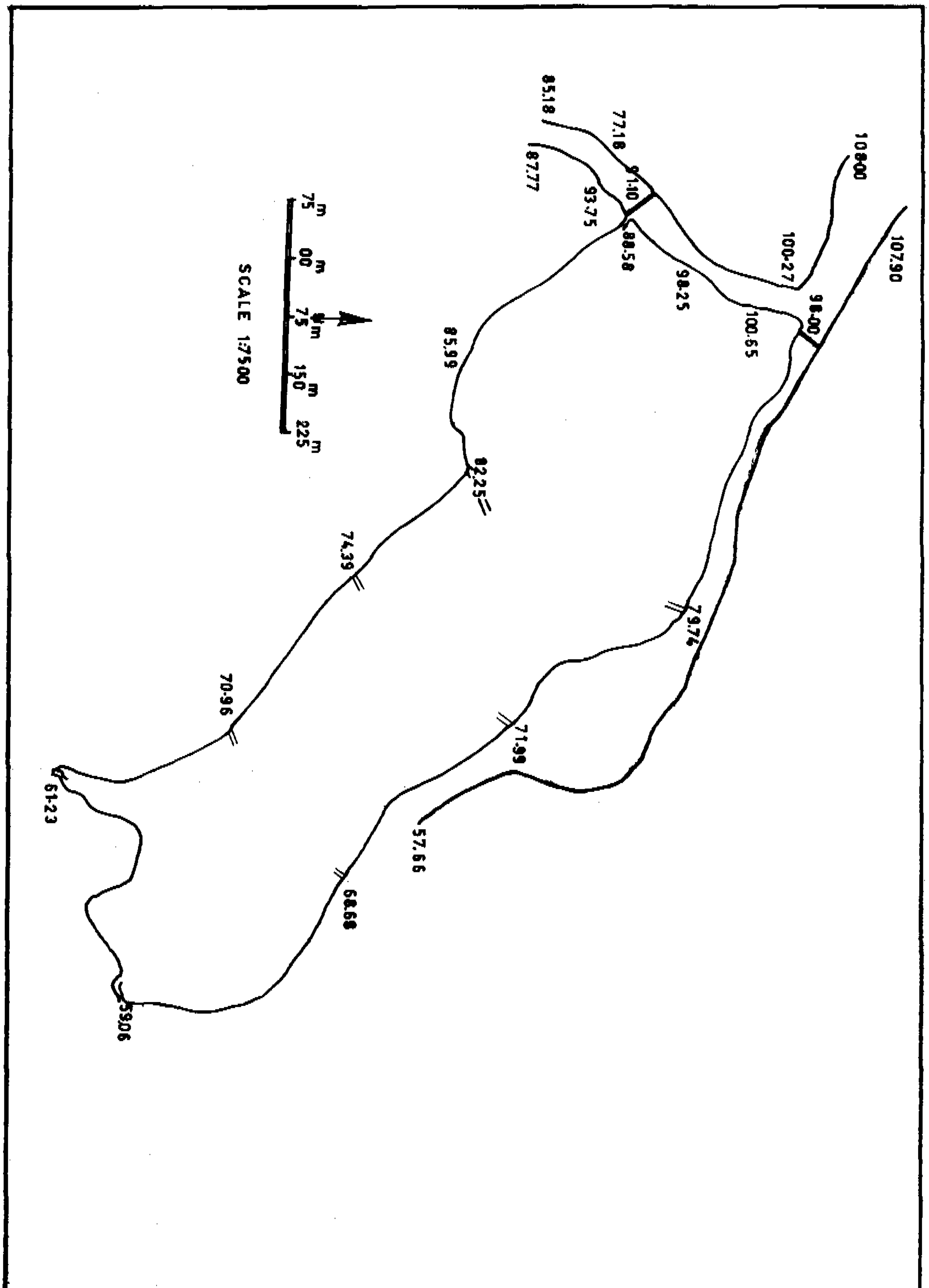

Fig.1. Map of the Bisheh Zard River, the weir position, and the floodwater spreading system sup-plied through the diversion weir.

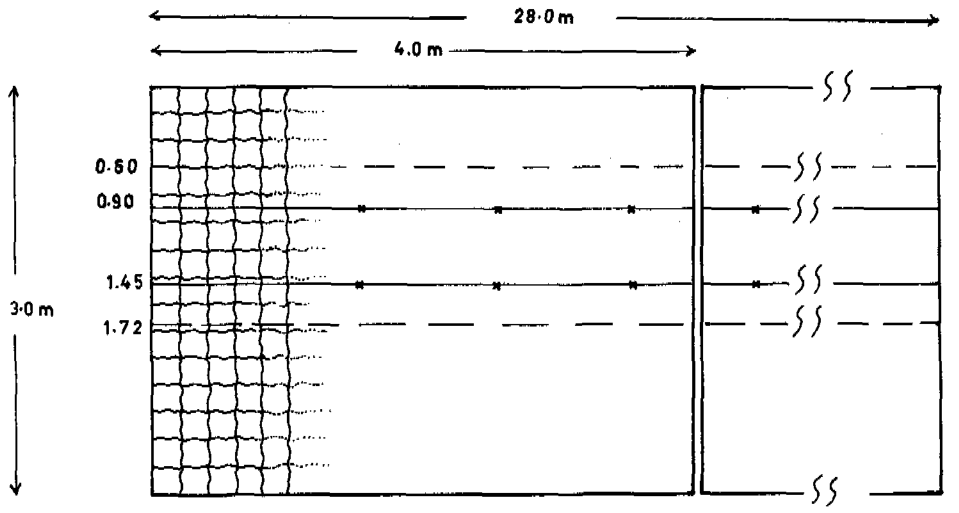

Fig.2. Schematic presentation of the nettings showing the markings for bending(--) and cross wire tying (x-x).

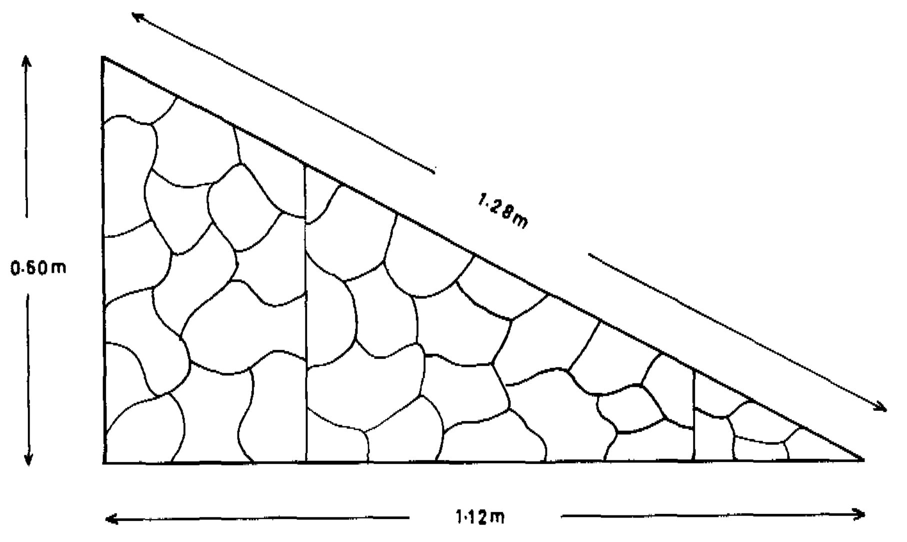

Fig.3. Cross section of the gabion weir showing the positions of cross wire tying.

The Catchment Rain Water System Used as Supplemental Water Sources of Cities and Towns

Wei Yu-rui*

Catchment rain water used as domestic water has a long history in many areas of china. That is not only major water source in short water areas, but also important supplemental water source in which far from water sources or bad water quality. With consumption increasing rapidly, water resource is deficient day by day. Catchment rain water for additional water sources is more and more paid attention to.

1. Introduction

In the northwest region of china and in coastal cities, there are short of fresh water, the persons have to dig pond to gather rain water; In the southwest region of china, especially Sichuan and Guizhou provinces, range upon range of mountains, resident quarters are far from water sources, thus rain water gathered becomes their supplemental water sources; With the industry developing and factories in rural regions and towns increasing, the environment of water resoure has been damaged, so that useful water sources rapidly decrease. On the other hand, with the raising of living level of the people, domestic consumption increases quickly, the contradiction between supply and need becomes more acute. The developing of industry has been restricted by the short of water. Therefore the guiding policy of "finding new sources and saving water "was made by the State Council, however the collective rain water as supplemental water sources of cities and towns is the effective way of "finding new sources". In many cities, it had been proved to be successful. For example, Tangshan city and Qinghuangdao city in Hebei province, there were very short water. So that many constructive programs were constrained by the lack of water. Much money was spent for saving water. In recent years , after the Dou River and Qinglong reseroirs were expanded and reconstructed, the contradiction of supply water was mitigated. Now the Dou River reservoir is the main water source of Tangshan city.

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2. The superiorities to use rain water

Now the functions to retain rain water is not only to control water or drain flooded fields. It but also gradually becomes into the major supplemental water sources for cities and towns. The superiorities to use rain water have been recongnized:

(1) To gather rain water as supplemental sources is in keeping with constructive policy of "finding new sources and saving water". it has been proved to be a effective way of "finding new sources".
(2) Catchment rain water systems should be built on available topography, so money invested is less and results achieved are fast.
(3) There are good and stable quality to catchment rain water in unpollution areas.
(4) Cisterns of rain have the function of sedimentation tank, the longer period of rain water staying, the better semdiment completing, the water turbidity is usually lower than surface water.
(5) In cities of mountain areas, to gather rain water for supplemental sources can save large amount of power and much money. It is very necessary for our country.

3. Example

This is one of the planning programs of a city in Sichuan province.

(1) Background

This city located in southeast of the Sichuan basin, where Yangtze River and Wu River cross. There are a temperate climate, hot summer, and warm winter. The average daily temperature is 18.2 degrees centigrade, and there is average 315 days as a period without frost annually.

The topograplic configuration of this city is low in the north and high in the south, and with a mountainous district on one side. The elevation of the living area is from 160 to 400 M, the average slope is about 20%, the difference of height in the living area about 240 M.

(2) The possibility of catchment rain water

This city located in upper reaches of Yangtze River is situated at the foot of a hill and beside a stream. There are warm and humid climate, good vegetation, environment unpolluted, and better engineering geology conditions, so it is suitable to build dams for gathering rain water. There are abundant rainfall that mean annual precipitation is about 1148.6 mm, the month of maximum rainfall is June (170.9 mm), the month of minimum rainfall is January (14.3 mm). The annual rainfall days of more than 0.1 mm are about 142 days. The mean relative humidity is about 81%. The limiting lowest temperature is -2.7 degrees centigrade. These are favourable conditions to built catchment rain water system.

(3) The design cauculation of catchment rain water system

According to statistics of rainfall data for many years in this region, the mean precipitation per month are showed in next table:

Month	1	2	3	4	5	6
Rainfall(mm)	14.3	21.5	40.1	93.1	144.7	170.9

Month	7	8	9	10	11	12
Rainfall(mm)	141.6	137.7	130.3	113.9	57.1	26.8

The area that height above sea level is between 350 and 400 M was known as the highest district in city planning program. The domestic consumption of the highest district (Q) is about 0.75 thousands cube M per day.

a). The area of gathering rain water ground (A)

The minimum annual precipitation (H) in January is adopted (H=14.3 mm), the surface runoff coefficient is chosen: r=0.6, and one month includes 30 days.

$$A=Q/(r*H)=750*30/0.6*14.3*0.001=2.62 \text{ (square KM)}$$

b). The volume of cistern (V)

Conditions of existing pond and domestic consumption are consided. The useful volume (V) of cistern is equal to the water supply amount for five days.

$$V=Q*5=3750 \text{ (cube M)}$$

The cistern may be constructed with stones and cement. The useful water height in cistern is about 2.0 M and the diameter about 49 M. Because the cistern bases on the existing pond, the construction costs is low. Because of good vegetation condition and gathering ground formed by mainly sedimentary rock, the rain water gathered is hardly polluted. In addition to cistern having another function of pre-sediment treatment, water in cistern has a low turbidity (general less than 20 degrees) and can be directly filtered.

Structure of cistern : the bottom in cone form is equipped with pipes for draining sludge and the upper with overflow way. If rainfall doesn't meet the need of consumption, other districts could supply water for the highest district (i.g coming from the surface water treatment plant).

c). The technological processes of rain water treatment system:

Cistern ------ Pressure Filtering Pots ---- Disinfecting ---
----- Clear - water Basin ------- User

d). The volume of clear - water basin (V')

According to the statistics of daily change coefficient of consumption, it is about 1.8 in this city. So that the volume of clear - water basin is estimated to be 5.4% times of daily domestic consumption :

$$V' = Q*K = 750*5.4\% = 40.5 \text{ (cube M)}$$

The clear-water basin form identify with that of standard tank of 50 cube M.

(4) Comparison of options for domestic water supply

Option 1:

In the highest district, domestic water comes from the surface water treatment plant which takes water from Yangtze River, there is a clear-water basin of 50 cube M. the difference of height to transmit water is about 279 M, and the water amount to transmit is about 750 cube M. Four steps high-lift pumping stations should be constructed to transmit water. The 6sh-6 model clear-water pumps would be chosen, with about 70 M altitude, rate of flow Q=126 cube M per hour, pumps efficiency 72%, the electric power 55 KW, pumps work for seven hours per day, the daily consuming power is about 1540 kilowatt-housr, the electric power price per kilowatt-hour is 0.21 yuan (Ren min bi) in this city.

The various items costs are estimated as following:
(unit of cost : thousands yuan Ren min bi)

Items	Costs
Electric power cost to transmit water per year:	118
Constructive cost of four steps pumping stations:	140
Pipeline cost of transmiting water in high pressure:	123
Clear-water basin cost:	210
The maintenance and management costs:	48
Depreciation charge:	47
The total costs:	686

Option 2: Catchment rain water system

In this program, electric power is not used in treatment processes. The flow depends on gravity. It is necessary to build gathering ditches and to reconstruct the existing pond into cistern with stones which are gained nearby. Available pressure filtering pots instead of filters can save constructive costs and operate easily.

The various costs of catchment and treatment rain water system are estimated as following : (The unit: thousands yuan)

Items	Costs
# Ditches cost:	120
Length of ditches: 1500 M	
local price for stone ditches: 80 yuan per M	
# Cistern cost:	263
Volume of cistern: 3750 cube M	
local price 90 yuan per cube M	
# Two pressure filtering pots costs:	50
# clear-water basin costs:	150
# Depreciation charge:	24
## The total cost:	607

(5) Evaluation of two programs

1). With the short of power resource in our country, it is very important for any projections to save power. In the option 2, all treating processes completely depend on gravity and electric power will not be used. By comparing with option 1. 118 yuan of electric power cost per year will be saved, the consumptive cost working for five years balance the costs to build one catchment and treatment rain water system.

2). The constructive costs of option 2 is lower than that of option 1.

3). Because the water supply system in the highest district is independent, it would not be urgent to reconstruct the surface water treatment plants and the pressure on pipeline system of other districts would be decreased.

4). The materials to build catchment rain water system gain from local areas, and it is easy to construct.

To sum up : The catchment rain water system is suited to local condition. Option 2 is better than option 1.

EXPERIENCE IN RAINWATER HARVESTING IN TANZANIA

by Mayo A. W.*

ABSTRACT

This paper discusses a wide range of experiences on practical aspects of rainwater harvesting in Tanzania. The discussion covers the prospects and difficulties experienced in aspects such as the cost of rainwater cistern systems, the rainwater quality, the adequacy of rainwater supply and the feasibility of rainwater cistern system in both urban and rural areas in Tanzania. In most of rainwater cistern systems, the quality of rainwater was found to vary widely largely due to the design and construction of the storage tanks, the consumers user habits and flushing system for first rains. The quality was generally found to be insufficient for full domestic use in most of the rainwater cistern systems and the availability of alternative sources of water was found to influence the rainwater consumers' habits.

INTRODUCTION

Water policies and master-plans are in existence in Tanzania for several years. Yet the implementation of these policies has always proved to be difficult mostly due to availability of funds and dependence on costly technologies. Due to these problems the percentage coverage for rural water supply remained stagnant at 45% for the whole of last decade in spite of foreign input to water projects (Ministry, 1989). Even those communities which have been provided by water supply at reasonable distance still face shortages of spare parts for handpumps or diesel engine pumps, lack of funds for running the system, inadequate maintenance of the system, etc. This means over 55% of about 25 million Tanzanians either consume water from polluted sources and/or waste a lot of valuable productive time for water collection.

One of the areas which have not been seriously considered in

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Tanzania as an alternative source of water is rainwater. The government has generally tried to impound run-off in reservoirs in drought prone regions but virtually little attention has been paid to rainwater harvesting from roofcatchment. Rainwater harvesting is known to be a traditional source of water in many parts of Tanzania especially in rural areas where reliable, adequate and potable water within a reasonable distance is rarely found. However, the collection system has not significantly improved the storage capacity for use in dry season partly due to affordability and partly due to lack or unawareness of existence of cheaper technologies. Even those who can afford large storage capacities, the quality of rainwater has remained a problem. This paper discusses some of the problems which causes available rainwater technologies not to be used to its full capacity in Tanzania.

MATERIALS FOR RAINWATER COLLECTION AND STORAGE

Roofing material has a significant influence on the acceptability of rainwater for domestic use. Most of the rainwater cistern systems in Tanzania rely on galvanized iron roof for rainwater collection due to acceptability of rain water collected over its surface. Thatched roof though the most common type of roof in rural areas are the least used due to the colour imparted in the water as a result of decomposition of grass used for roofing and smoke from firewood from kitchen.

In Tanzania the proportion of thatched roof depends largely on whether the area has urban or rural characteristics as well as state of economy of the area. Table 1 shows typical proportion of various roof types in a semi-urban area. However, in general the proportion of thatched roof in an area may vary from less than 5% in urban area to more than 95% in same parts of rural areas.

Table 1: The rooting materials distribution at Chalinze Town.

Roofing Material	Number of houses	Percentage of Samples
Corrugated galvanized iron sheets	304	80.2
thatched	55	14.5
Corrugated cement asbestos	17	4.5
Clay tiles	2	0.5
reinforced concrete	1	0.3
Total	379	100.0

A typical rural area in Tanzania has between 60 and 80% of thatched roof but in some places such as Moshi rural this proportion may be as low as 20 to 30%. In Newala district a survey carried out by Whittington et al (1989) has shown that about 74.8% of 822 houses sampled were thatched and the remaining 25.2% were galvanized iron roof.

The most common gutters found in Tanzania are the galvanized iron roof (G.I.) ridges which are basically manufactured for roofing purposes but were found to be suitable for rainwater collection. In poor societies however, empty cooking oil tins which are cut and reshaped for rainwater collection purposes are common as well as other cheap metals, plastics and bamboo gutters.

Downpipes are rarely found in private housing rain water collection system in most of rural localities. This is generally replaced by extended form of gutters leading to tanks and containers with top covers. Open containers normally receive rainwater which falls from the gutters directly. Whenever down pipes are found, the occurrence of plastic pipes of 100 mm are predominant over G.I which are more expensive.

Numerous types of containers for water collection and storage are available in Tanzania depending on the state of economy of the individual , available material and technology in the area and whether the occupants own the house or are tenants. Some of the containers in use are :

(a) <u>Burnt clay pots</u> : These containers vary in size between 20 to 60 litres. They are normally not used for collection but are used for storage of rainwater inside the building especially for drinking purposes due to the fact that the water stored in clay pots is normally cool. One disadvantage of clay pots is that they are brittle and break easily but if kept at a safe location they can be used even for many years. There is an evidence that containers older than 50 years are still in use in some areas. Minor holes and cracks causing leakages may be sealed by cement mortar.

(b) <u>Metal tins</u> : These tins were originally used as containers for cooking fat and oil, mostly imported from abroad. Once the fat or oil is consumed, the tins may be reused for water collection from wells, public standpoints, rainwater collection or even for grain storage and other uses. Due to their available size in the market of 20 l capacity, they are not used for longterm storage purposes but only for rainwater collection and short term storage. One disadvantage of tins is its short lifetime mostly due to corrosion and weakness of material. A survey carried out in Morogoro has shown that about 56% of tin users replace them at least once every month and 74% of tins are replaced at least once every two month (Makongwa 1990). The average replacement rate is estimated to be 9 times annually. Leaking tins can however be used as gutters after being cut and reshaped or for storage of grains and flour.

(c) Plastic containers : Depending on the size of the containers, these containers can be used for collection and sometimes for storage of rainwater. Durability is better and corrosion is not a problem. The major failure mode is cracking but cracks it can be refilled by burning pieces of plastic material in place. The owners may successful carry out repair works. Plastic containers are said to last for 1 to over 10 years depending on the quality. Small buckets of 20 l are produced locally for sale and for storage of paints but larger once are containers which were originally imported into the country with textile chemicals and dyes.

(d) Metal containers: This is perhaps the most common type of rainwater containers found in the country. Four types of these containers are available. These are galvanized iron tanks which were originally containers for engine oils, vehicle break fluid and agricultural chemicals, cast iron drums and corrugated galvanized iron (G.I.) tanks and aluminium or galvanized iron tank made from plane sheets.

Corrugated G.I. tanks were specifically manufactured for water storage in the buildings and only a few of these are found in rural areas for rainwater storage. The most common tanks are G.I. drums. Figure 1 shows galvanized iron drum in use for rain water harvesting. There are used in most cases after applying cement mortar in the internal walls because it corrodes fast and spoils water. Application of paints for coating has proved ineffective as paints bulge and pearl-off due to the effect of water and temperature. G.I. drums normally lasts for 3 to 4 years. Cast iron tanks survive longer and 20 years old tank are still in use today.

(e) Blockwork tanks : Blockwork tank though one of the most durable type of tank is found in few houses (mostly affluent families) due to the high capital cost involved. Both circular and rectangular shaped tanks either constructed above or underground with sand cement or concrete blocks are in use in Tanzania. The major problem of these tanks are cracks which cause serious leakages. The major reasons for formation of cracks are poor quality of mortar and/blocks, expansive soils such as black cotton soil, and lack of maintenance. For instance Writtington et al (1989) has reported that 48.5% of 305 tanks in Newala district are out of operation. No statistics have been collected at Chalinze yet, but a number of blockwork tanks including one at Chalinze dispensary suffer leakage problems.

Fig.1: Rainwater collection by galvanized iron drums.

For tanks connected to the tap, pipe fittings has also been another cause of water losses. Water losses may occur due to loss of plug, failure of bib cock or an elbow joint. Such failures are unfortunately difficult to repair since during the process of repair large quantities of water may be lost. In any case leakage looses much more over a longer period of time.

(f) Ferrocement tanks: Ferrocement tanks though one of the widely used tanks elsewhere (Vadhanavikkit, 1983) is relatively unknown in Tanzania. The first demonstration tank was built at Iringa in Tanzania in 1989, thanks to the efforts done by African Medical Research Funding (AMREF) who brought masons from neighbouring kenya to do the work. Since then one additional tank was build at Chalinze dispensary in February 1990 by University of Dar es Salaam mason who was among the trained personnel at Iringa demonstration. No experience with these tanks is yet documented but so far the tanks are operational. However, the supply pipe for Chalinze dispensary tank was broken in February 1991 by children who attempted to collect water from an otherwise empty tank after all the water was consumed.

(g) Concrete tanks : Though this is one of the widely used tanks but its exhorbitant cost limits its construction to parastatal organization and government bodies, religious centers, private companies and industries. Most of these tanks are used for storage of surface water with an exception of few which store both rainwater and water from municipal system. The largest tank in use in Tanzania for storage of rainwater and municipal water supply is the one at Sunguratex, a textile factory with a capacity of 2000 m^3.

(h) Wooden containers : These tanks are also not very common in Tanzania but some trials have been carried out under bamboo and wood starve project at Iringa. Planks of wood are joined together and joints are cemented with wood glues to prevent leakages. In some cases minor leakages may be allowed which normally disappear as wood swells. However, the disadvantage of wood-starve containers is that they are attacked by termites and require to have water all the year round otherwise the tanks may contract and leak, which makes its application for rainwater harvesting difficult.

THE COST OF THE RAINWATER CISTERN SYSTEM:

One of the major factors which hinders maximum use of rainwater in Tanzania is the cost of the system as compared to the income of the prospective users. The cost of the most commonly used quality of galvanized iron sheets which lasts for approximately 15 - 20 years is about 1000 TShs/m^2. The average family which requires about 50 m^2 plan area needs about 65 m^2 of roofing material (allowing for wastage and overlaps) which requires TShs. 65,000/=, the amount which is 26 times the official monthly minimum wage. The cost of downpipes and storage tanks are equally prohibitive. The cheapest downpipe is a 100 mm PVC pipe which costs TShs. 750/m and the cost of G.I. ridges used as gutters is 250 TSh/m. The costs of various forms of storage containers earlier discussed is given in table 2.

Small containers though the most affordable but its cost per m^3 of water stored is high and requires frequent replacement. Large containers require large capital costs which many families can not afford. However, local materials such as burnt bricks and glanary basket commonly used for building houses and grain storage respectively may be promoted to be used for rainwater harvesting as well.

Table 2: Material costs for various circular containers and tanks constructed above the ground surface.

Container Material	Container size (1)	Total Material Cost (Tshs)	Material Cost per Unit Volume (Tshs./m^3)	Material Cost per Volume (US \$/m^3)	Labour (Man days
Tin	20	200	10000	50.00	Market Price
Plastic Bucket/ containers	20 30 50 60 110	1200-1600 3500 5800 6500 9500	60000-80000 116700 116000 108300 86360	300-400 583.50 580.00 541.50 431.8	All Market Prices
G.I. Drum	110	1500-4000	13600-36360	68-181.80	
Galvanized Iron	1000 10000	25000 110500	25000 110500	125.0 55.25	Market Price 10
Blockwork 230 mm wall with R.C.C. cover	10000 25000 50000	94400 139500 241600	9440 5580 4830	47.20 27.90 24.15	20 37 60
*Ferro-cement	10000 25000 50000	68300 110500 166400	6830 4400 3300	34.15 22.11 16.64	48 80 135
*Reinforced Concrete	25000 50000	337900 488300	13500 9800	67.58 48.83	400 500
Blockwork 150mm wall, no cover	10000	34200	3420	17.10	9

* Source: Ilesanmi, 1990.

RAIN WATER QUALITY

Rainwater quality was investigated in 17 tanks, fourteen of which are located at the University of Dar es Salaam (UDSM), two at Chalinze Roman Catholic Church and one at Chalinze dispensary. Chalinze is located some 100 km west of commercial city of Dar es Salaam. It receives mean annual rainfall of 765 mm , some 245 mm less than the amount received at Dar es Salaam. Half of this precipitation is received between March and May.

The rainwater at UDSM is collected in basement storage tanks with the capacity of 80000 l. The daily water requirement is pumped to the roof tank which supplies water to the kitchen and toilets by gravity. Chalinze dispensary has a 10000 l ferrocement tank which provide water via a tap. Chalinze R.C. Church has three tanks, two of which were sampled. All tanks are constructed underground,one about 2 m infront of the church door (tank I) and another about 1 m infront of Reverend house (tank II). The later is provided with a handpump which elevates water to the roof tank which eventually supplies water to kitchen, toilet and bath.

The analysis was mostly based on bacteriological quality although a number of tests on physical and chemical parameters were carried out to assess the palatability of stored water for drinking purposes. The physical and chemical parameters tested include colour, turbidity, electrical conductivity, pH and total hardness. The results of the analysis presented in table 3 shows that most of the parameters are within acceptable limits as required by temporary Tanzania standard. The pH value of the UDSM system was however rather high and was suspected to have been caused largely contractors' failure of removing cement mortar debris from the basement tanks. Unremoved debris also contributed to unpleasant bitter taste of water as a result of which 54% of the household owners declared the water unsuitable for drinking purposes. (Mayo and Mashauri, 1991). Household owners who later on thoroughly cleaned their tanks admitted that the taste has significantly improved.

It is suspected that cement leachate from the tank walls is a cause of clogging of showers. High pH encourages formation of precipitates which clogs the showers in about 4 to 6 months, thereby hindering smooth operation of showers. However, this problems is not regarded as a serious one as the showers can be cleaned using vinegar to remove the precipitates.

The results of the bacteriological quality tests depicted in table 3 shows that the University of Dar es Salaam rainwater cistern system has the better water quality whereas Chalinze R.C Church has shown relatively poor bacteriological quality.

Faecal streptococci where absent in 47% of the samples tested at the University of Dar es salaam rainwater cistern system. About 86% of the faecal coliform analyses were also free from contamination and only 10% of total coliform samples have exceeded the maximum permissible concentration in accordance with temporary Tanzania drinking water standards (Mayo and Mashauri, 1991) shown in table 3.

All the samples at Chalinze dispensary tank and Chalinze R.C. tanks analysed for faecal coliform , faecal streptococci and total coliforms were positive. Dispensary tank was however relatively better than the Church tanks. The pollution of dispensary and church tanks is perhaps partly contributed by lack of foulwater flushing system. The quality of water in church tanks in perhaps worsened by inflow of run-off from the surroundings into the underground tanks

Table 3: Rainwater Quality

	Chalinze Dispensary	Church Tank I	Church Tank II	UDSM	Temporary Tanzania Standards
Faecal Coliform (no/100 ml)	1-1460 (40)	944-22200 (3644)	15-9500 (1850)	0-37	nil
Total Coliform (no/100 ml)	55-2896 (167)	2560-29640 (12765)	450-15680 (5860)	0-26	<10
Faecal Streptococci (no/100 ml)	43-750 (219)	200-4600 (998)		0-135	n.m.
pH	7.0-8.6	7.3-7.7	7.0-7.8	9.3-11.7	6.5-9.2
Electrical conductivity(μS/cm)	(126)	(101)	(136)		<3100
Total hardness (mg $CaCO_3$/l)	15-45	55-80		25-55	<600
Colour (mg Pt/l)	0 - 5	0 - 10	0 - 5	0-5	<50
turbidity (NTU)	0 - 5	0 - 10	0 - 5	0-5	<30

Note: Figures in parenthesis represent geometric mean values
n.m. = not mentioned

which are not sufficiently raised nor provided with drainage system against possible intrusion of run-off. In addition rainwater is drawn from the tank infront of the church with buckets which cannot guarantee quality.

Inspite of the inferior bacteriological quality of rainwater at Chalinze church, it appears that owners are using the water without boiling or any other treatment. When adviced to boil the water , the reaction of the consumers was apparently negative. The main reason being that Chalinze is supplied water by vendors who collect water from impoundment with no proper collection point. The vendors who supply water to town go 5 to 10 m inside the impoundment to get relatively low turbid water. This impoundment which is fed by run-off during rainy season was found to contain as high as 36800 faecal coliform/100 ml and turbidity of 120 NTU. Inspite of the bad quality, most of the Chalinze inhabitants drink this water without boiling and no incidence of major disease outbreak such as chollera has been reported at Chalinze although thousands of lives have been claimed by chollera in other parts of Tanzania since 1977. Due to this fact Chalinze inhabitants who psychologically believe rainwater is pure and free from contamination do not see importance of boiling water prior to consumption.

Long storage time of rainwater also suffer likelihood of growth of larvae and worms especially where open containers are used, where foul water system is not used and where containers are not adequately washed. Open containers attract mosquito breeding and when constructed underground may also be turned to breeding sites for frogs, which discourages long tern storage of water.

RAINWATER CONSUMPTION RATE

In a survey carried out at Chalinze, 11 household owners with permanent and semipermanent storage facilities were asked on their rainwater consumption rate. Nine of the eleven interviewees appear to be using between 20 and 38 lcd with the mean at roughly 30 lcd. One (dispensary) was not able to estimate their consumption. The remaining one (church) with in-house plumbing system appears to be using higher amounts of water daily since they are supplied with water from the impoundment with electric pump to 60000 l underground tank (tank III). The water from underground tank is then pumped to overhead storage tanks for further distribution to the toilets, bath and kitchen. It appears that consumption rate in all households is not controlled for use during dry season partly because there is an alternative source of supply in the area although the quality is inferior. The advantage of rainwater quality does not appear to be a major criteria for storing water for use in dry season due to the reason mentioned earlier, although the capacity of tanks in most houses are too small for the purpose. The typical mean roof catchment area of 50 m^2 in the area can collect about 28 m^3 annually if adequate storage is available. With the estimated average family size of 6 persons (Mayo, 1990; Whittington et al , 1989; Makongwa, 1990), this volume will assure a consumption rate about 12.5 lcd, which will be sufficient for cooking and drinking purposes.

In a typical rural area, the average per capita consumption rate is perhaps lower than 30 lcd. Whittington el al (1989) in their survey in rural areas in Newala district have recorded a consumption rate of 7.8 lcd during dry season and 15 lcd during rainy season for families depending on rainwater if no other supply is available at a reasonable distance. In another survey carried out at the University of Dar es Salaam, only about 16% of the households provided with rainwater cistern system with a capacity to provide an average family with 68 l/c/d, confirmed that rainwater was adequate for the whole year if it is used entirely for purely domestic purposes (Mayo, 1990).

CONCLUSIONS AND RECOMMENDATIONS

The cost of roofing materials and rainwater storage tanks compared to the income of prospective users appear to be one of the limiting factors for the maximum use of rainwater as an alternative source of water especially in rural areas. The use of materials and technologies available in rural localities such as burnt bricks and glanary basket tanks should be assited and encouraged by the government. Foreign donors should preferrably be encouraged by the government to take part in promotion of rainwater harvesting.

It also appears many users consider availability of water as the most important factor than bacteriological quality of Chalinze perhaps due to ignorance of consequences that may happen and due to the fact that bacteria cannot be physically seen. General health education in this case should be promoted and government should also take this advantage to promote rainwater harvesting as an alternative safe and potable source of water. The University of Dar es Salaam rainwater cistern system has shown that rainwater pollution may be minimized if proper collection, storage and use of water is practiced. The pollution of Chalinze church tanks appear to be caused by improper location of the tanks and the use of dirty containers for water collection in one of the tanks.

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WATER OF ISLAND IN JAPAN

Isao MINAMI*, Kouichi TAKEYAMA **

ABSTRACT

So far the water situation of small islands far from main land of Japan was especially very serious. The water had been developed from rainfall by several traditional methods. But there was no enough studies on suitable apparatus and facility to store that rainfall. Then many islands were very strict in water utilization.

Lately Japan government had issued big budget to improve this water shortage in remote islands, and they had developed the water of remote islands introducing various technology and engineering methods.

We would like to show the comparison between old situation and present situation of water resources of remote islands.

Rainfall distribution of island in Japan has big difference between north part and south part. But most serious part is the islands in Seto Inland Sea. Then we had performed field survey on water situation on this area. The smallest island was Uwoshima island and the most developed island was Nakajima island.

(old situation of water in islands)

a. Rain water cisterns were used on inconvenient parts of islands

b. People has clustered in flat places along seashore

c. People has been endured serious shortage of water

d. Ground water had been developed, but sometimes salt water was contained.

(present situation of water in islands after development by government)

a. Ground water was developed by wells and pipe line system were introduced.

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b. Small water use facilities, small dam ,freshening reservoir and underground dam were introduced.
c. Public building with big scale has rain water store room under their building.
d. Drinking water in small islands can be supplied through under sea pipe line from main land.
e. Small islands can buy water from other main land by water transport boat.

1.GENERAL SITUATION OF PEOPLE AT ISLAND IN JAPAN

Though there are many islands in Japan, the islands where the people are living are classified as shown in Table 1.

The maximum number of people in big remote islands are more than 50,000 and 160 islands are less than 500. They need water for drink and for living. Another consumption of water is due to the animals as shown in Table 2.

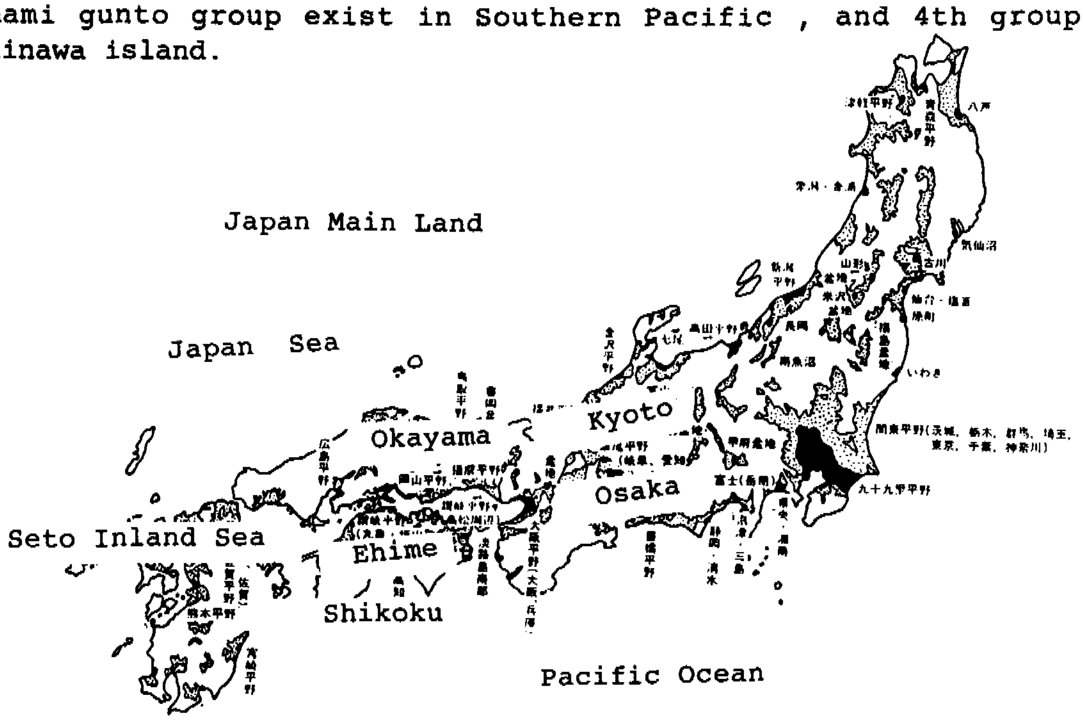
Table 1. population classes for island of Japan

population	number of island	percents
1 - 500	160	55.0
500 - 1000	43	15.0
1000 - 2000	27	9.4
2000 - 3000	14	4.9
3000 - 4000	7	2.4
4000 - 5000	9	3.1
5000 - 10000	11	3.6
10000 - 20000	9	3.1
20000 - 30000	0	0
30000 - 40000	2	0.7
40000 - 50000	2	0.7
more than 50000	2	0.7
total	286	100.0

Table 2. Number of Animals in remote island

year	name of island group	number of animal cattle milk	meat	pig	hen
1985	islands belong to main land	6,752	48,550	48,515	40,644
	Ogasawara island group	-	19	-	533
	Amami gunto island group	22	14,818	12,377	111,198
	Okinawa remote islands	892	23,766	23,624	130,474
	total	7,666	87,153	84,516	482,849%

All islands can be classified in 4 groups.
The first groups is the group lie near Japan main land, and 2nd group is Ogasawara islands lie in Pacific Ocean and 3rd group is Amami gunto group exist in Southern Pacific , and 4th group is Okinawa island.



note:
Association For Remote Islands Development of Japan
(30 years records for development of remote islands)

Fig.1 map of Japan main island

Cattle ,pig and hen are a typical animals.
The number of people living and staying temporarily on island depend on seasons. Fig.2 shows the number of outside people who visited island for recreation in summer etc., and also there are many people who would visit their native island for the traditional religious ceremony. They need more temporary water for tourist over the steady domestic water for the people of islands.

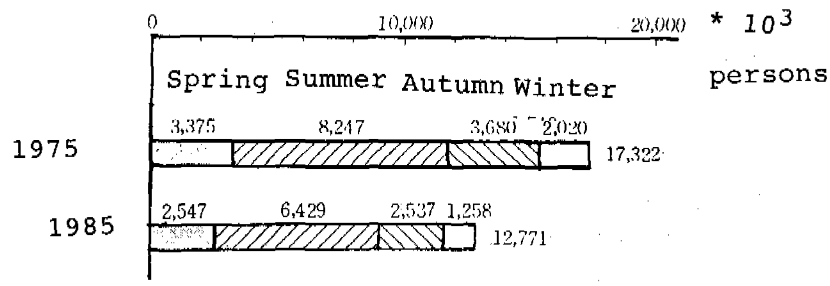


Fig.2. variation of visiting persons at remote islands

The Japan Government had prepared the development law of remote islands called "law of remote island development ". Concerning the public project of small scale drinking water, the present share of construction cost by government is about 50%.

2 LIVING SITUATION

To improve living situation , the water problem are the most important problem among national policies.

(1) present situation for drinking water

Usually on the remote island ,rivers are short in length,and rapid run off of rain water , also the ground water in island is little and sometimes its include salt water . The water shortage occurs not only in Summer season, but also in Winter season. Namely another water shortage occurs temporally at the season when the many relatives who are living outside of islands would return to islands, for traditional festivals. Another water shortage is for visiting persons in Summer. Industrial water ,especially for various fish productions needs much fresh water . Expensive construction cost for drinking water facilities needs more support from government not only budget, but also new techniques for water production.

(2) How to improve the drinking water in islands

The followings are the methods which had been tried so far.

deep wells
small dams
water supply from main land through pipe line on the bottom of the sea
water transport boat
desalination plant of sea water
various public water project

(3) old situation

The social situation before 1950 was understood by following description.

a. necessary time for carry of drinking water to each house was from 2 to 3 hours in average.
b. the people about 60% could use the water less than 16 liters per day.
c. the people about 60% could take baths less than 10 times for one month.
d. rain water , wells and small rivers on islands were the origin of water , but unfortunately these water were not suitable for drinking according to the modern water test.

The water quantity and water quality should be improved under the budget support by government. Without such support the people of island will escape from their native island to more comfortable region in main land.

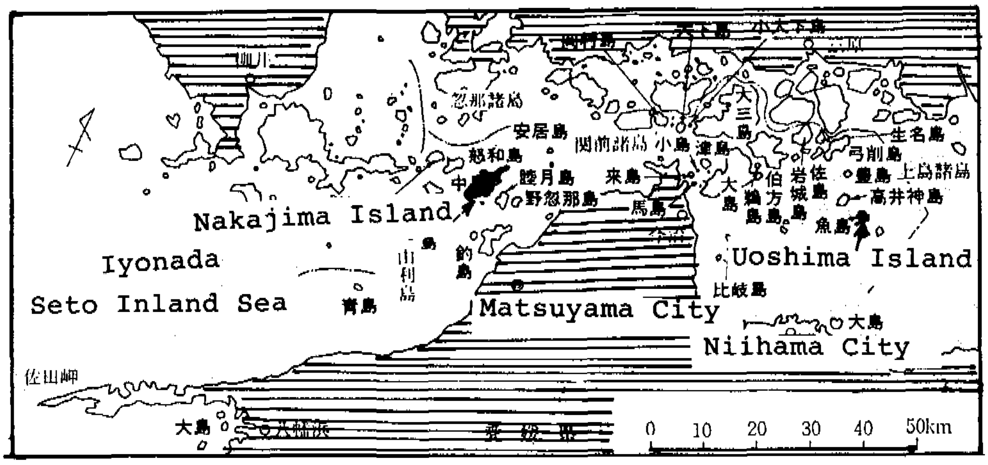


Fig.3. Nakajima and Uoshina islands in Setouchi Inland Sea

2.RAIN WATER SITUATION AT ISLAND IN SETO INLAND SEA REGION

We can show the rainfall distribution diagrams on Nakajima island and Uoshima island in Seto Inland Sea as shown in Fig.3. Fig.4 shows the frequency distribution of daily rainfall at Nakajima island for 5 years from 1981 to 1985.

Fig.5 shows the distribution of continuous no-rain-period for the same 5 years. Fig.7 shows the maximum potential rain water resources under optimum rain cistern volume which can be calculated by the vertical line between rainfall accumulation curve and horizontal line of the maximum consumption for average year in 5 years from 1981 to 1985.

Fig.7 shows the frequency distribution of daily rainfall at Uoshima island for 5 years from 1979 to 1983, Fig.8 shows the distribution of continuous no-rain-period for the same 5 years and Fig.9 shows the maximum potential of rain water resources at Uoshima which is calculated between rainfall accumulation curve and potential maximum consumption.

The maximum daily rainfall is 123.7 mm/day for Nakajima and 103 mm/day for Uoshima, and average rainfall 3.7 mm/day for Nakajima and 2.4 mm/day for Uoshima, and the standard deviation is 10.9 mm/day for Nakajima and 7.7 mm/day for Uoshima.

The longest continuous no-rain-day is 55 days for Nakajima and 46days for Uoshima, and average is 4.6 days for Nakajima and 5.7 days for Uoshima, and standard deviation is 6.8 days for Nakajima and 7.7 days for Uoshima.

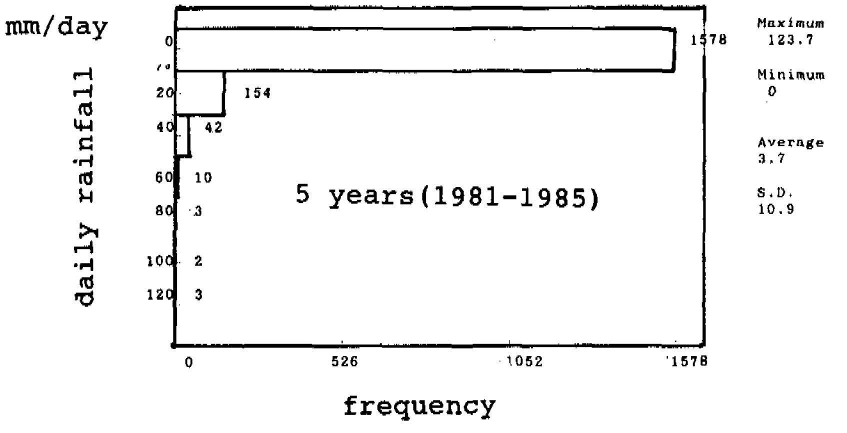


Fig. 4. rainfall distribution at Nakajima island

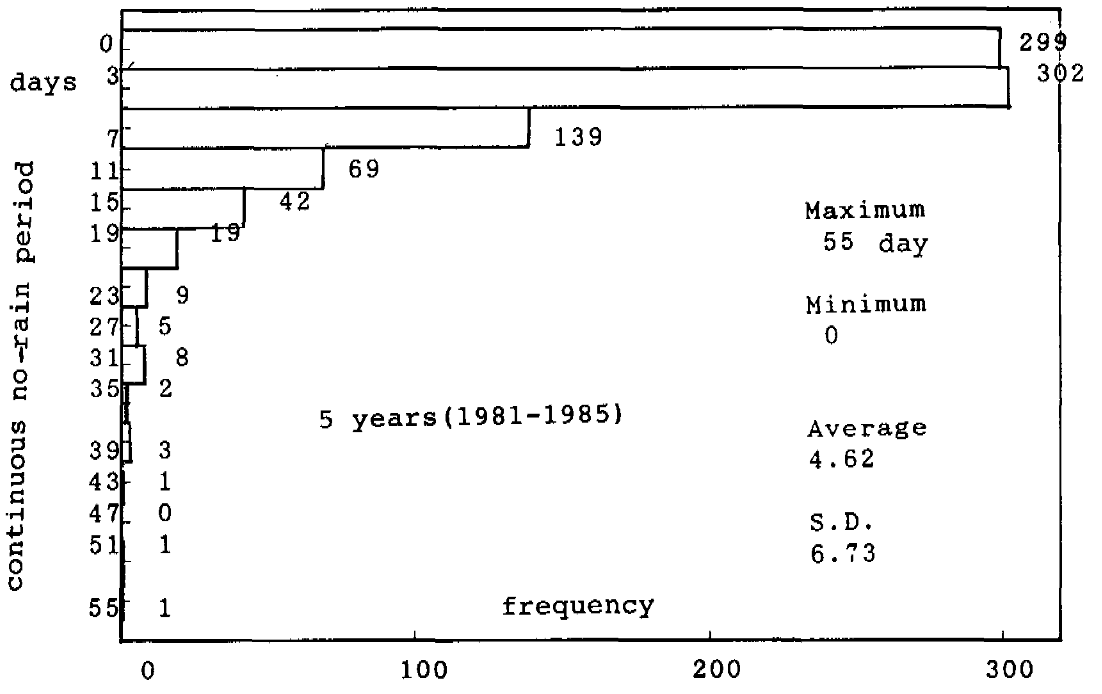


Fig. 5. period of continuous no rain at Nakajima island

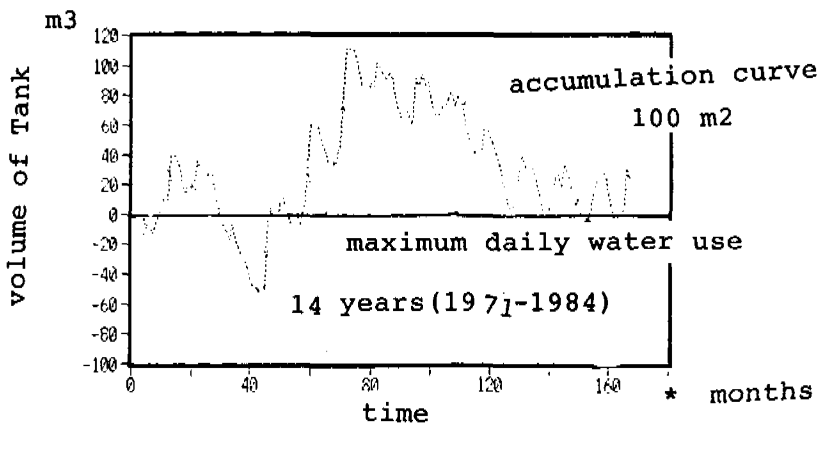


Fig. 6. maximum potential of water resources development of Nakajima island

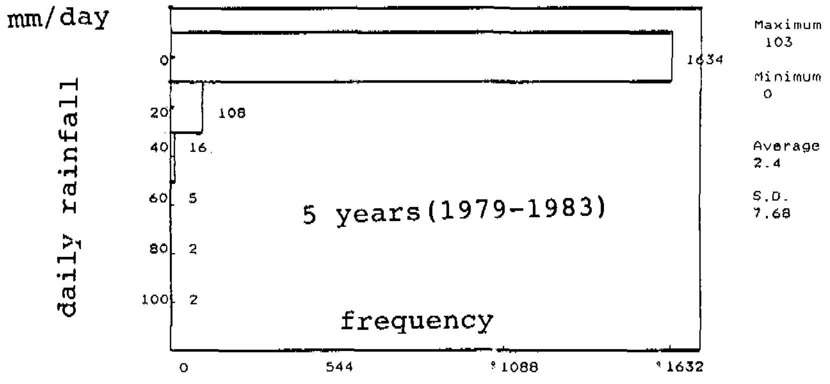


Fig. 7. rainfall distribution at Uoshima island

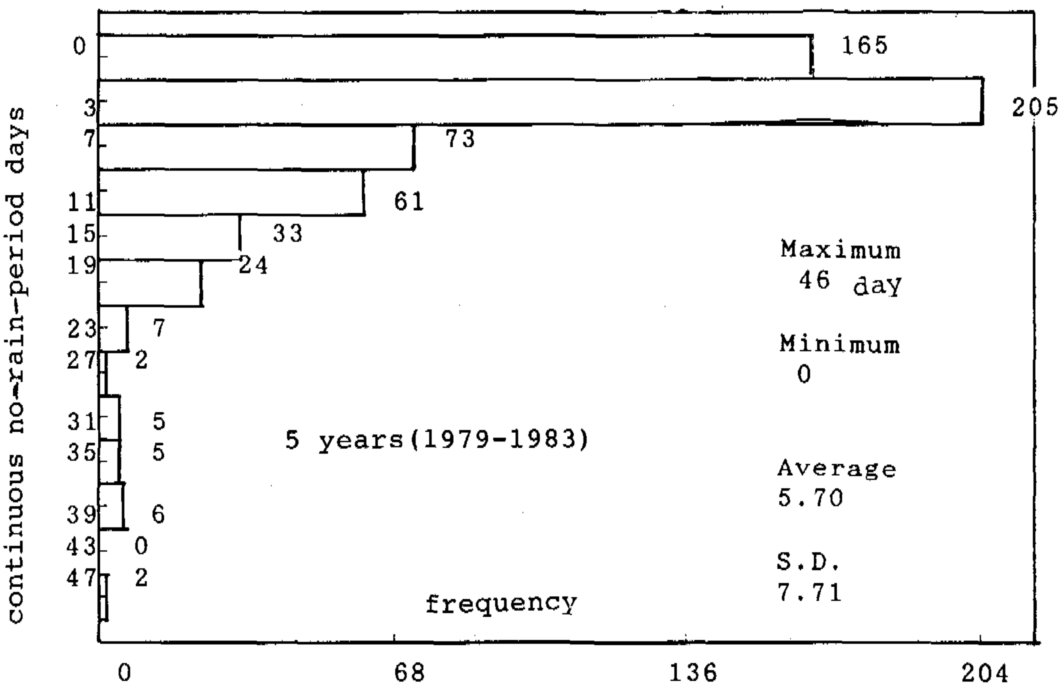


Fig. 8. period of continuous no rain at Uoshima island

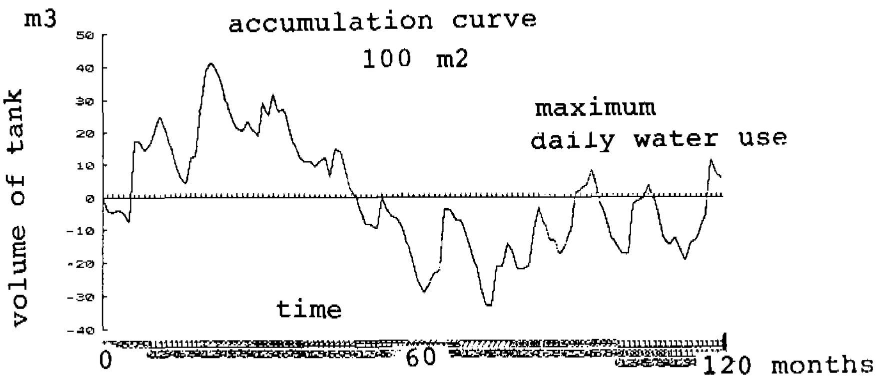


Fig. 9. maximum potential of water resources at Uoshima island

3.VARIOUS TECHNIQUES TRIED AND INTRODUCED IN ISLANDS

To solve water shortage problems for remote islands where the people lives, the various modern techniques were introduced into islands.

(1) desalinization plant project

The convenient scale drinking water project (101-5000 persons) has experimentally adopted the desalinization plant. The original water is pure sea water or blackish water , and the capacity of water production is from 6 m3 to 2,650 m3. The test period was from 1969 to 1986.

The results were not compatible for people living in remote islands ,because of expensive water production cost.

(2) Water transport boat method

The drinking water for the people in remote island have been bought by the town office or village office from outside main land by mean of water carry boat, but this water is also expensive water, and sometime bad weather prevent the regular water transport.

(3) Water supply through pipe line set under the sea

At the remote islands existing not so long distance from main land, the public office can construct water conveyance pipe system on the sea bed. This idea and method was welcome very much by the people of island.

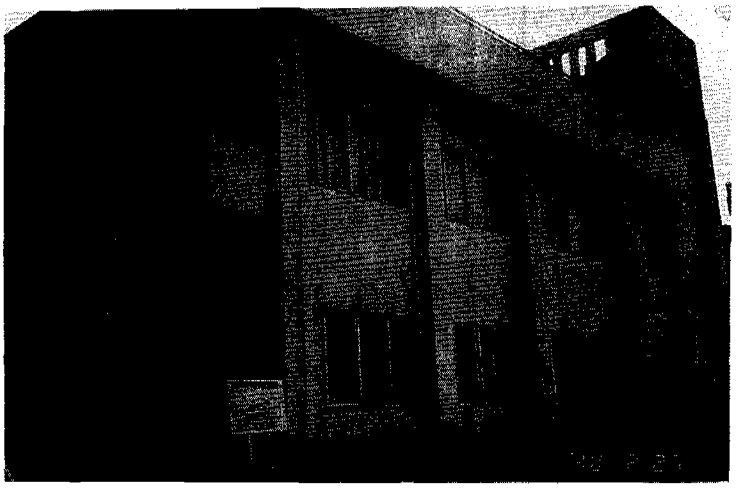


Photo.1 rainwater catchment system and underground storage of water at public building of Uoshima village office

Photo.2 water catchment of Primary school at Uoshima

4.IMPORTANCE OF DIRECT DEVELOPMENT OF RAIN WATER RESOURCES

Unfortunately, the development of rainfall for drinking water was not studied deeply so far. But new techniques of direct develop of rain water resources should be developed from the stand point of environment problem, as the alternative of water development by dams.

Photo.1 shows the public building of village office at Uoshima with rain water collection system and store room under ground of public building. Photo.2 shows the underground rain water storage system at primary school of Uoshima island.

I am deeply appreciate to the many researchers who gave me the good chances to be able to study with the member of International Rain Water Catchment System Association.

Utilization of rain water for domestic activities in Thaibinh and Nghetinh Provinces in Vietnam

Nghuyen Van Tuan*, Le Van Lanh**

I. Physical geological characteries of Nghetinh and Thaibinh provinces in relation with the water supply.

1. Physical geological conditions of Thaibinh province.

- Geological position:

Thaibinh is one of the provinces situated near by the sea in Bacbo plain (fig 1). Three sides of it are large rivers: Red River, Luoc River making natural border between Thaibinh and Haihung at the North and Thaibinh and Hanamninh at the South. Its Eastern side faces Biendong sea.

The area of this province is 1495 Km^2. Population is about 1,539,500 people with a density of 1022 people/Km^2.

- Topography of Thaibinh :

It is a province in the plain in the Red River estuary. It's Topograph is out by the rivers and streams outside as well as inside: Red River, Luoc River (outside), Trady, Hoa Rivers (inside) and a lot of ponds marshland, lakes. Density of rivers is about 0.25 Km/Km2.

The area of all lakes and marshland is 11044 ha and the lenght of canels is over 45 Km. It's has over 50 Km coast line. It means that salinity intrusion into the land goes throughout the province. So salinity takes place nearly everywhere of the province.

- Meteorological characteries:

Thaibinh is one of coastal provinces in the tropical and mosoon zone. It's rainfall is rather high. It often happens together with storms. The rainy season costs for 6 months (May to October) and the rest six months belong to the dry season.

The following statistic (1) shows us the yearly, monthly and daily of the province (table 1).

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Table 1: The yearly, monthly and daily average and maximum rainfall

Month Pmm	I	II	III	IV	V	VI	VII
Pmonth	27,5	30,0	45,8	87,2	167,8	206,1	233,8
P^{May}_{Day}	62,1	46,9	65,5	122,2	151,5	194,0	294.9
Date	30	8	7	17	10	25	24
Year	1969	1976	1933	1973	1975	1966	1963

The continue of the table 1

Month Pmm	VIII	IX	X	XI	XII	Pyear (mm)
Pmonth	342,4	343,8	216,6	80.1	22,6	1804,7
P^{May}_{Day}	253,6	290,7	215,8	148,7	86,7	294,9
Date	31	7	18	23	24	24-VII
Year	1975	1964	1982	1959	1977	1963

The table 1 and fig 3 show us that the rainfall of Thaibinh province is rather high 1804,7 mm/year and evaporation is rather high too $\bar{E}$ = 871 mm/year. Average temperature is about 23,2°C. Maximum temperature can rearch 39,2°C, Minimum temperature is about 4,1°C. The average humidity is about 86%. The water resources of Thaibinh province.

The average raifall of Thaibinh province is about 1804,7 mm/year, fall on an area of about 1495 Km^2 that creates a water mount about 1804,7 mm * 1495 Km^2 = 2,696 Km^3 of water and the evaporation mount.

E = 871 mm * 1495 Km^2 = 1,302 Km^3

So that the internal surface water is Y=P-E=2,018-1,302=1,302Km^3

The internal water flow throughout Thaibinh by the Red River has a discharge of about 2710 m^3/s. Therefor the river carries throughout Thabinh a volume : W=2710m^3/s* 31,5 10^6 s=85,365Km^3

throughout Thabinh a volume : W=2710m^3/s*31,5 10^6 s=85,365Km^3 -

The groundwater. Thaibinh is a province in a zone of deposit IV Q of plioxen system. The geographic section (3) shows that the over class is created by the clay. The allurial sedimentary constants a lot of coal. So that it's water is often stingking and yellow color.

The under class is created by sand and gravel. The groundwater is fresh water. It can be pumped by handle pumping of the UNICEF. But in two districts near the sea. The fresh ground-water only exists in the lens form the over class of water is salinitied

- The economic characteries relate with the water providing. There are seven districts in Thaibinh : Quynh Phu, Hung Ha, Kien Xuong, Vu Thu, Dong Hung, Thai Thuy, Lien Hai and Thai Binh town. The traditional production is rice, jute, fish and raising animal.

Jute grows in Hung Ha, Quynh Phu, Vu Thu, district because people deep the jute in water so water is very dirty. People got gynecological disease over 38%. The trachoma is over 86%, worm is over 80%. The results of the research (4) reveal the deep jute zone of Quynh Phu district as follows.

Before deep jute in comparison with after deep jute by index (Cu) are 8,32 VK/1ml and 11,100 VK/1ml. The rate of organic increases from 203,5mg/l to 344,0mg/l.

2. Phisical geological characteries of Nghetinh Province - Geological position:

Nghetinh province is a province in central part of Vietnam (fig 1). The total natural area is about 22,502 Km^2. The population is 3457,900 people with density of 154 people per Km^2. It's eastern side is East sea. The North is Thanhhoa province. South is Quangbinh province and West is Laos.

Topography of Nghetinh province:

This province not only has mountains but also have plain. 3/4 of it's area is hills and mountains and the rest is plain. They are deltas of the rivers Lam, La, Nghen. At the West is Truongson mountains higher than 800m. At the North and South sides area the mountain across to the sea (Deo Ngang, Hoang Mai mountain). There are many streams and rivers in Nghetinh. The main rivers are Lam river, La River, Ngan Sau River, Ngan Pho River, Nghen River, Bung River, Cam River. Dencity of streams and rivers is about 0.4 Km/Km^2. Lam River and La River are the two largest rivers. They join together at Ducquang village of Ductho district creating a pond zone near the bank of the river in Ductho and Namdan district. That will be shown in this report. The logging land includs 17 villages among which 8 villages are of Ductho and 9 villages are of Namdan. The total area is about 6,378 ha. There are 150 Km coastline in Nghetinh. The pend of the rivers is high there. So saline- water can't rearch far in land. There is only the down stream of Lam River. The two districts Ductho and Namdan surface and ground water are salted very much because the field level is 1,2 - 4m about sea level.

Table 2 : Yearly average rainfall and maximum daily rainfall and date in Nghetinh province

Station	month / P mm	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	P_{year}
VINH	P_{month}	52,0	44,0	46,6	61,2	136,2	116,4	122,5	188,0	490,0	407,4	192,1	68,7	1944,3
	P_{day}^{max}	57,6	53,0	93,0	75,7	196,9	268,3	264,0	248,0	484,0	399,0	255,2	119,0	484,0
	Date appear	23	14	28	5	29	6	16	17	17	25	17	3	17-IX
	Year	1914	1936	1943	1914	1943	1958	1932	1940	1931	1934	1982	1935	1931
HATINH	P_{month}	102,0	68,0	56,0	71,0	136,6	139,5	137,3	109,7	531,8	651,8	378,9	159,6	2642,0
	P_{day}^{max}	102,0	42,9	74,5	200,0	214,0	284,3	391,9	456,1	502,4	570,0	229,0	164,0	570,0
	Date appear	15	12	5	15	31	19	8	15	17	1	5	8	1
	Year	1935	1964	1944	1942	1935	1985	1973	1979	1987	1934	1941	1965	1934

- Meteorology characteries:

There are many natural calamity in Nghetinh. The dry season lasts for 9 months (XI-VII). In this season Laos wind is a kind of hot and dry winds wish enhance droughts. In the rainy season (VIII-XI) 3 months appear many storms. Look at (1) we can see rainy characteries of yearly, monthly and daily rainfall of a lot of stations as table 2 and fig 3. It shows that rainfall in Nghetinh is higher than that in other provinces of the country. The average rainfall is from 1200 to 3000mm and daily maximum volum can rearchs to 570mm/day because high rainfall, high pend of the rivers and channels at the estual among to the seaside. So they make more in undate more seriously.

Evaporation in Nghetinh is rather high at Vinh town station E = 954 mm/year and at Hatinh town station E = 799 mm/year. The average temperature is about 23,9°C. The humility is about 80%.

Water resource in Nghetinh :

Nghetinh have an abundant water resource mainly determined preciritation. Average rainfall of all province is over 2000 mm. An area about 22,502 Km^2 gives a water volume about 45,004Km^3 Evaporation is 900mm * 22,502Km^2 = 20,25 Km^3. Balance water is Y = P - E = 24,752 Km^3, Run off coefficient Y/P = 0.54 Groundwater in Nghetinh : Nghetinh is created by sedimentary of the generation IV Q of the system plioxen and Mioxen (3) The over class is kind of Mioxen deeper than 100m and is created by sedimentary of allviuon clay, sand and bazan, granit at mountain the under class is of Mioxen system deeper than 100m created by sandize and gravel.

The ground water here is very much and high quality. But at the downstream of Lam River water is salted. The surface water is good in dry season. Rate of alluvium is described in table 3

Table 3: Alluvium characteries of the rivers in Nghetinh:

Station	River	alluvium dischange Kg/s	Maximum alluvium dischange Kg/s	Average content alluvium mg/l
Hoaquyet	Ngansau	13,8	1830	113
Sonrem	Nganpho	4,83	780	95
Yenthuong	Lam	108,0	9400	210
Quynhchau	Hieu	13,0	11800	181

Table 3 shows us the alluvium content of rivers in Nghetinh which are smaller than Red River. Alluvium content is less than 100mg/l in the dry season and increases much more in the rainy season make it can't be used.

II. Water control using traditional measures for donatis activities in two provinces Thaibinh and Nghetinh.

1. Situation of utilization of rainy water for donatis activities The research results (4) shows us the water using measures for people livehood in the two provinces as following:

a. Drinking water from rainfall

For long time ago people in two provinces used rainy water for drinking. The in trument that have been used are tank built rock, small water jar, cylindrical earthenware jar, barrel, jarful to content rainy water flow from house of bamboo with a thatched palm roof or tiled roof or strees (fig 3). In Thaibinh, there are about 65% families having tank to content rainywater. In it 45% tanks can contain 0,5 - 3,0m^3 and 20% tanks can contain 4,0m^3. Calculation and practice show that families of over five people which use water for drinking, fit food, wash, swim can use tanks of 4,0m^3. That can ensure enough water for the dry season. It means that there are about 20% families having enough water to use. 45% families have small tank, which contain an amount only enough for two months in six months of the dry season, and 25% families haven't any tank to contain rainywater. They store water in barrel to use in a month. In Nghetinh the number families have tanks is only about 30%.

The river water is rather clean and fresh. So that people use the river water in the dry season or use water from wells. At 17 villages of in undare zone of two districts Ductho and Nam Dan at the time river water is dirty (in flood season), they use other intrument to contain rainy water.

b. Water from lakes, ponds and streams Thaibinh and Nghetinh have abundant water resources take from rivers, ponds, lakes other wise far from the sea. People produce jute so water resources are dirty. The studying result (4) shows that in Thaibinh over 20% families use river water without filting, 30% families use with filting, 70% families use river water only for washing.

In Nghetinh, in villages among banksof Lam River and La River 70% families use river water for livehood, 20% families use striate dirty water, the rest uses rainy water or filted water from river.

c. Using water from wells built by rick, coneret filling typa public well or UNICEF pumping.

This is a regular measure. There are 100,321 in Thaibinh take over 40,5% of families having well. Nghetinh is about 207,474 wells. Over 30% of families. In it there are 38% is good. The rest have to rehability. The general wells are 1600 wells in Thaibinh and 850 wells in Nghetinh. Hygienec standard of these wells are not enough. Filting wells are built near the pond, using sand to filt water. UNICEF hand pump is a kind of well attack for people is rural areas of Thaibinh and Nghetinh. During 3 years emplement movement of rural water wells in Thaibinh and Nghetinh 1057 hand water pumps were built. It is rather smaller than command.

2. Estimation of water using situation for people's livehood in Thaibinh and Nghetinh.
   The water using by rainy water contented in to tanks. That mean a traditional measure and insure a good quality. But number families have tanks is small, taking 40-45% of total families.
   The inundate zone as 17 village of Ductho and Namdan, Thaithuy Uenhai province Thaibinh have to build water rainy tank to use in the rainy season because in this season water in the river lakes is very dirty.
   Rick well is a good kind which can use in fresh water zone at the mountain, midle zone of Nghetinh and high zone of Thaibinh The UNICEF hand pump is very much advantagrous, but still of a small number.

III. Measueres to use rainy water for domestic activities.

To satisfy the demand of drinking water to the year 2000 th follow (4) showing that a person in the country uses 90 - 100 lit water per day. In it water for wash, tooth brush and eat dring is 10 - 12 l/day. Water for wash and person hygiene is 30 - 40 l/day. Water for clean hygiene of latrine hole and raising animal is 50 - 60 l/day.

The objective of health ministry will surpose for person to eat food and drink about 10 - 12 l/day to resolt this demand Thaibinh and Nghetinh plan a measure combine between all kind of supply water methods.

1. Building the big tank to store the rainy water with a large capacity. Following norm 10 - 12 l/day is that in a family average 5 people that need 50 - 60 l/day and during 5 months of the dry season will need 10,8 m^3 water. A family have 10 m^2 of roof house with an average rainfall 1804,7 mm in Thaibinh will give 18,047 m^3 of water and in Nghetinh with an average rainfall is 2000 mm will give a volume of rainy water are 20,0 m^3 Compare with the demance of water that is enough. Because the rainy characteries in the two provinces in dry season rainfall gets 20% - 30%. The rainfall of year. The family demand in a year is 10,8

m^3 in 5 months of the dry season can give itself 20% - 30%. So that it is only built a tank about 7,0 m^3 water is enough.
For 17 villages of the inundated zone of Ductho and Namdan districts when building tanks it must be noted 3 unfortant points as follows.
- Tanks have to be built higher than flood level.
- If there are built lower than flood level they will shave dirty water.
- May have pumps to pump water from tank to inlaid flood when flood people must stay in their house.

2. The UNICEF hand water wells :
Need using an advantage of budges from UNICEF to quickly build wells in rural areas, particulary, in 17 villages of Ductho and Namdan need fund to finish this work.

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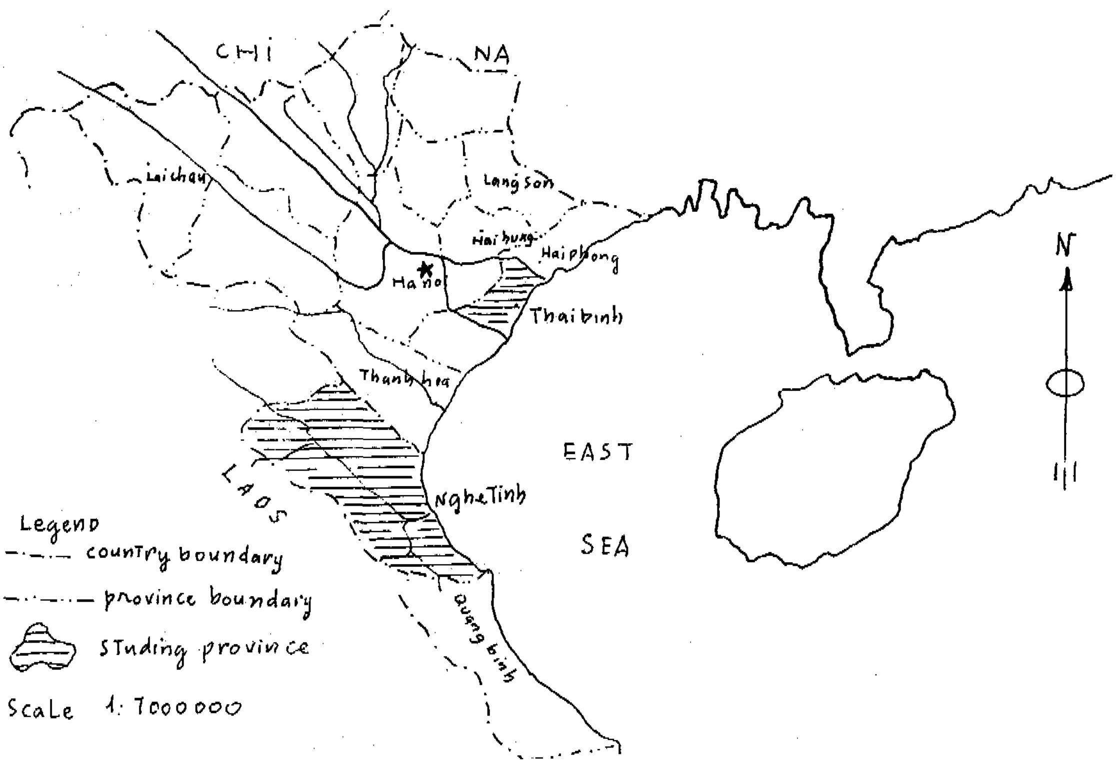

Fig. 1. Administrative Map of North Viet Nam

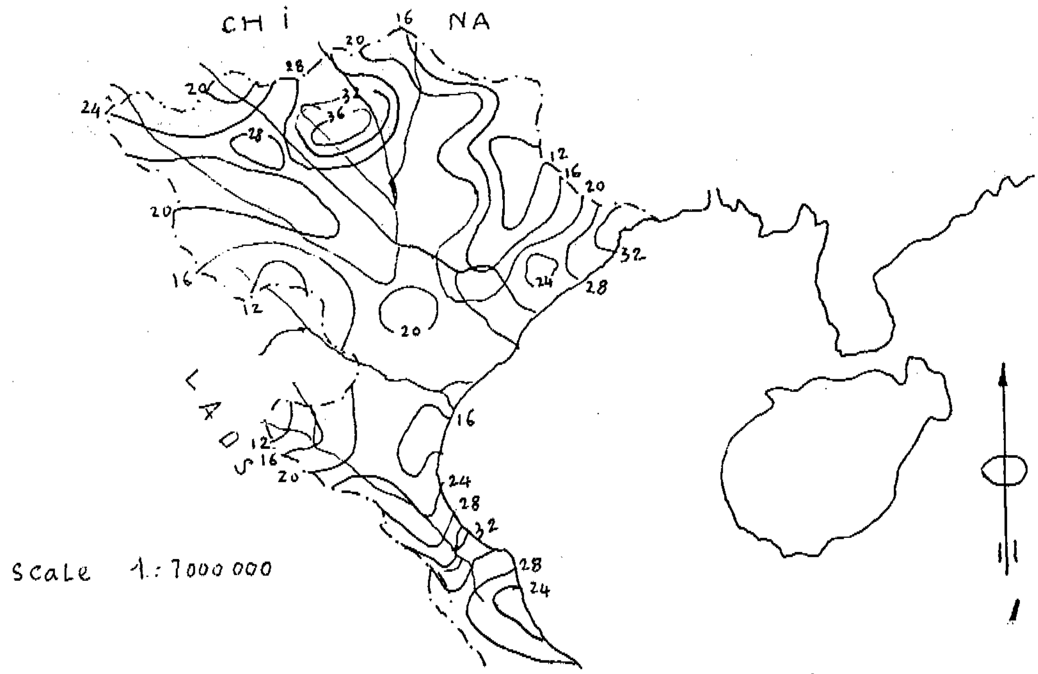

Fig. 2. Map of Annual Rain Fall (unit dm)

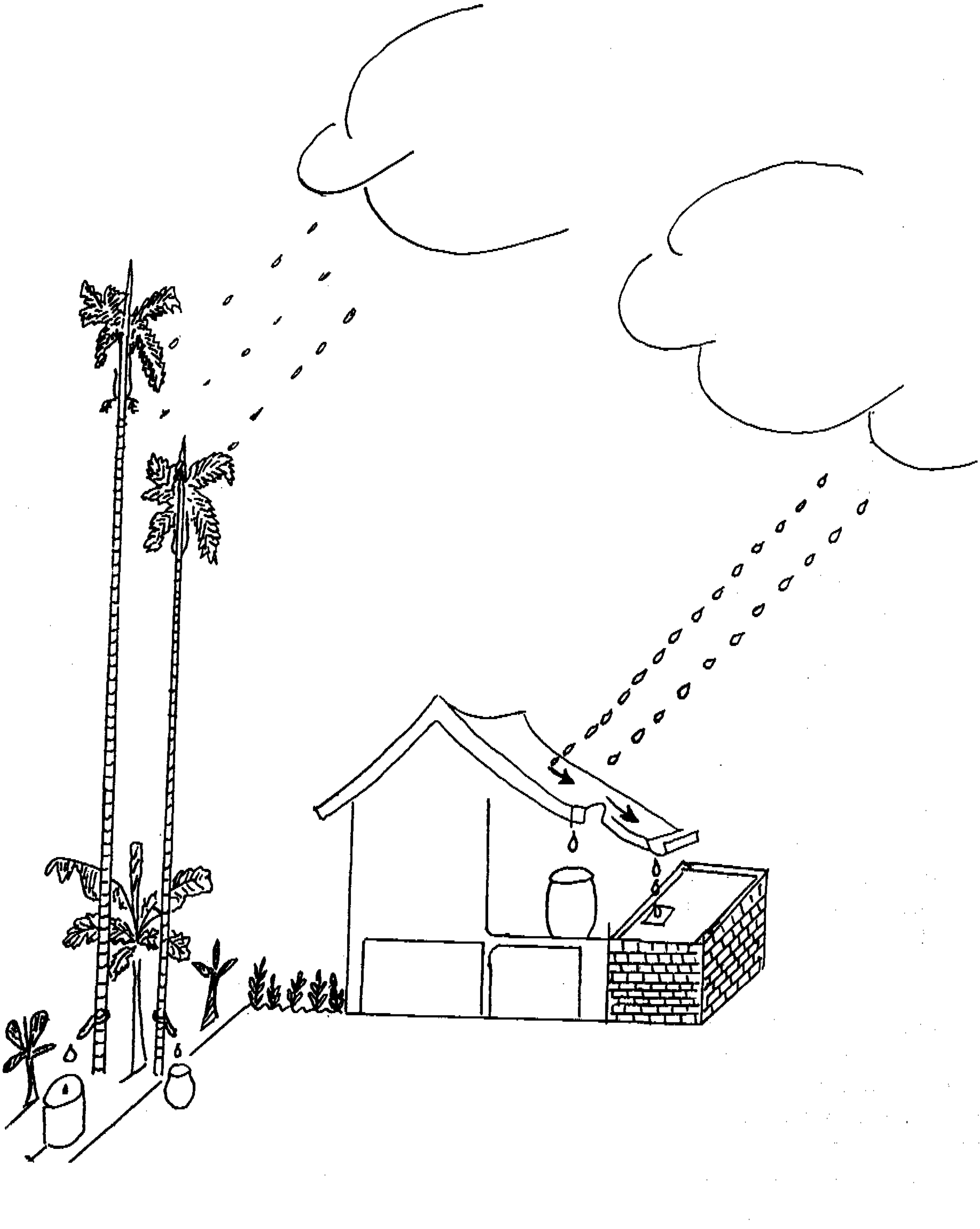

Fig. 3. Methods of Tranditional Utilization of Rain Water

RAINWATER HARVESTING SYSTEMS FOR DRINKING WATER SUPPLY IN CHINA

Ling Bo*
Liu Jiayi**

ABSTRACT

Rainwater has been harvested and used for domestic water supply in area lacking good alternative water sources, especially in loess plateau of the northwest China.

There the rainwater harvesting system ,in general , consists of ground catchment area, collecting drain, silt trap, sedimentation tank, screen and water cellar.

The initial cost for 20 M^3 storage volume was equivalent to U.S. Dollar 35 that could be afforded by a farm family in general.

In China, rainwater cistern systems have been mainly used for domestic water supply in rural areas where groundwater is unfit for human consumption, such as bitter brine water in Northwest plateau or surface water is heavy polluted with wastewater discharged from the village enterprises in Southeast coast. The cost of purification for facilities, maintenance and operation would be extremely high due to the advanced treatment processes have to be applied for those water sources. Rainwater has been, therefore,harvested and used popularly for domestic water supply in areas lacking good alternative water sources, especially in loess plateau of the Northwest, where annual rainfall is pretty low, only 316 mm,and its 64% is concentrated between July and September each year. There the groundwater ,either containing a great number of minerals, is too bitter to drink, or too deep to withdraw, otherwise, surface water is very seldom and too far to transport, more than 10 km from the water source to the consumers. The deep wells with the high lift pump have been, on trial ,built in some areas, but it ceased because too high cost to operate in comparison with very low output for drinking water supply. Seeing that, more than 0.2 million cement

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cistern systems for rainwater collection have been built to solve more than 0.6 million people's problem on drinking water supply since the United Nations' International Drinking Water Supply and Sanitation Decade (1981-1990) was put into practice in China.

I.Design

Such cement cistern systems were specially designed for rainwater harvesting. They, in general, consist of ground catchment, collecting drain, silt trap,screen, sedimentation tank and cement vessel, as showed in Fig.1. The components of this system and their functions are described as below:

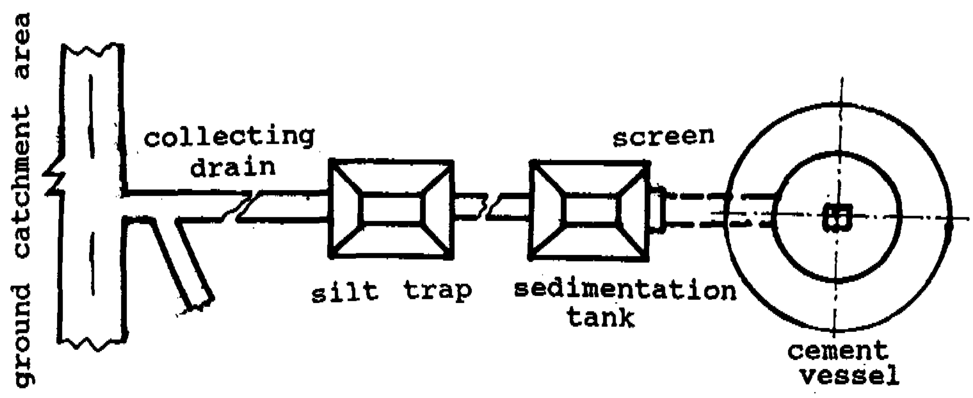

Fig.1. Components of Rainwater Harvesting System

1. Vessel

Its configurational space, as indicated in Fig.2, is optimized so that the maximum water volume can be stored with the minimum input such as material, labor-day and construction cost.

There is much less leakage in the vessel made of cement than that of the compacting earth, of which the vessel used to be made. Also, the cement vessel is not easy to cave in because the higher allowable stress could be available.

Such a type of below-ground storage facilities have the general advantage of being cool and dark, benefiting to prevent algal and bacteria growth and the breeding of mosquito larvae as well as no loss of water through evaporation.

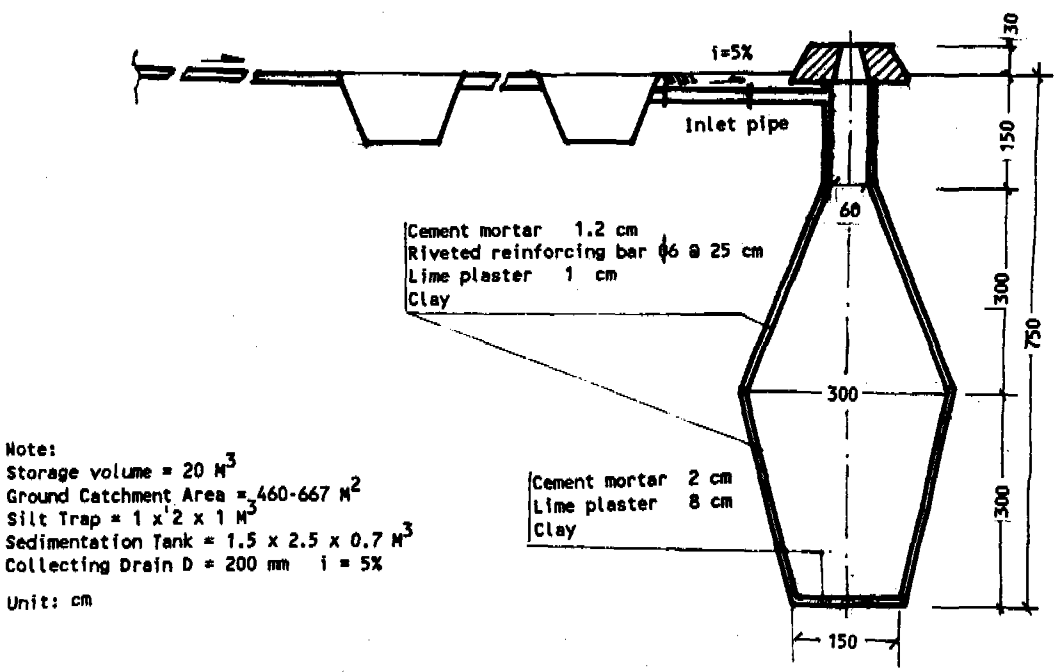

Fig.2 Structure Design of Vessel

2. Ground catchments

Ground catchments were used for collecting rainwater runoff. The main advantage with using the ground as a catchment surface is that water can be collected from a quite large area where the annual rainfall is very low. The ground surface is compacted to reduce its infiltration losses.

The basic disadvantage of ground catchment surface is that the water supply can easily become contaminated and since it can only be stored below the surface, it is less convenient to withdraw the water for use.

3. Screen , Silt trap and Sedimentation tank

The collected water can be purified through screen, silt trap and sedimentation tank prior to stored. The inorganic pollutants can be removed rather than the organic matters.

4. Tap water supply

In order to take water indoor more conveniently and to safeguard the hygienic quality of the collected rainwater, the facilities for tap water were built up in some area. When the vessel bottom is ,in altitude, above the roof of the house, the tap water can be supplied with installing a hand vacuum pump for initial operation, as presented in Fig.3-1. When the vessel bottom is , in altitude, below the ground surface, the tap water can be provided with installing a hand pump on it, as indicated in Fig.3-2. As a result , the supply of tap water could save 50-60 man-day per year, which was spend for taking and carrying water, and prevent dust, sand ,leaves, insects or other pollutants from entering. In addition, the hand pump does not need to consume energy and oil. Consequently, such tap water supply was acceptable to the local residents, especially to the women, who would like to be married with the farmer having the rainwater harvesting facilities with tap water installation.

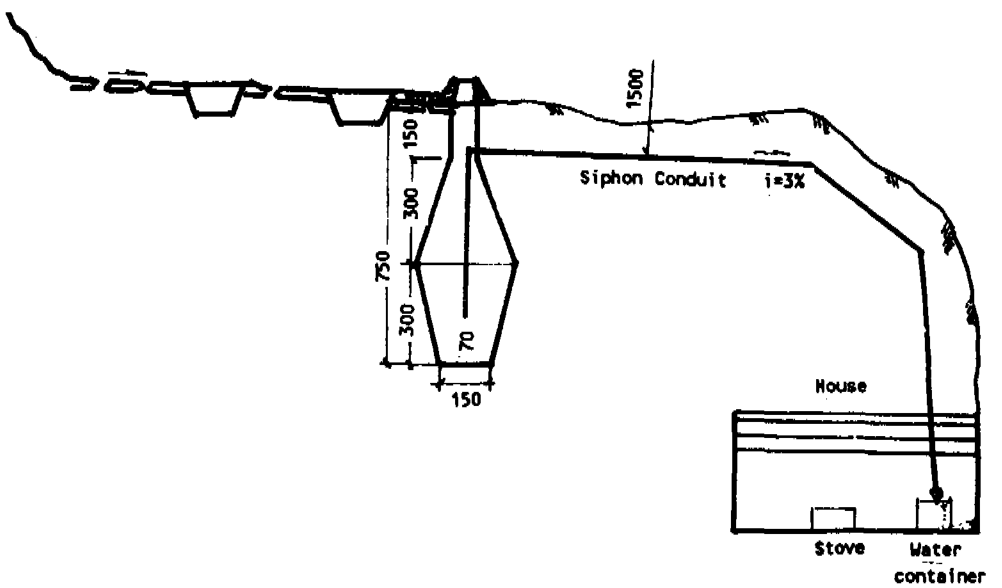

Fig.3-1. Rainwater Harvesting Facilities with Tap Water

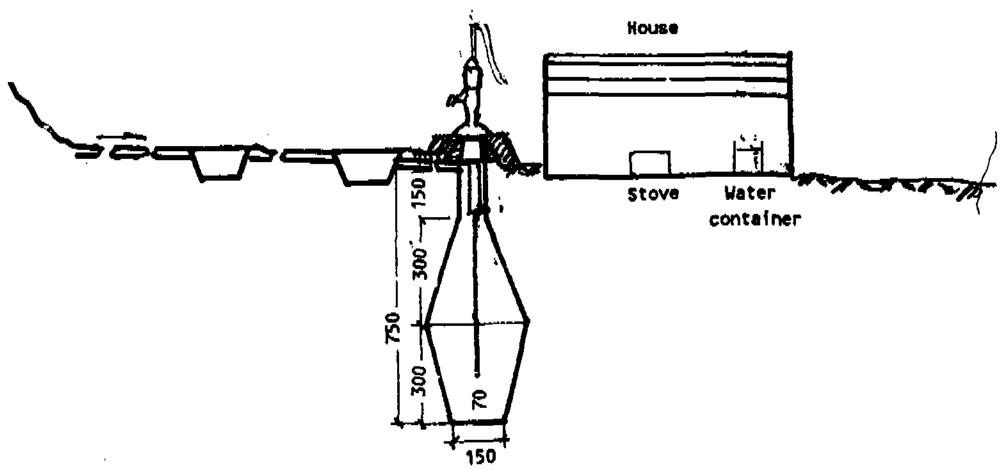

Fig.3-2. Rainwater Harvesting Facilities with Hand Pump

II. Construction and Cost

For 20 M^3 of storage volume, the vessel constructed of the local earth was excavated , shaped and rammed firstly. After that, it was trawled with hemp-fibre and lime plaster, of 1 cm in thickness. Then ø=6 mm reinforcing bar, at a distance of 25 cm between each one, were riveted into the wells of the vessel as the waterproofed frameworks. Following, cement mortar was applied for plastering the walls, of 1.2 cm in thickness. Further, cement paste was used for polishing the walls. Finally, the vessel was sealed for 8-9 days curing before it is put into operation.

The storage volume of 20 M^3 can provide the four-month-consumption of a household with 5 persons for domestic use. For such a set of rainwater collection system, the initial cost was equivalent to U.S. Dollar 35, including cement 330 Kg, steel products 33 Kg and 7 labor-day of skilled workers. Each farm family was able to afford to paying for it. For a set of rainwater collection system with the tap water installation, the initial cost was equivalent to U.S. Dollar 58, including cement 360 Kg, steel products 35 Kg, polyethylene pipe (Dg 20-25) L=65M, and 10 labor-day of skilled workers. The running cost was almost negligible and no energy needed. It is easy to operate and maintain. The main problem is, however, that collected water was easy to be polluted in a course of water harvesting, especially where nightsoil, garbage, animals and poultry were not in order. Consequently, the more consideration should be given to the environmental sanitation management such as monitoring and supervision so that hygienic quality of drinking water provided by the rainwater harvesting system could be ensured.

In order to meet the United Nations' Water Decade's goal for providing by 1990 all people with water of safe quality and adequate quantity and basic sanitary facilities to safely dispose of human waste, the quality improvement of water from rainwater cistern systems should be further studied.

RAIN WATER HARVESTING SYSTEMS IN SOUTHERN AFRICA

JOHN M ERSKINE*

ABSTRACT

Poor water supplies and sanitation services continue to be critical problems in the less developed rural areas of southern Africa despite considerable effort to improve and expand access. It is widely recognized that safe, easily available water supplies provided in a form acceptable to the communities concerned are essential for rural development.

Most rural communities depend on local sources of water which are available naturally - river water, open wells and springs - and these are frequently polluted. Not nearly enough use is made of rain water collection systems.

This paper describes the research and development work conducted on rain water harvesting systems in southern Africa in recent years. A case study is referred to for the purpose of illustrating the approach being used to meet the water needs of communities in some less developed rural areas for domestic as well as agricultural use, with particular reference to the introduction of simple, cost effective rain water harvesting technologies. The approach emphasizes the need for attention to be given to community involvement, through appropriate institutional arrangements, in choosing suitable technologies.

INTRODUCTION

In the less developed rural areas of southern Africa, most communities depend on local sources of water which are available naturally - river water, open wells and springs and these are usually polluted. Often, too, water may not be easily accessible and women and children carry it for long distances in buckets or other receptacles, adding to the health hazard.

This situation has not only contributed to the problems of poverty which is linked to low agricultural production, but has also escalated the problem of migration of rural people to urban areas. Moreover, inadequate and unsafe water for drinking and domestic use

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adversely affects the health and well-being of the rural people. Water-borne diseases and poor sanitation continue to prevail in these areas.

An adequate supply of water for agriculture, industry and people depends on human intervention in the water cycle and the development of all available water resources not only on the surface but in the ground. Providing good quality water to rural communities poses many problems. It is not merely a matter of installing pipes, pumps and other high technology equipment as it would be in an urban area, even if this can be afforded by the communities concerned. In rural areas people are often not only without the expertise to operate and maintain such equipment but they do not consider it their responsibility to do so if the system is installed "over their heads" by some outside authority without any consultation as to their particular needs.

To meet these needs care must be taken generally to provide the simplest technology available, making use of whatever local resources there are, and it is essential to involve the community concerned in any decision-making regarding water supplies. The aim must be to provide technology which is not only affordable, effective and reliable, but acceptable to the people who are to use it. This paper places emphasis on the potential of simple rain water harvesting technologies to solve the water supply problem of rural households, for both domestic use and small scale agriculture.

WATER RESOURCES DEVELOPMENT PROBLEMS

As in other parts of the world, the core problem in developing water resources in the less developed rural areas of southern Africa has been identified as that of human resource development. Some important factors inhibiting efforts by government and non-government organizations to improve the water supply situation have been identified by the Council for Scientific and Industrial Research as follows:

* Many rural communities are largely illiterate; those that are not lack the information and expertise to improve the situation themselves, and there is a dearth of personnel to facilitate development projects.
* Attempts by government organizations to upgrade water supplies without consulting the potential users of the water scheme do not foster a sense of community pride in the ownership of such facilities; they are seen as having been imposed upon the

community and people lack the motivation to work with the authorities in operating and maintaining equipment.* A lack of infrastructure for water schemes or ones that function properly.

* Low-income communities lack the motivation to become involved in efforts to improve their situation for fear of financial commitment beyond their means.
* If First World technologies are implemented there is a shortage of staff to maintain equipment; spare parts are not readily available; there is a lack of communication in advising the appropriate authorities about breakdowns and no transport to obtain the needed parts. People fall back on unimproved traditional water sources for survival and once again there is a threat to the health of the community.
* Because of ignorance about the health hazards associated with inadequate water supplies, rural communities may see the provision of other facilities, such as a clinic, as a more pressing need than proper water supplies, not realizing that inadequate and polluted water can cause diseases like diarrhea and typhoid as well as troublesome skin complaints.
* Efforts to provide simple technology appropriate to the circumstances are sometimes met with resistance from authorities because of the prestige attached to First World high technology.

Against this background description of the most important factors constraining water resources development in the less developed rural areas of southern Africa, it is pertinent to examine the potential role of rain water harvesting technologies in meeting the water needs of rural people, particularly at the household level, for domestic use, agriculture and even cottage industries.

RAIN WATER HARVESTING IN SOUTHERN AFRICA

Rain water harvesting in various forms has constituted part of man's strategy for survival since before Christ and there is certainly evidence of primitive rainharvester systems being used in southern Africa many centuries ago. In more recent times, mud and dung and ferrocement catchments have been tested. Rainharvesters have been installed in many sites, in Botswana in particular (Gould 1983) and also in Namibia where Hellwig (1968) suggested the use of rain water harvesting on a large scale; in the latter case, several techniques including bitumen sprayed onto the soil surface have been tested.

The utilization of roof runoff is a well known phenomenon in the commercial agricultural sector in South Africa and other southern African countries, especially in the more arid areas (Alcock 1984). Water derived from roofs also constituted an important and sometimes the only potable source in arid urban areas of South Africa such as Grahamstown before reticulated supplies became available (Reynolds 1984). In such circumstances, the practice was to have two rain water tanks with the first galvanized tank acting as a settling tank draining into a second galvanized tank, from which potable and general household water was drawn. Water destined for domestic consumption was not boiled or treated in any manner. In the more arid areas of southern Africa, for example Botswana, roof runoff constitutes an important source of supply in the smaller urban centers and until recently was vital in the larger urban centers, such as Francistown, as well. In South Africa, the National Building Research Institute has designed low cost housing for use in African urban and peri-urban areas incorporating a 3 000 1 rain water tank with a secondary 225 1 tank for kitchen and shower use (Arrigone 1978). Each house can be fitted with a slow sand filter to purify the rain water for potable use where reticulated water is unavailable.

Thus, rain water harvesting, in one form or another, has been applied over the years in both developed and less developed areas of southern Africa. However, it is an accepted method for the procurement of water amongst only a very small proportion of the population that could potentially make use of it. In the little research that has been done on the system ,emphasis has been placed on rain water harvesting as a partial solution to rural water problems in the more arid parts of the region. Undoubtedly, the technique has application in high rainfall areas as well.

RAIN WATER HARVESTING IN KWAZULU : A CASE STUDY

In recent years, Alcock and co-workers have conducted extensive surveys in two less developed rural areas of kwaZulu, located near to Pietermaritzburg, for the purpose of determining existing water supply sources and consumption patterns as well as formulating recommendations concerning the design and introduction of improved water supply systems (Alcock 1985a, 1985b ; Alcock and Lea 1985).

One of these areas is the Inadi Ward, in the Vulindlela district of KwaZulu, which is situated 15km south west of Pietermaritzburg and covers an area of 66,35 km^2 it is divided into nine sub-wards and has a population of 30 722 people of Zulu descent. The mean annual rainfall for the area is 931 mm.

Most households in the area, each with an average of 7 people in the family group, obtain their water from perennial springs (protected and unprotected). Other sources of water include streams, rivers and dams. At a limited number of protected springs, ferrocement reservoirs have been erected by the KwaZulu Department of Agriculture. A relatively small number of households and a few schools utilize roof rain water runoff and collection in tanks as a source of water. No borehole water or purified reticulated supplies are currently available in the ward. Sanitation is either non-existent or, with the exception of a few septic tank systems, confined to pit latrines.

Over one half of the households in the area consist of two or three buildings. Housing in the district is in a state of change from traditional thatched rondavels to a more westernized form consisting of rectangular wattle and daub or mud brick dwellings with corrugated iron roofs. An increasing although still rare trend is the plastering of the outside walls of houses with cement. In the few cases where gutters are present, they are made of galvanized iron in most instances. The corrugated iron roofs and gutters are not usually painted.

The water collected in the various ways referred to above is not normally boiled and very few people add disinfectant solution or chlorine tablets. As a result, water borne diseases are a major cause of ill-health and, sometimes, serious disease (for example, cholera) in the area.

Just prior to the survey work conducted in the Inadi Ward, five rainharvester units and two fog interceptors were erected in the area to evaluate optimum design materials and construction systems, and also to compare the purity of the water collected from these systems with that collected from the other water sources in the Ward. Bacteriological testing of the water from the various sources revealed that most unprotected surface sources were heavily contaminated whilst, in most instances water collected from protected springs, roofs and from the rainharvesters and fog interceptors was relatively clean. Nevertheless, if the South African Bureau of Standards bacteriological standards are strictly applied in terms of the E. coli content of the water, all the samples of water collected from the various sources would have to be rejected for human consumption if not boiled or treated with a disinfectant. Quite clearly, such exacting standards are not appropriate in respect of water supplies in less developed rural areas. Since the location of pit latrines is not controlled and there is widespread defecation in the open, extensive contamination of surface water is not surprising.

Where rain water is collected from roofs, a survey of households with such a collection system revealed that, on average, there is a 41% reduction in the potential water recovery from the roof due to inefficient gutter installation and inadequate storage capacity. The usual collection system consists of two uncovered 220 l metal drums and a number of smaller plastic containers.

Water perception and source selection are important factors to be considered in any attempt to upgrade water supply systems. In the India Ward, the order of preference for water sources is springwater, rain water and, last, surface water; this observation accords with that made in Lesotho by Feacham (1978). Turbidity is the single most important visible water quality parameter used by residents to assess potability. Surveys indicated that people will choose to collect water from a nearby river or stream in preference to a protected spring if the return journey to the nearest such spring is in excess of 1,5 km, particularly where steep terrain has to be traversed which is often the case in the hilly Inadi Ward.

The survey data reveals that the failure of more people to install rain water collection systems on their buildings and/or their rejection of rain water as a potable source usually stems from inadequate installations; people are understandably reluctant to drink the water when the storage vessels are uncovered and rusty or unclean. Rejection, therefore, centers on poor or inadequate technology rather than the source _per se_. It seems that the technology deficiency derives from a lack of information concerning appropriate technology. Lack of funds or lack of knowledge concerning credit availability are of course other reason why some households have not introduced gutters and storage tanks.

PROMOTING RAIN WATER HARVESTING (ROOF COLLECTION) IN THE INADI WARD AND ELSEWHERE

Technical considerations

The water supply potential of a given roof system will be influenced by locational factors which include topographic location, with consequent rainshadow or orographic effects, orientation of roofs with respect to the main rainbearing winds and the presence of shelter belts. Roughly 17% of the metal roofed houses in the Inadi Ward display the postulated optimum roof orientation. Clearly, new houses should be constructed with this optimum orientation in mind.

The pitch of a roof in relation to the surrounding terrain also influences the catch efficiency. The higher catch recorded by raingauges normal to the surrounding slope has been demonstrated (De

Villiers 1980). Thus, houses situated on relatively steep land are likely to intercept a greater rainfall, especially under high intensity conditions, than houses situated on flat land where roof inclination does not approximate a right angle to the terrain.

Once rainfall has been intercepted by the roof, a further set of factors become involved in determining runoff. Depression storage on the roof surface will retain a certain amount of water and wetting of the roof surface will retain a small volume of rain water. In general, however, a runoff coefficient of 0.75 - 0.95 is commonly accepted for roof surfaces (Chow 1964) and the higher value will apply to more impervious surfaces such as corrugated iron sheeting. Once runoff has been achieved, gutters which are (a) too close or too far away from the roof eaves or (b) which exhibit an excessive fall or (c) which leak, can result in a considerable loss of utilizable water together with spillage down the wall and the consequent structural with spillage down the wall and the consequent structural effects. The lack of fascia boards on most houses in the less developed rural areas results in practical difficulties when gutters are attached either to the eaves poles or the roof.

The type of material used in the manufacture of gutters is important with regard to both possible hail damage and installation difficulties; asbestos and PVC gutters are not recommended and the former material is also excluded on health grounds. Galvanized iron gutters (made from 0,6 mm thick sheeting) are the best option at the present time but rust is a problem and regular cleaning to clear blocked sections is essential. Downpipes may be made of polyethylene tubing.

A type of gutter assembly that is currently recommended in southern Africa for simple houses is one known as the Msinga Gutter Sling Bracket for use with corrugated iron roofs and galvanized iron gutters. With this system ,a short galvanized angle iron is bolted directly onto the overhanging edge of the corrugated iron roof sheet and the gutter is held in place by a length of galvanized wire attached to the two ends of the angle iron and suspended below it. Two clips hold the wire in place on the gutter. The length of the wire and the positioning of the clips on the wire can be altered to regulate the slope and angle of the gutter. This system has the following advantages : low cost; simple and quick installation; no fascias required; adjustable for any roof pitch; compatible with all types of roof construction; accommodates any gutter shape; and, because it is rigid, it withstands the build up of hail.

For household rain water storage, a choice of there materials is available:

* Relatively inexpensive galvanized tanks (made from 0.6 mm thick

sheeting) which have the important advantage of ease of installation, although their long-term durability is questionable. Some form of exterior protection against rust, such as coating with bitumen-based paint, may be necessary. If the wall of the tank has rusted,repair may be effected using bird-netting wire and cement.

* Glass fiber reinforced polyester tanks which are more expensive but also easy to install. These units have a considerable life-span but are not as readily available.
* Ferrocement tanks, also cylindrical, which are durable if properly constructed. However, the construction of such tanks requires specialized skills and the necessary building equipment is not readily available to rural householders.

In all cases, a well-fitting detachable cover for the tank is essential. This should include a short section of suitable diameter piping in the center to facilitate connection of the downpipe. An elevated collar is especially important to prevent dust mixed with rain water from entering the tank via surface inflow. A tank overflow pipe, which must be covered with a section of gauze to prevent entry of insects, will facilitate the hygienic collection of excess runoff which may also be piped or carried to other areas of use, for example, trees or a vegetable garden near the house. The gutter outlet pipe should also be covered by a piece of gauze which will act as a primary filter. The gauze filters can be attached by means of a contact adhesive and Velcro self-gripping fastener tape.

Water tanks, no matter what material is used in their construction, should be mounted on a well-drained rock-mortar concrete or wooden framework pedestal to prevent deterioration of materials arising from ponding at the base. Several designs are available for a simple "first flush" mechanism which allows the initial roof runoff containing particulate matter to run to waste (Jenkins and Pearson 1978). In practice, however, most households will probably not bother to use such systems; they must, however, be installed on larger buildings such as schools. A standard 15 or 20 mm diameter tap with a hose union must be fitted and should be threaded into the tank rather than soldered to ensure quick replacement if necessary. A simple tap locking device is inexpensive and readily available.

Where rain water is to be collected for purely agricultural purposes, for example, to supply water to the birds in a poultry (broiler) unit, extensive use is now being made of a roof runoff collection system that consists of :

* A poultry shed with a corrugated iron roof which has a sufficiently large surface area to provide enough runoff during

the wet summer months to provide water for the unit right through the dry winter months.

* An underground water tank consisting of a plastic liner supported by a stiff wire mesh structure; a plastic cover is held in place in a cone shape above the tank with a central pole and supporting wires.
* A header tank suspended below the roof of the poultry unit for supplying water by gravity feed to the bird drinkers on the floor of the unit.
* A simple hand pump for pumping the water from the underground tank to the header tank.

The installation of rainharvesters or fog interceptors, where appropriate, can be considered in those situations where efficient household rain water collection is not feasible and other sources of water are not available. An important advantage in times of drought is that rainharvesters can serve as emergency reservoirs supplied by tanker. However, such community water resource facilities can be successfully implemented only if the local community is fully involved in planning the system, erecting it and maintaining it.

Socio-economic considerations

Cost is a most important consideration in the utilization of rain water collection systems by rural households. The present cost of installing a simple household unit (with an 11 m gutter length) with a 1 300 1 storage capacity is estimated to be of the order of R800 (approximately U.S. $320). This figure includes the guttering (galvanized iron), downpiping, tank (galvanized iron),pedestal, tap and filters.

Since the average household cash income in the less developed rural areas is of the order of R800 per month, it can be seem that finding sufficient funds to install a rain water collection system is a real problem, particularly because there are no widely available long term credit facilities available to rural people.

A second problem relating to the installation of rain water collection systems is that of transporting bulky tanks to the rural areas where most people do not own vehicles of any type. Neither manufacturing companies nor local hardware firms are willing to enter into hire-purchase agreements for the supply and transport of materials to households. Investigations have revealed that a lay-by system (whereby the householder deposits cash over a period of six months with the supplier for the materials to be ordered : ownership of the goods is transferred on delivery when the balance of the money owing has been paid) is acceptable and may be the answer to the problem of financing rain water collection systems. Voluntary savings clubs operated by local communities are another possibility.

The degree of acceptance of rain water collection systems by rural householders is a reflection of individual perceptions concerning their worth, in monitory and non-monitory terms. One of the problems regarding rainwater is that many householders are not aware of the annual runoff yield from their roofs. Another is that there is little understanding of the effectiveness of a safe water supply in combating disease problems in the less developed rural areas. A rider to this ,of course, is that sanitation development must not be allowed to lag behind water resources development, for both are equally important in reducing the severity and incidence of various diseases, gastro-enteritis in particular.

In those areas where some rain water collection systems exist already, rusted roofs, gutters and storage vessels as well as the presence of silt on roofs does not encourage other residents of the area to invest in such systems. It cannot be over-emphasized, therefore, that properly trained technical personnel are required to advise on the installation of systems and on their on-going maintenance. A solution frequently proposed to overcome the shortage of technical skills in the rural areas is that of training one or more residents from the area in question. Experience has shown, however, that results are often disappointing because many residents would prefer to deal with a responsible agency rather than with independent (although trained) entrepreneurs.

It seems that any accelerated upgrading programme for rain water collection systems will require the attention of an already established water agency with fully competent staff working closely, in the first instance, with the local development committee. Thus, the promotion of the desired development is the outcome of a collaborative partnership between the community and the development agency in which neither is dominant and each understands and accepts its role. This type of relationship places new demands on both parties : communities must become the focal point of decision making, and development agencies must help create or support conditions in which community-based action can occur.

CONCLUSIONS

Making more water available and more accessible to people living in the less developed rural areas of southern Africa is one of the principal goals in development work in these areas. Access to a clean water supply should be as close to the home as possible to foster the use of more water for hygiene practices. The promotion of rain water harvesting systems, particularly rain water collection from the roofs of private homes, is an excellent way of achieving the goal of improved access. Properly installed gutters will help to reduce the incidence of structural deterioration resulting from water splashing against walls. Excess roof runoff can be used to water small vegetable gardens, fruit trees, etc, with consequent upgrading of the household nutrition.

Quantifying the health effects of water and sanitation development is vital in the process of motivating people to introduce rain water collection systems. Water supply and health programmes should emphasize community involvement and also hygiene education to encourage people to use more water for personal and domestic hygiene. There can be little doubt that health benefits are the major - but not the sole - justification for promoting water supply and sanitation development; such improvements also have wide economic benefits. It is important to note that behavioral changes combined with greater access to facilities are the basis for health benefits through improved water supply and sanitation.

Finally, local institution-building is the key to transferring the sustainable skills required for building appropriate rain water collection systems.

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THE NECESSITY AND SCOPE OF RAIN WATER HARVEST IN BANGLADESH.

Md. Rafiqul Hoque*

ABSTRACT

Bangladesh is a tropical country influenced by Monsoon climate. The average annual rainfall is about 2300 mm. But more than 80% of that rainfall occures during a short period (May-August) resulting in huge runoff volume and subsequent floods. On the other hand, during the dry season (Nov. - Feb.), there is almost no or very little rainfall resulting in too much shortage of water with subsequent severe draught conditions. Due to this two extream and opposite conditions prevailing in Bangladesh the total economy of the country is suffered tramendoushly.

In this paper, with respect to taking care of this two extream situations to some possible extend, the necessity and scope of rain water harvest in Bangladesh has been discussed and suggested some strategies.

INTRODUCTION

Bangladesh is one of the most densely populated country in the world having a population of about 110 million in an area of 143,500Km^2 only. It is located between 20°30' to 26°45' north latitudes and 88°01' to 92°56' East Longitudes.

Bangladesh is an agricultural country strongly influenced by tropical monsoon climate. The water resources play the vetal role both for agriculture and domestic use of the vastpopulation in the country. Rainwater is the main source of water supply in the country. But according to the physiographic and climatic condition prevailed in Bangladesh, specially due to quite uneven distribution of rainfall, once for too much of water and again for too little

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water it has to suffer tramendonsly from severe floods and draughts respectively with subsiquint effect on national economy and human life.

Under these conditions, like other countries in this region, there is a great need and scope for rain water harvest, storage and management both for agricultural and domestic perposes. But unfortunately no or very little attention has been given in this regard, although it is very urgent under Bangladesh conditions.

PHYSIGRAPHIC FEATURES OF BANGLADESH

Bangladesh geographically is of deltaic origin formed by the combined action of one time mighty rivers the Ganges, the Brahmaputtra and the Meghna and flowing from the Mountancous region in North to the Bay of Bengal in South.

The snow and rain falling over the easter Himalaya in Bhutan, Nepal and Asam to the North of Bangladesh provides the major water supply of the Ganges-Brahmaputra-Meghna river system. During the dry period, snow melts from the Himalayas augments their low flow.

In Bangladesh, during the rainy season by mid July the monsoon rains floods the plains and depressions. The generalized innundation land types map of Bangladesh (Fig. 1) indicates the distribution of land levels in relation to seasonal flooding.

CLIMATIC CONDITIONS OF BANGLADESH

The climate of Bangladesh is tropical because of the modifying effect of the Himalayas mountains and plays significant role in agroecology and human life.

Temperature

The cool weather in Bangladesh is from November to February during which the temperature varies from a minimum of 10°C to a maximum of 24°C. The hot weather starts from March and continues to rise upto the end of may at a maximum of about 36°C.

Humidity

The average annual relative humidity of Bangladesh is about 65 percent. The relative humidity varies from a minimum of 45 percent to a maximum of 85 percent. During rainy season it varies from 65-85 percent.

Evaporation

The average annual evaporation is about 1550 mm. The evaporation is at minimum during the month of November to February varying from 50 to 90 mm per month and at maximum during the month of March to June ranging from 130 to 180 mm per month (Fig. 2).

Rainfall

The climate of Bangladesh is dominated by Indian subcontinent monsoon system. Annual rainfall ranges from 1400 mm in the dry Rajshahi (North west) region to over 5000 mm in the wet Sylhet (north east) region (Fig. 3) The average annual rainfall is about 2300 mm. More than 80 percent of the total annual rainfall occures during the rainy season in four months from May to August (Fig. 4) resulting in huge runoff volume and subsequent floods. On the other hand during the dry season from November to February there is almost no or very little rainfall resulting in too much shortage of water with subsequent draught conditions (Fig. 4). According to the rate of evaporation, rainfall distribution pattern prevailed in Bangladesh and from the water balance records (Fig. 5) it appeares that droughts of varying intensities occurs in almost all parts of Bangladesh during the dry season from November April.

During the dry season, specially at the southern coastal region of the country the salinity problem become accute with the rise of about 1200 ppm salinity limit.

WHY AND HOW THE RAIN WATER TO BE HARVESTED AND STORED

Under Bangladesh conditions, the rain water needs to be harvested and stored for the purposes like-domestic uses, irrigation, fishing, navigation and flood control etc. Through proper storage of rain water in excavated ponds, lakes, ditches and canal canals etc. specially during the rainy season, the peak runoff volume, which results in subsequent floods and damages can signifivantly be reduced. On the other hand the stored rain water can benificially be used during the dry season. At present the huge number of existing ponds, ditches, lakes, canals and small revers have lost their storage capacity upto 6° to 8° percent due to sedimentation and lack of maintenance. Through proper excavation and maintenance those can be made more effective for rainwater storage.

Bangladesh is one of the most densely populated country in this region. A huge amount of water supply is needed for domestic uses of the vast population. Among the domestic uses, water supply is needed for drinking, bathing, cooling, washing and cleaning etc. Under Bangladesh conditions specially during the dry season there is a great crisis for domestic water supply. The main sources of domestic water supply are ponds, ditches, rivers and tube wells. In dry season, the surface water supply including the tubewell water supply become limited due to the depletion of groundwater level. Even during the rainy season there is problem for drinking water supply. For example, during the severe floods in Bangladesh in 1987 & 88, at most of the flooded areas, the tubewells used for drinking water went under flood water level resulting in accute problem for drinking water specially in the rural areas.

Biologically safe, fresh and clean water is essential for human life. In Bangladesh, for drinking purpose, the tube wells are used as the main source of water supply. But when this sources of supply becomes limiting or beyond the use, the situation becomes worse specially in rural areas. Under this condition, the harvested and properly stored rainwater can potentially be used for drinking and other purposes. In the southern coastal region of Bangladesh, where due to salinity problem even the ground water can not be used, the people has to depend on the harvested rainwater as the only source of drinking water supply. In those areas the peoples are therefore using their indegeneous techniques in harvesting and storing the rain water. For example in a coastal upazila (Dacope) the peoples are observed (Hossain and et al. 1988) to harvest rainwater by using their clean 'Sharee', bed sheets or polythince sheets etc. and collect it in the locally made 'Kalshi' and 'Motka' for subsequent use (Fig. 6). In area where, house roofs made of C.I. sheets are available, attempts have been made to harvest roof water.

In most of the areas of Bangladesh specially in the rural areas, the house roofs are made of C.I. sheets. Therefore the rain water can be easily harvested, stored and treated for potential use in Bangladesh using modern and appropriate techniques followed by the other countries in this region and else where.

Under Bangladesh conditions and the above mentioned facts, it can therefore be said that there is a great need and significant scope for rain water harvest and storage in Bangladesh.

CONCLUSIONS

According to the physiographic and climatic conditions prevailed in Bangladesh there is a great need and potential scope for rain water harvest and storage in order to adjust with the two opposite and extream solutions once for two little water and again for too much water.

The storage capacity of the existing ponds, ditches, lakes, canals and small rivers can significantly be increased with proper excavation and maintenance in order to harvest and store rainwater for future uses.

In most of the areas of Bangladesh specially in the rural areas, the roops of houses are made of C.I. sheets. Therefore the house roots an easily be used for rain water harvest specially to use for drinking purpose under adverse situations.

The rain water harvesting techniques already practicing in the limited coastal areas of Bangladesh needs to be properly monitored and evaluated. Proper attention needs to be given in order to improve the technique and to expand it throughout the country in the light of the experiences earned in this field by other countries.

CAPTIONS FOR FIGURES

Figure - 1 The generalized innundation land types map of Bangladesh.

Figure - 2 Mean monthly evaporation at different locations of Bangladesh.

Figure - 3 Annual rainfall at different locations of Bangladesh.

Figure - 4 Mean monthly rainfall at different locations of Bangladesh.

Figure - 5 Water balance conditions at different locations of Bangladesh.

Figure - 6 A schematic diagram of a rain water harvesting technique using a pieces of cloth in Dacope upazila, a coastal area of Bangladesh.

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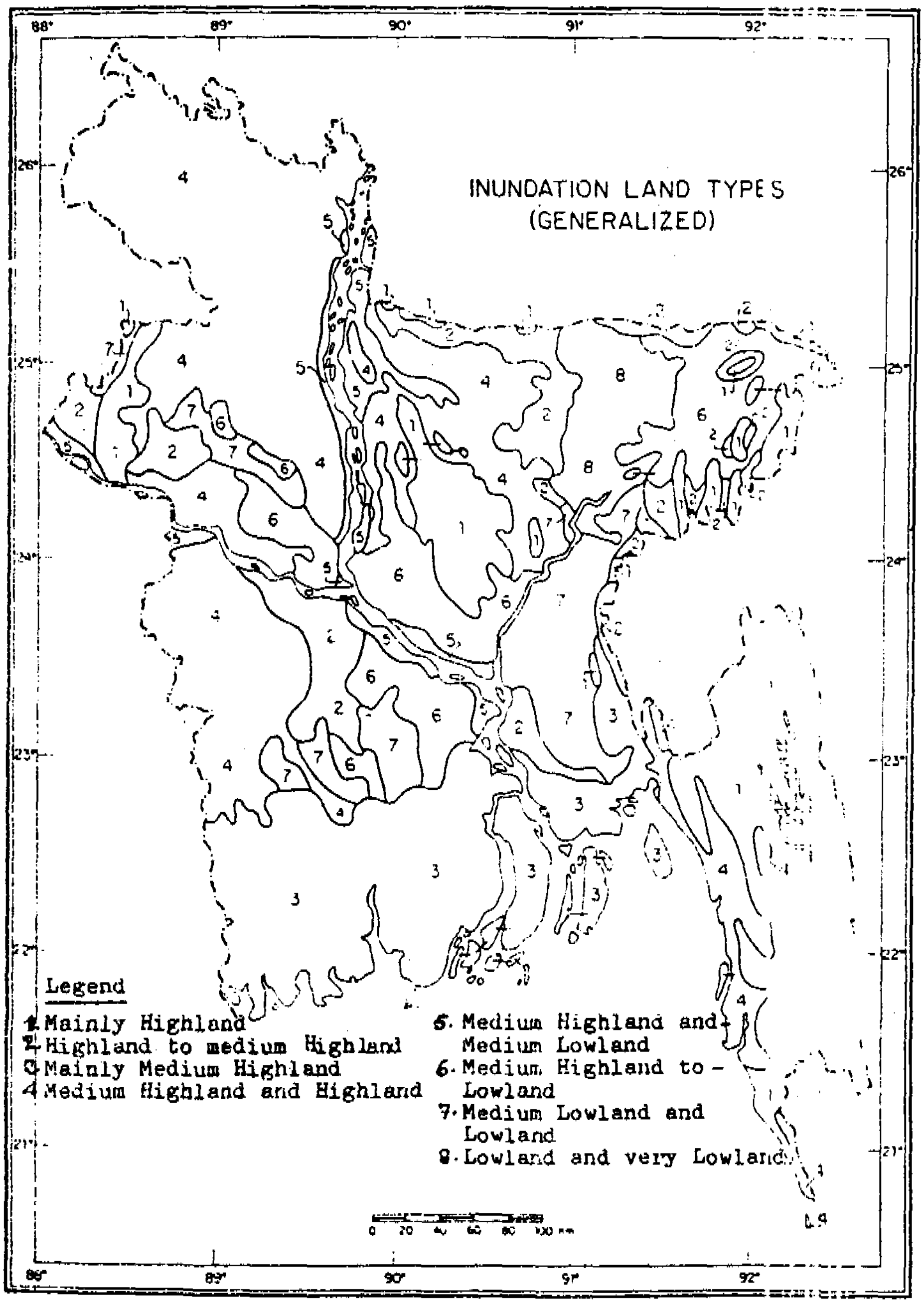
INUNDATION LAND TYPES
(GENERALIZED)
Legend
1 Mainly Highland
2 Highland to medium Highland
3 Mainly Medium Highland
4 Medium Highland and Highland
5. Medium Highland and Medium Lowland
6. Medium Highland to Lowland
7. Medium Lowland and Lowland
8. Lowland and very Lowland
88° 89° 90° 91° 92°
26° 25° 24° 23° 22° 21°
0 20 40 60 80 100 km

Figure 1.

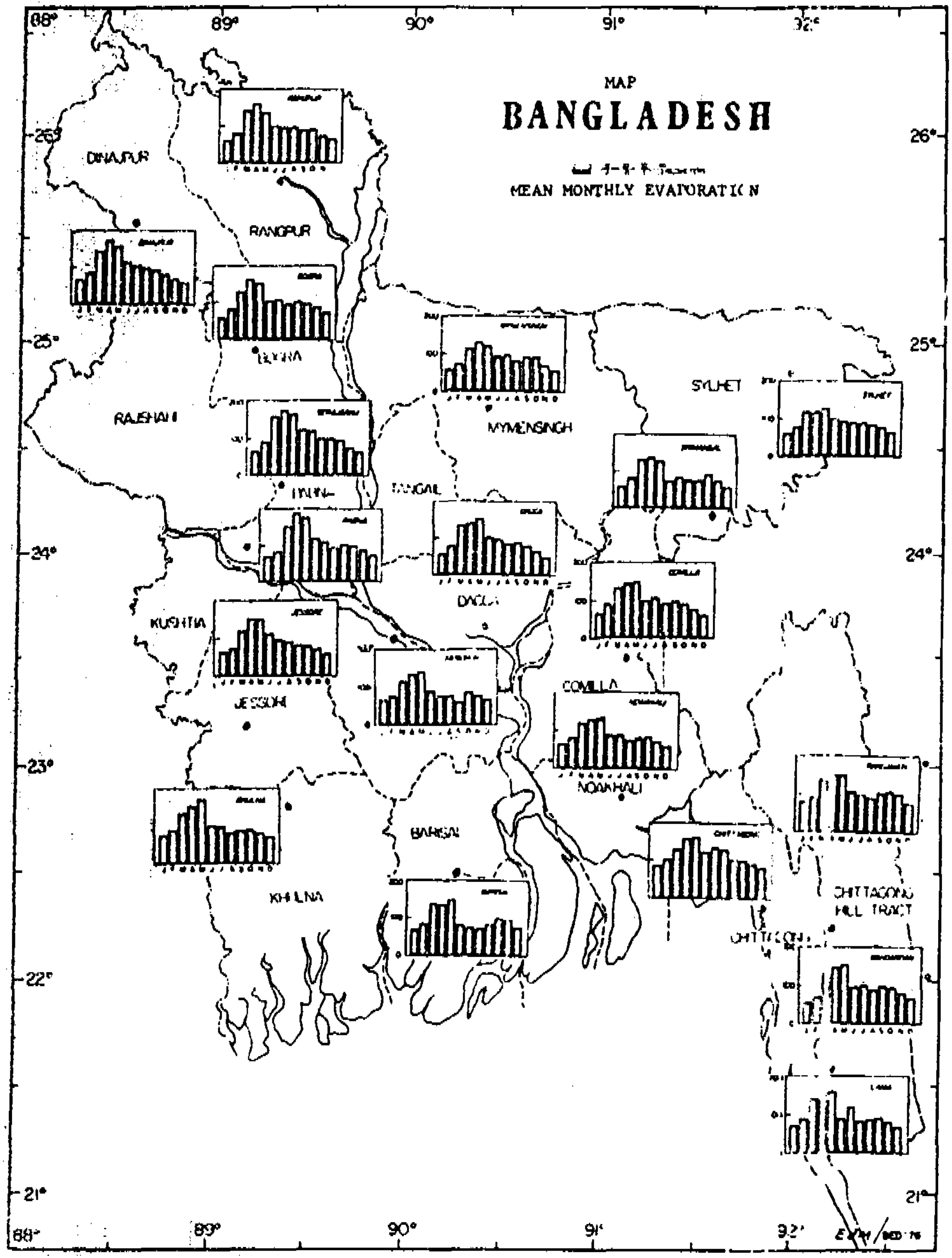
MAP
BANGLADESH
MEAN MONTHLY EVAPORATION
DINAJPUR
RANGPUR
RAJSHAHI
MYMENSINGH
SYLHET
TANGAIL
KUSHTIA
JESSORE
COMILLA
NOAKHALI
BARISAL
KHULNA
CHITTAGONG HILL TRACT
88°
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°

Figure 2.

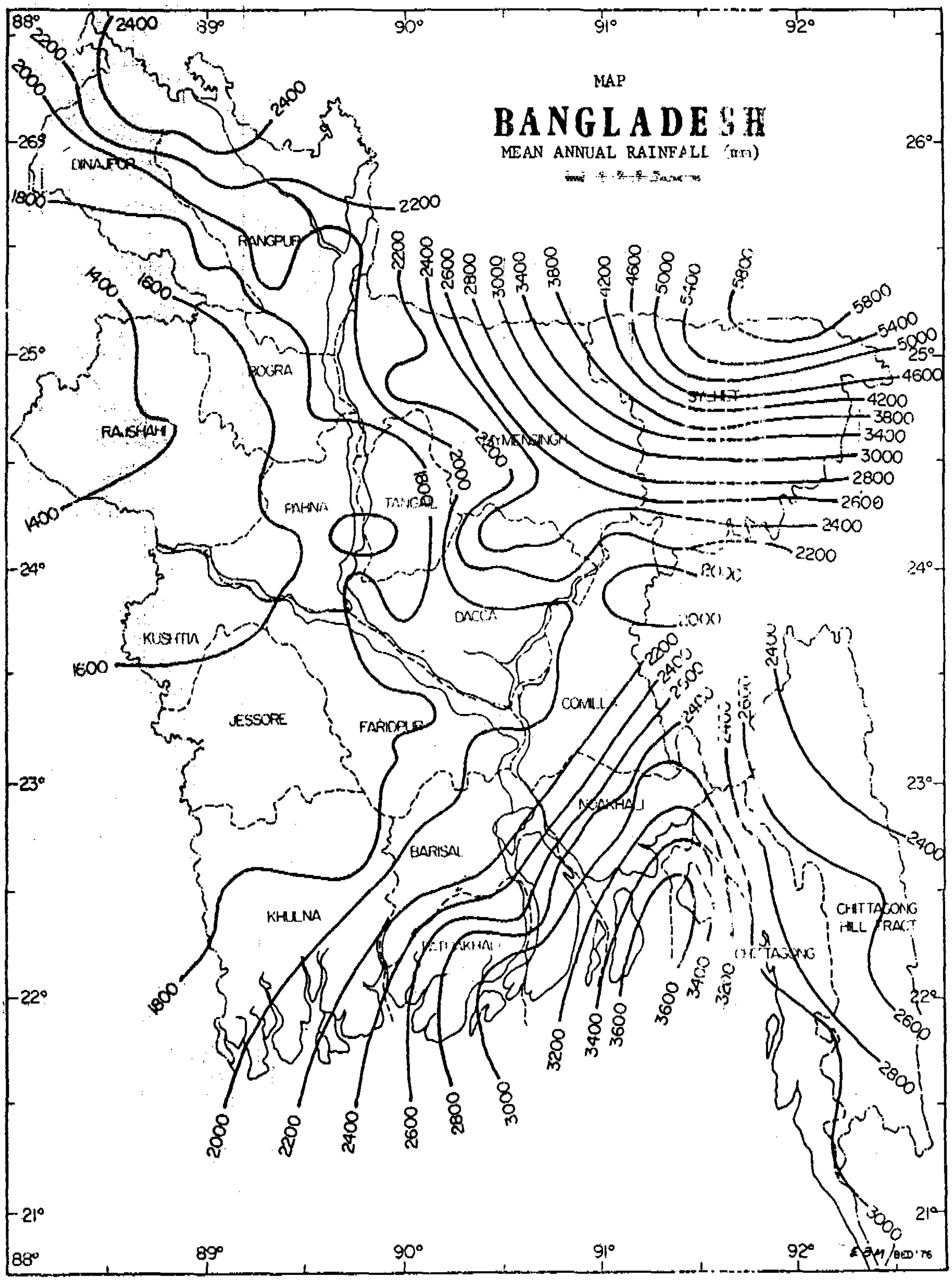
MAP
BANGLADESH
MEAN ANNUAL RAINFALL (mm)
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
PABNA
KUSHTIA
JESSORE
FARIDPUR
DACCA
COMILLA
NOAKHALI
BARISAL
KHULNA
CHITTAGONG HILL TRACT
88°
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°

Figure 3.

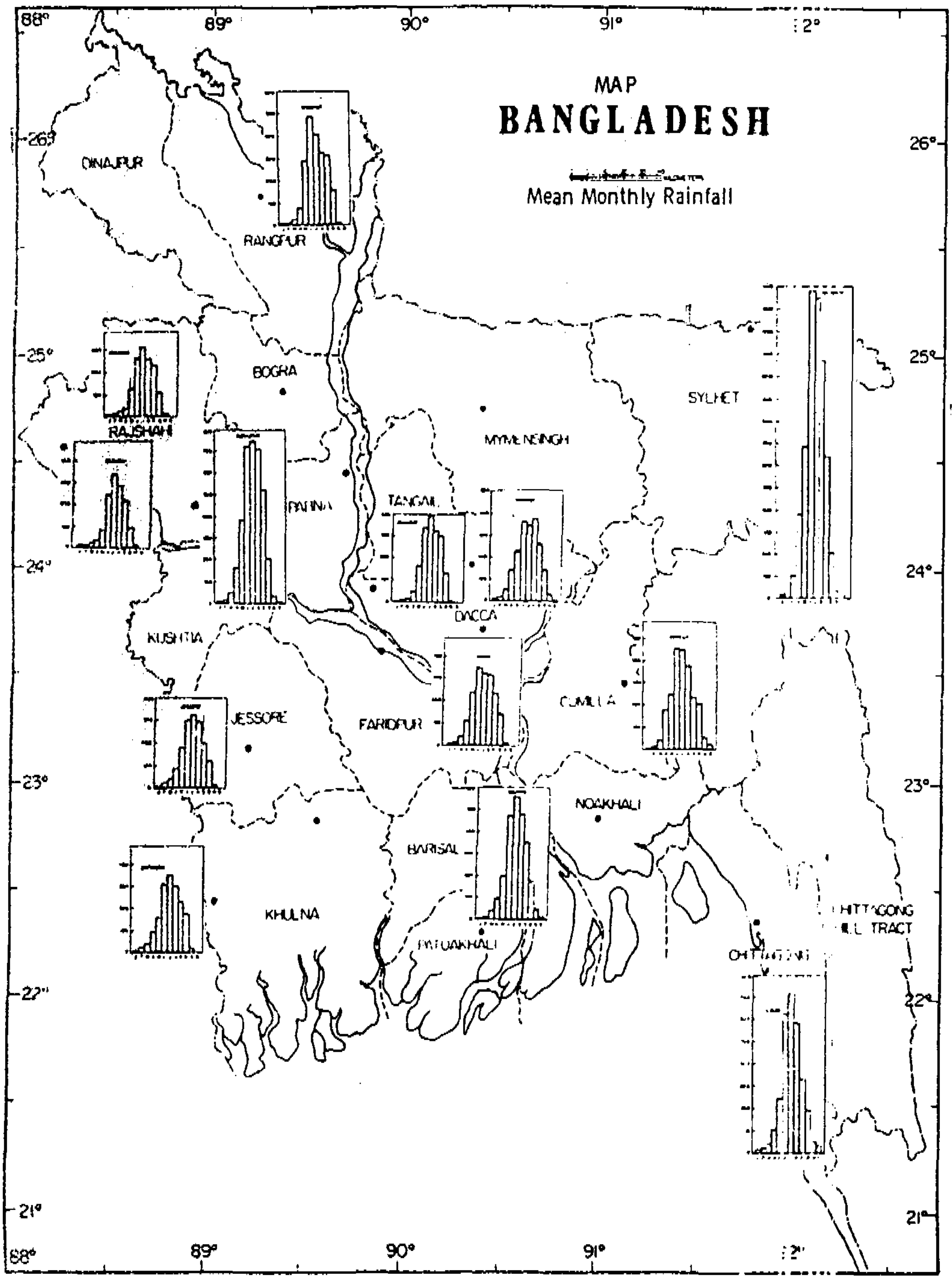
MAP
BANGLADESH
Mean Monthly Rainfall
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
TANGAIL
MYMENSINGH
SYLHET
DACCA
KUSHTIA
JESSORE
FARIDPUR
NOAKHALI
BARISAL
KHULNA
88°
89°
90°
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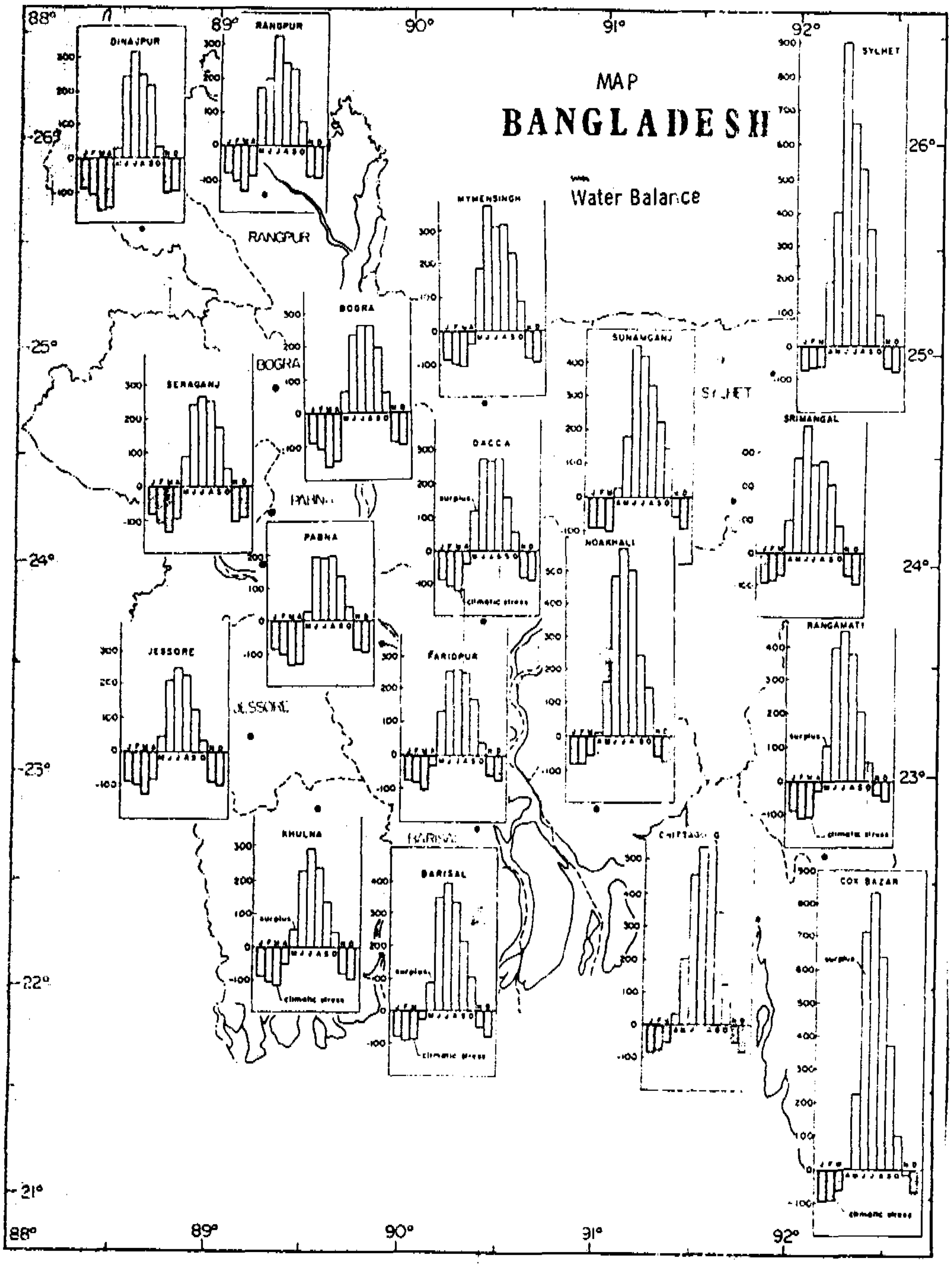
Figure 4.


MAP
BANGLADESH
Water Balance
DINAJPUR
RANGPUR
MYMENSINGH
SYLHET
BOGRA
SERAGANJ
SUNAMGANJ
DACCA
SRIMANGAL
PABNA
NOAKHALI
JESSORE
FARIDPUR
RANGAMATI
KHULNA
BARISAL
COX BAZAR
88°
89°
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25°
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22°
21°

Figure 5.

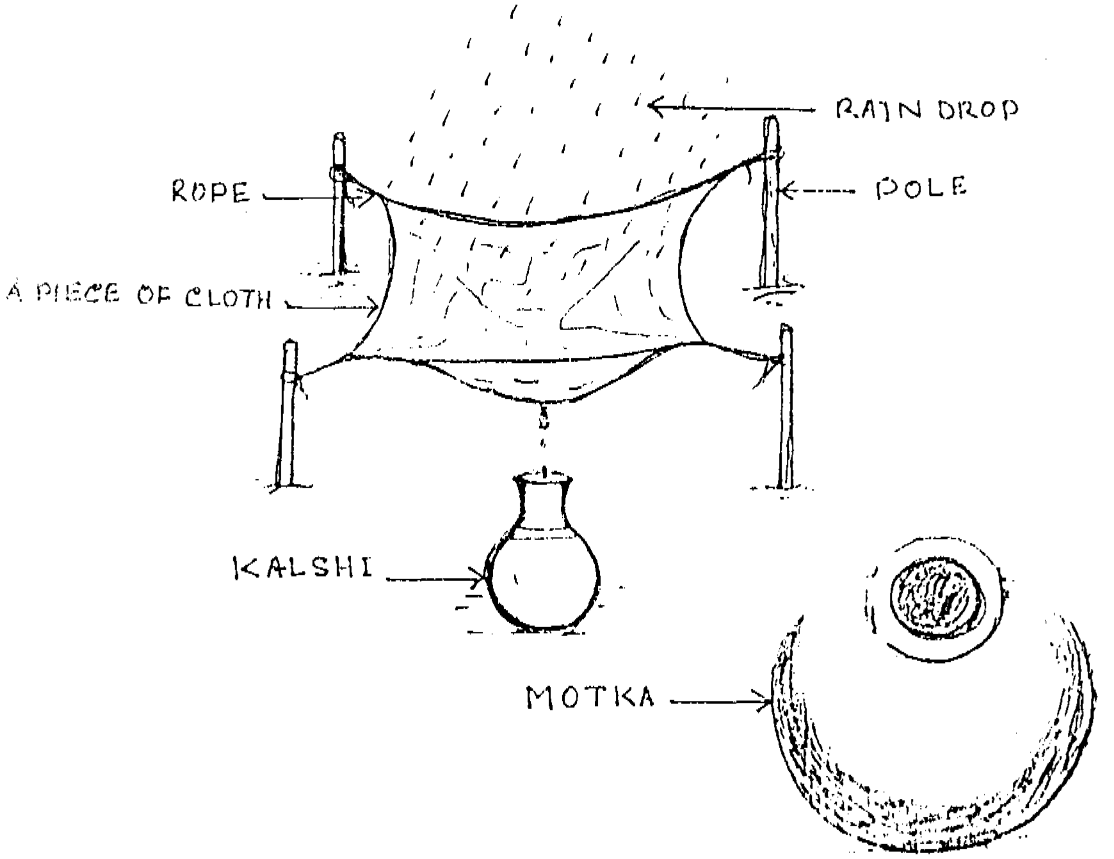

Figure 6.

MALIAN EXPERIENCE IN RAIN WATER CISTERN SYSTEMS

Souleymane KONE*

Abstract

Water needs, supplies and uses constitute a compound subject in Mali. The appropriateness between Water needs and resources Varies throughout the year. The rain season (2 - 4 mounths long) undergoes serious climatic disturbances these last two decades. People do not have enough access to water, because there is not enough systems (wells, reservoirs, pumps) to make the most of the potential water supply and the situation becomes more complex with the nature of the persons who supporte all the water supply charge. Whatever the reason, water shortage is especially prevalent in rural areas.
In this complex water supply system, the surety technology is not necesserily the one which occures more water at less cost, but which occures water at a specific moment in a specific place. It is the case of rain water cistern and catchment systems, which exempt women from supply duties at the moment when they have heavy agricultural charges.
The rain water cistern and catchment systems used in Mali depend on the geoclimatic factors of the different regions, the nature of the needs to satisfy (domestic,agricultural)and the way of life of the people (settlement).
According to the nature of the need, there are individual and collective implemented systems. Some of the systems are widely used in many areas and the others are known only in a small part. The importance of the rain water cistern and catchment systems is well known in Mali.
Traditionnal and modern techniques have been presented and the contraints and limits analysed for more wide application and efficiency use.

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Background

From its geographical situation, Mali knows a unequally shared out rainfall. The annual rainfall varies from 1400mm in the South (e.g.Sikasso)to fewer than 76mm in the North (Kidal).As a Source of life rain is essentially used in agriculture.
However its direct use for domestic needs is not unknown in Mali.
A lot of techniques are required for catching and stocking of rain water. Those various techniques generally depend on geoclimatic factors of different areas of the country, the nature of needs to be satisfied and the concerned group of population way of life. Cases of some most employed techniques in Mali since years will be discussed

Water tanks in the Dogon region

The Dogons' water tanks are built with dirt inside the dwellings. The roofs of houses which communicate between them gather rain that is stocked in tanks. The water tank is recovered by a terrace toped with a dome. A cover on the roof permits to draw water with a sump.
The insertion of water tank of rain water collecting and stocking at home in the Dogon region presents some advantages
.To avoid the sinking of well which is a very difficult activity often impossible for most of the Dogon Living in mountanous areas.
.To avoid the far transportation of water through hills.
Now, water tanks have been improved. They are built in a reinforced way.

Characteristic of water tanks

.Making :bricks in clay, wiring, ciment, concrete, bricklayer.
.Capacity of stocking :from 3.5 to 13m3 per water tank.
.Need satisfied :drink,cooking of food, washing.
However in lack of water tank, water collecting is individual and is made in all kind of available vessels :brickets, canaries,basins, casks.
Water is caught for current needs or tremendous activities which need water : e.g
- women in town :washing, dishes, bathing....
- farmers in countries :drink,work of banco.

Water collecting vessels are put on the soil around huts or under the side of roofs or evacuation gutters of ran water.

Dogons' Canaries :"Prais"

The technique of "Prais (canary in Dogon) consists to put in fields big canaries very strong (2 to 3 field) to stock rain water.
Water is first collected in differents vessels, the stocking being done in canaries. Therefore, the gathering is manualy achieved. Canaries are put in field once and for all and are used as source of drinking water for farmers in their fields.
The technique of "Prais" was spread in the southern part of Mali. Now, this technique is little used due to the available easiest means of water transportation and the adoption of agricultural hamlets where wells exist, distant fields grew scarce.Yet, the dogon region, with its mountanous relief where the arrangement of wells and sumps rise serious problems to the populations, remains an area of the use of Technique dealing with "Prais".

Characteristic of "Prais"

-Manufacturing by women : This domestic manufacturing is made with cooked clay.
-Capacity of stocking :20 to 100 liters per "Prais".
-Satisfied needs : water for drink, for farmers, breeders, hunters and even travelers.

Trunks of trees

Trunks of some big trees (ex: baobab) helped the population of some southern regions in Mali, as means of collecting rain. They were many methods of collecting rain water by trucks of trees.
-Collecting along the trunks of baobab by sticking in the bark an iron the side towards wind for the filling of canaries.
-Utilization of hollow trunks (baobab....) as cistern. Water pouring from branches is stocked in the cistern. This technique was generally used by hunters and some farmers in distant fields.

In some cases the collected water had medical and prophylaxical utilizations. The technique of utilization the trunks of trees by men for collecting rain water is in disapearance now. The long drought of the last decades and demographic problems have deterioted most of these systems.

Ponds :

Ponds are natural and artificial formation allowing rain to stay in a precise place.
Natural ponds are found all over Mali. However they are artificial ponds fitted up by particular groups for the satisfaction of their need in water gardening. In some Dogon regions the arrangement of ponds is spread enough.
Thus ; that to avoid the difficulties of supplying in water with in a long period a year. The arrangement consists to dig the pond in order to increase its capacity of water collecting.The work is a collective one and can gather lots of villages.
It is done with crude means that the population has at its disposal.
Decisions are taken together to keep water in the pond :
- Prohibition to grow in a 150 to 200 ray meters.
-Prohibition to wash or to do dishes in the pond.

Micro dams of keeping in water

In Sahel, after rain, much quantity of water is gathered and overflows places. It flows towards streams that it overflows and devastates everything on its way. Some hours after, it disappears and lets only gullies. The technique of micro dams known and practised by Dogon long time ago, permitted farmers in the hills to keep on agricultural exploitation beyond rainy season which is peculiarly hazardious (300 to 500 mm water per year).Thus Dogon traditional dams are the result of the first small dams of keeping in built by catholic mission of Bandiagara, the national direction of civil engineering and NGOs.
From 1972 to 1987 the joint project of national direction of hydraulic and energy, and GTZ (GTZ a german agency of technical cooperation) succeeded to achieve about fifteen works of the second generation, about 80 small dams in the Dogon region.
The effect of those small dams is very noticeable. The exploited surface in market gardening is valued 200 to 550 hectar thanks to this technique. Important quantity of water is kept in yearly for the grow of onion, tomato and sweet-pepper (main resources of the population gain).
The selling of those products allows the population to buy grain in difficult years.
Recently, the technique of micro-dams has known a strong appreciation. It permits to keep in water in order to improve the table-cloth.

As a result the sinking of wells for gardening and for drink in dry season is simplified.

Zais

Zais is an agricultural technique, in the dogon region, that is spread in the Sahel. It consists to dig holes in the fields(Zais) in which people sow. Dimensions are : diameter 20 cm and depth 15 to 20 cm. The holes are dug in such a manner to collect as much water as possible in the field for plants. The technique of Zais is used on small plats of land (less than 1 ha). Other methods consist to keep in all the rainfall water in the field by a small dik. The presentation of this technique (Zais) does not respond only to a need to be more exhaustive. but its importance for the agriculture of the region gives it a specific character which deserves to be mentioned as rain water catchment system.

Constraints and Limits to rain water collecting and stocking techniques :

The different techniques used in Mali for collecting rain water have some constraints such as :

1. Technical constraints:
The traditional technique to make canaries doesn't permit to get vessels of great capacity. Now, made canaries do not go beyond 100 liters ; so there is a problem of stocking for a long time.Furthermore, in countries it doesn't always exist technical competences and building materials for modern system of stocking with a great capacity.

2. Hygienic constraints:
Decisions taken to prevent stocked water from pollution are generally insufficients. The checking of water quality is quite out of reach. Consequently, water becomes source of lots of severe diseases (case of ponds).

3. Socio-cultural contraints:
Architectural methods in most cases (thatch roof, terrace in banco, flat roof) don't facilitate the rain water collecting by the roof to satisfy to domestic needs. It should exist some difficulties concerning the utilization of "Zays" technique in some parts of the

country (especially in the South) where agriculture is enough mechanized. This technique is particularly applied on small agricultural exploitation where work is manual.
Another constraint, certainly the main one is the population viewpoint about rain water. The risky characteristic of rain, and favorable conditions, made that the population has in mind an immediate satisfactory role of rain. Thus, the possibility of stocking water for lasted period utilization is not always catch sight off.

Conclusion:

The expertness of water constitutes a priority of national programme of development in Mali. The different actions set up in that field concern essentially :

. The realization of sinking and reinforced wells rustic and pastoral hydraulic.

. The arrangement of lakes and dams of keeping in by irrigation and fishing.

The analysis of collecting and stocking technologies of rain shows their importance in the satisfaction of the population needs in water. However, the situation shows that those technologies are practically unknown in most areas of the country, and we must ask the reasons of this non-broadcasting. Some isolated tentatives to the introduction of some techniques didn't succeed well.
A work of information becomes necessary for a generalized utilization of the systems of collecting and stocking rain.
In most cases an effort of adjustment and improvement of technologies are prescribed.

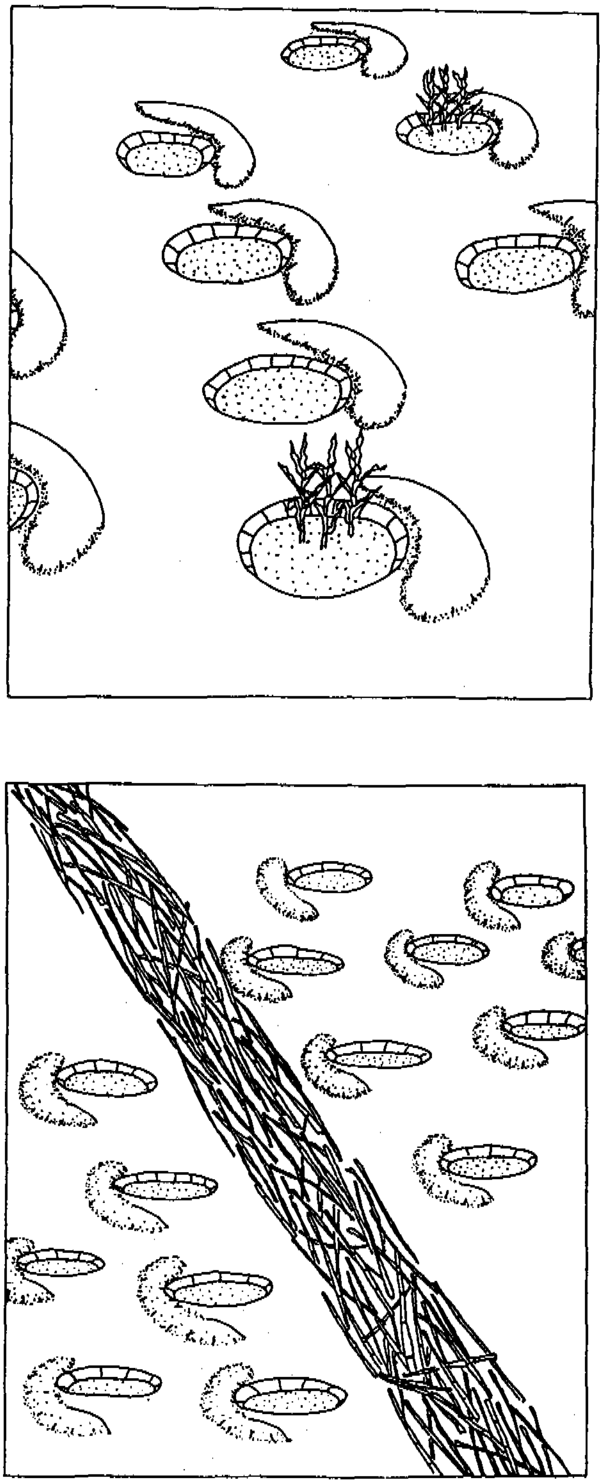


Figure 1. The technique of zais

Citerne Dogon

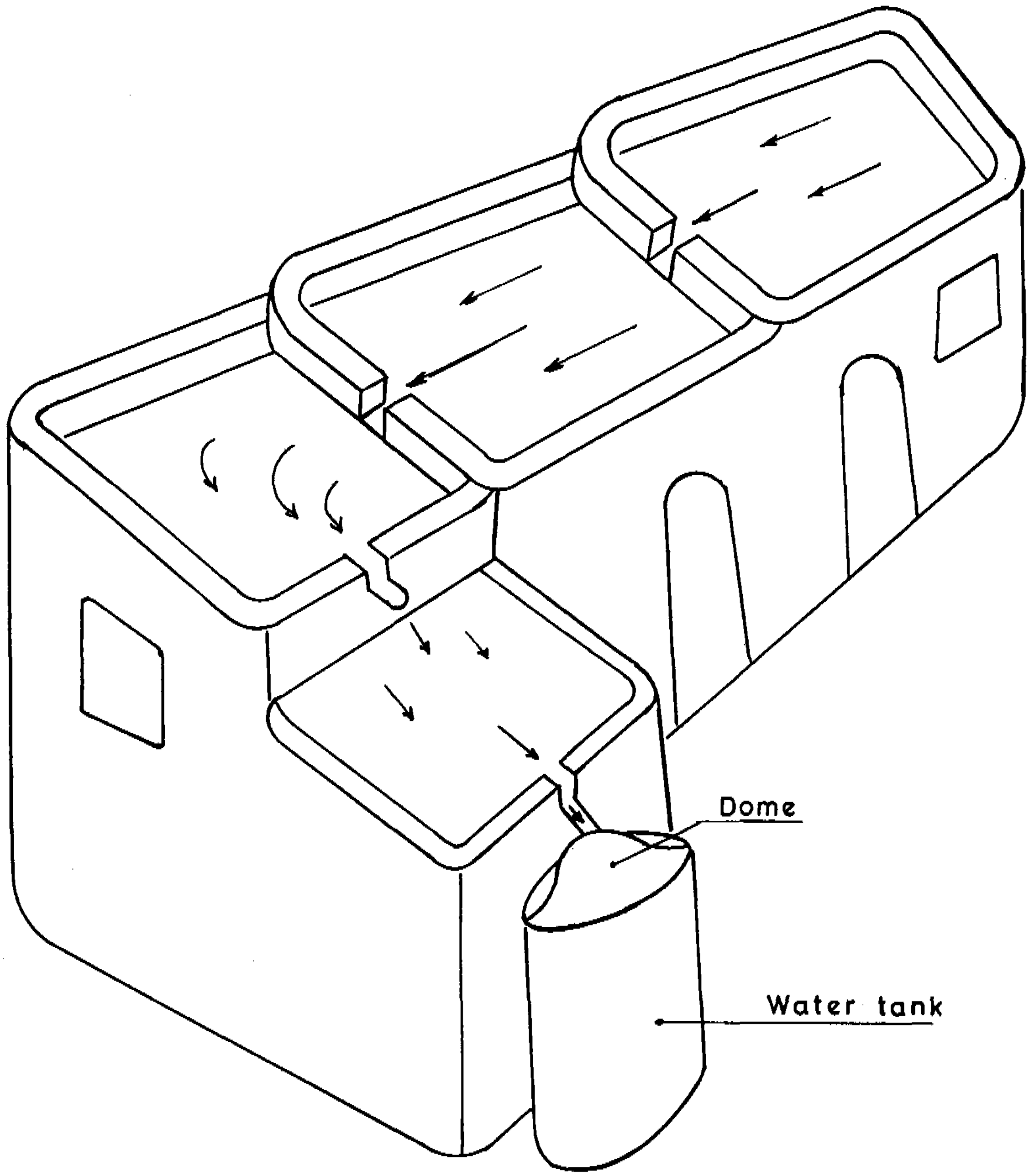
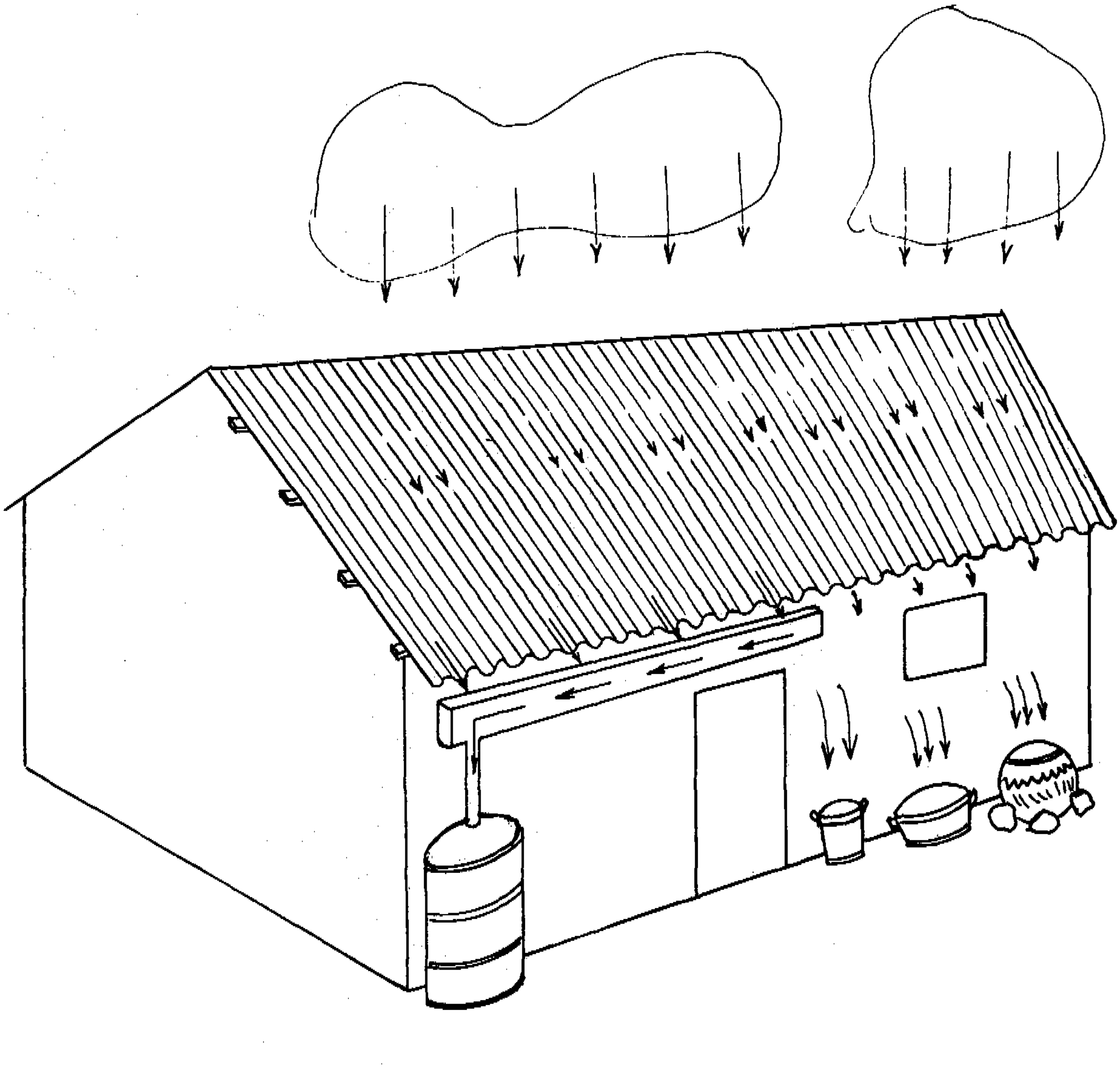


Figure 2.



-Keeking in water under the roof-

Figure.3

RAIN WATER CISTERNS - A NEW APPROACH TO SUPPLEMENT THE RURAL WATER SUPPLY SYSTEM IN SRI LANKA

RAJINDRA DE SILVA ARIYABANDU*

ABSTRACT

The envisaged target for the IDWSS decade in Sri Lanka was to construct 16,000 tube wells to provide adequate safe drinking water for the rural population. However, due to the unsettled situation in the country coupled with lack of funding have resulted in a shortfall of 4000 tube wells by the end of the decade. It is hoped that the target could be achieved by 1995 if funding is granted by the Government of Sri Lanka and International donors to cover the spiralling cost of constructing tube wells.

This paper proposes a novel approach to supplement the shortfall in the tube well programme by introducing rainwater catchment through roof run-off. Having an annual rainfall of more than 1000mm in the dry zone, Sri Lanka's potential for success in this approach seems positive. This approach if proves to be a success would save time of the peasants otherwise used in fetching drinking water from distant places. The time thus saved could be utilized in more productive occupations like paddy coutivation or animal husbandry. Collection of rain water will be either in jars (2-3m^3) or in small tanks which ever the cheapest and preferable in the area. Approximately, it is estimated that cost of a jar of 2m^3 is 3% of the cost of constructing a tube well. At the existing cost estimates even if the state gives a jar free of cost to every beneficiary household in a tube well community, the state can save upto 30% of cost of constructing a tube well. With a drinking water requirement of 5 liters per day per person a jar can supply drinking water for 60 days for a family of five. With an additional jar a family can store sufficient drinking water for almost half the year. The implementation of the project will seriously take note of the social aspects of drinking water specially from roof run-off. Project anticipates to conduct classes to women in the community to educate them and eliminate any myth about drinking water off roof catchments and having safe drinking water. The men will be trained in for

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jar/tank construction with the help of the National Water Supply and Drainage Board.

With the current 20% rejection of tube wells due to salinity and high Iron content, this novel approach to supplement drinking water to the rural poor is bound to be a success in the future.

INTRODUCTION

In the welfare-oriented policy package implemented in Sri Lanka over the past four decades, housing, water and sanitation received low priority till the end of ninteen seventies. The adverse consequence of this legacy is reflected in the situation pertaining to safe drinking water and sanitation even at the end of the United Nations proposed International Drinking Water and Sanitation Decade, which officially ends by year 1990.

At the current state of progress, it is unlikely that Sri Lanka will achieve the decade targets even by end of 1995 (the terminal year of Sri Lanka's International Drinking Water and Sanitation Decade). Although initial estimates showed that Sri Lanka could realize 100% coverage in urban water supply and sanitation, the task has become complicated due to institutional and economic factors, due to, problems such as revenue collection and inadequate operation and maintenance capacity. The situation in the rural sector is worse. Only 7% of the population is served with pipe water in 1990 leaving a gap of 8% of the population to be served with pipe water supply to achieve an estimated target of 15% of the rural people by end of 1995 (Public Investment Programme 1989-1993). The quality of supplies provided also fall below accepted standards due to poor operation and maintenance practices. Further, 60% of the rural people are served with protected wells leaving a margin of 25% to be covered by 1995. This leaves an almost 33% of the rural population without any form of safe drinking water by the end of 1990.

At the same time nearly 35% of the rural population has no toilet facilities. Since the affordability levels of these communities are very low, the task of providing them with safe water and sanitation facilities, though vital is very complicated.

If government of Sri Lanka hope to achieve the decade target of supplying water to the rural population at least by 1995, it has to invest approximately 474 millions per annum. This is substantially higher than investments in previous years. It is also much higher than capital investment allocation included in the five year public investment programme of 1988 to 1991. However, its evident that if past levels of performance are used as a basis for assessing the scope for attaining decade objectives, it will take over twenty years for decade targets to be achieved in the rural and estate sector.

As a consequence, it is useful to explore other less expensive technologies that would provide the rural population with safe and adequate drinking water. Development of rainwater catchment systems is one such option available to supplement rural drinking water requirements.

Rainwater Collection

Historically, rainwater collection dates back to 2000 BC. The Israelis in Negev Desert collected rainwater for agricultural and domestic purposes. Rainwater collection from roof catchments was common in Southern Europe in Phoenician, Carthaginian and early Roman times.

Today the collection of rainwater from roof catchments, for domestic use is widely practised, specially in the developing countries. In the developed world this system is mainly restricted to the rural areas where other sources of water are either saline or polluted.

In Europe and Northe America catchment systems slowly dwindled as more expensive piped supplies have replaced the remaining rainwater cisterns. However, in Australia these systems still exist in remote farmsteads where the settlement density is too low for the pipe water supply to be economical (Latham and Gould, 1986).

In developing countries like Kenya, Thailand, Indonesia, Malaysia and Zimbabwe rainwater catchment systems have become very popular mainly due to poor quality of ground water and the distants users have to travel to collect water for domestic use.

The rapid expansion of this technology in many rural areas of the developing world could be attributed mainly to the transition from thatched roofs to clay tile, and corrugated iron roofs.

Roof Catchment Systems

In Sri Lanka, this technology had been in use in many rural areas, specially in the water scarce areas of Anuradhapura and Hambantota. Though not in organized manner and unlike in other developing countries, the Sri Lankan village folks have realized the value of this scarce resources and developed their own indigeneous rainwater collection systems.

Villagers in Mihintale (North Western Province) have used leaves of Royal Palm Borassus Habellifer tied upwards (like a funnel) to open ended gutters during heavy rains to collect rainwater. In Ampara, (Eastern Province), villagers have used the tarpaulin sheet catchment technique during rain to collect water.

In Tissamaharama in the Hambantota district (Southern Province) many of the old Irrigation Department Quarters had underground sumps built to collect rainwater. Besides these examples, many tea plantation bungalows in Nuwara Eliya (Central Province) have built surface concrete tanks to store rainwater for domestic purpose.

For domestic water supplies (drinking, cooking and bathing) the most common type of rainwater catchment system for individual household use is the roof catchment. The advantages of using a roof as a catchment area are: (a) The chances of contamination are much less compared to a ground catchment because the roofs are less accessible to animals and human beings. (b) Roofs provide an inexpensive impervious collector surface without any additional cost. (c) Because the roofs are elevated, they permit either above or sub-surface storage systems.

The best use of roof catchment can be seen in the US Virgin Islands in the Caribbean and in North-East Thailand. In the former case a well organized community-oriented multi-user water supply scheme is in operation while in the latter case a planned individual household water supply programme is in operation.

Objectives of the Pilot Project

The overall objective of the pilot project is to introduce an organized system of rainwater harvesting to Sri Lanka.

In realizing the major objective the proposed pilot project intends to achieve the following specific objectives.

a) To study the efficiency of existing rainwater catchment in Sri Lanka
b) To determine the appropriateness of the rainwater catchment technology.
c) To identify areas and appropriate hardware that suits local condition.

The project anticipates to conduct a research programme for a period of one year (two seasons). The research programme will commence after implementing the hardware component of the project, which is mainly to develop an appropriate storage system.

During the past decade more research and applied experimentation was diverted towards the development of a cheap robust and easy to build rainwater tanks design. Unfortunately this pre-occupation with the hardware side of rainwater catchment systems led to insufficient attention being paid to the software side of project implementation. The software side includes promotion of community awareness, motivation, organization, skill and resource generation. Thus, it was realized in isolation excellent hardware alone is insufficient to ensure a clean reliable and a well-maintained long term water supply.

The research component of the pilot project will attempt to monitor the changes in community, attitudes, behaviour and practices with regards to rainwater collection from roof run-offs and using it as drinking water. The research will also monitor the level of community participation both in construction and maintenance. Finally it is anticipated to assess the efficiency of the project at the end of one calender year by comparing the base (pre-project) situation.

Design

The main hardware component of the rainwater catchment system is the storage tank. Thus, there are many designs used all over the world to construct storage tanks. The most notable designs of storage tanks vary from Thai ferrocement jumbo jar to bamboocement tanks of Indonesia. However, the type of the storage tank is entirely location or country specific thus, there is no universally ideal storage tank for this purpose.

What would be appropriate to Sri Lankan conditions are either the Thai type jumbo jar of 200-3000 litre capacity or an rectangular underground tank of similar size. In the case of the underground tank a portable Chinese made hand pump can be used to draw out water. In the jumbo jar water can be taken on demand from a tap fitted at the bottom of the jar. An important component usually ignored at the design stage is the gutters. In developing rainwater catchment system elsewhere in the world very little concern has been shown for gutters. Usually, guttering is left to the houseowner and its not incorporated in the project. The result is that the gutters are poor, leaking or inadequate thus valuable water is wasted. Specially in low rainfed areas collecting all the rain available is crucial to deliver the benefits of the system.

Construction

Construction of both jumbo jar or the underground tank will be done at site. However, construction of the jumbo jar is more complicated than the rectangular underground tank. Therefore it would be necessary to field test the jumbo jar before its approved for large scale production. On the other hand the rectangular underground tank could be constructed by the community with minimum technical guidance.

Though the jumbo jar system costs much less than the tank system, the former is much more complicated in construction. Therefore it would take a long time before the technique is mastered in the jar construction. (Table 1)

Table 1:

Construction Cost/Unit (Rupees)*	Jumbo Jar System	Underground Tank System
Cement 3 bags	600	600
Reinforcement wire	800	-
Calvanised cover	200	600
Bricks and sand	100	900
Metal dust	200	200
PVC Gutters 04 Nos	800	800
Down pipes 02 Nos	400	400
Terminal cups 04 Nos	80	80
Cutter Boxes 02 Nos	50	50
"T" joints 01 Nos	50	50
Hooks 48 Nos	480	480
Clips 05 Nos	25	25
Joints 02 Nos	20	20
Portable hand pumps (8B 95)	-	2100
Labour - through community	-	-
Sub Total	3805	6305
Contingencies	380	630
Total	4185	6935

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*Sri Lankan Ruppes 40 = US 4 1

METHODOLOGY

a. Implementation Stage

The proposed project will be pilot tested in an "Udagam village" (Village Reawakening Programme) in Anuradhapura district (North Western Province-dry zone). An "Udagam village" has been selected because tile roofs are an essential component in collecting rainwater. Further it would be easier and appropriate to fix gutters to tile roofs than to palm thatched roofs.

At the planning stage of the project, the researchers will visit an "Udagam village" and conduct a need assessment survey to assess the necessity for drinking water specially in the dry season. The target group for this exercise would be householders of the selected "Udagam village". If majority of the householders respond positively, that particular village will be considered for implementing the pilot project. If the need for drinking water is not a problem during the dry season the researchers would select another village to conduct the need assessment survey. In this way the actual implementation of the project will be done only where there is an acute need for drinking water.

As this is going to be a novel approach in Sri Lanka to supplement drinking water through roof run-off a thorough training will have to be given to the recipients. Once the final selections are done on the village, the researchers will embark on a comprehensive training-cumdemonstration approach to enlighten the recipients of the benefits of the new system. Fog this approach the researchers will adopt a four point training programme. This will include:

a) Maintaining quality of rainwater.
b) Domestic use of rainwater and personal hygine.
c) Water quality testing.
d) Jumbo jar/tank construction.

DEMONSTRATION ON KEEPING QUALITY OF RAINWATER

There is a popular belief among village people that quality of water gets better when exposed to sunlight. The effect of sunlight as a biological contaminant and keeping quality of water in properly secured containers will be demonstrated to the villagers before the commencement of the project. It is expected to demonstrate this through simple experiment using homebased equipments.

DOMESTIC USE OF RAINWATER AND PERSONAL HYGINE

This aspect will be conducted through a series of training classes specially for women folks in the household. It is believed that rainwater is mostly free of impurities thus, drinking rainwater can reduce the incidence of waterborne diseases.

WATER QUALITY TESTING

It is proposed to test the quality of rainwater periodically at least for the first year to examine the rate of contamination (if at all). It is hoped to conduct water quality testing in collaboration with CISIR* or Gannoruwa Agricultural Research Station.

COMMUNITY TRAINING OF JUMBO JAR/TANK CONSTRUCTION

Training on construction will be handled by personnel competent in the field of civil engineering. It is hoped to train all the male members of householders in construction and installation of jumbo jar/tank. If the entire male community in the village is too large to train at once, 5-10 villager leaders will be trained as "village technicians". In return, these village technicians are expected to train all other adult males in the village on construction of rainwater cistern systems.

For the purpose of training it is hoped to seek the assistance of National Water Supply and Drainage Board (NWSDB) or from the Department of Civil Engineering, University of Moratuwa. While the jar constructions are conducted on site, arrangements would be made to lab test the jumbo jar for its mortar strength at the Department of Civil Engineering, University of Moratuwa.

The main feature of the methodology is the participation of the village community right from planning stage. At all stages of implementation community participation would be given highest priority. The project does not envisage to hire the services of contractors in the jar/tank constructions. Past experience from Kenya and Thailand have shown that hiring contractors have led to total failures in similar projects. When the community is involved from the planning stage it becomes much easier for subsequent operations and maintenance.

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b. Assessment Stage

To assess the impact of the project an evaluation will be done at the end of the first year. The impact assessment will be carried out using multiple methodologies to portray and capture effectively the dynamics of the total impact within its physical, human and social context. The methodologies to be used for the impact assessment will be:-

a) administration of questionnaires to household heads and house wives.
b) informal discussions with community leaders and health officials of the area.
c) randomly carried out participant observations.

ASSESSMENT INDICATORS

The following indicators will be used in assessing the impact of the project.

a) Distance travelled to collect domestic water.
b) Incidence of diarrhoeal or other waterborne diseases.
c) Use of opportunity time in other useful activity.
d) Number of persons seeking OPD (Outdoor Patients Department) treatment due to waterborne diseases.
e) School attendance during peak dry season.

JUSTIFICATION

Analysing 37 years of rainfall data for Anuradhapura* shows that the driest months are from May to September where the average monthly rainfall varies between 300mm to 1875mm. During this period rural people have to walk long distances to fetch domestic water. This burden has been partly rectified with the introduction of the tube well programme. However, the tube well programme has not been the sole answer to the domestic water problem in the rural areas. A recent survey carried out by the author in four dry zone districts of Sri Lanka suggest that majority of rural people prefer using well water for domestic use than using tube wells water. With a tube well density of 120 persons per tube well and an overall rejection rate

*Anuradhapura is one of the main agricultural districts in the dry zone receiving less than 1875mm of rain annually. Dry zone in Sri Lanka is classified as areas receiving less than 1875mm annual rainfalls.

of 20% due to ferrous contamination in water, this programme has fallen short of its expectations. Another significant reason for the failure of this programmes in some parts of the country is due to certain tube wells having insignificant water yields. The accepted standard yield of a tube well is 10 liters/minute. However there are tube wells with yields as low as 0.1 litre/minute. Such wells have served no purpose to the community it is intended. Another problem in the dry zone is drying up of tube wells. Drying up of tube wells is a result of ground water table depletion due to indiscriminate ground water exploitation, specially through deep tube wells. This could eventually make the entire dry zone a desert. Similar situations have occured in certain parts of Tamil Nadu where large number of agro-wells exploit ground water. Tunis in North Africa is another example where indiscriminate ground water exploitation for agricultural purposes is depleting the ground water table at a rate of ½-1 meter annually. The result of all this is the rural people still have to walk long distances for their domestic water or have to spend long hours quequing up at common tube well posts to collect water.

The following calculation illustrates the potential for collecting rainwater during the wet period in Anuradhapura (October to April).

Average rainfall during the wet period (Oct-April in Anuradhapura district) = 1052mm

Volume of rainfall that can be collected on an effective roof area of $46m^2$ = $46m^2$ x 1052mm = 48,392 litres

Considering a waster factor of 0.2 (20%) the actual amount that can be collected = 48,392 x 0.8 = 38,714 litres

Number of days required to consume 38,714 litres for a family of five (considering an average of 5 litres/person/day) = $\frac{38,714}{5 \times 5}$=1548days

Considering an average domestic requirement of 135 litres/person/day in the rural areas, the collected water over the wet period would last 2.0 months according to the following calculation.

For a family of 5 at an average of 135/litres/ person/day = $\frac{38,714}{135x5}$=57days
= 2.0 months

The foregoing calculation shows the potential for rainwater collection provided adequate storage facilities area available.

The proposed jumbo jar or the underground tank would contain to a maximum of 3000 litres (666 gallons) which could last for 120days for a family of five if used only for drinking purposes. If the same quantity of water is used for domestic purposes it will last for only 22 days based on the assumption that each household has only one jar/tank. The amount of water that can be collected with be more, depending on the number of storage tanks one can afford.

With regards to costs, the construction of an individual rainwater catchment system is just 0.5% of constructing a tube well. The current cost of installing a tube well is approximately Rs. 83,440 as against Rs. 4,075 for an individual rainwater catchment system. A tube well on the average serves a population of 120 persons. Thus it would appear that tube wells are more cost-effective. However, considering the present rejection rate of 20% due to high iron contamination, low water yields and drying of tube wells, rainwater catchment systems can be socially more profitable and cost-effective in the long run.

WATER QUALITY

Sri Lanka's major problem is not access to water per-se but access to safe drinking water. According to health statistics there had been no significant decline in morbidity. Hospital records indicate that diarrhoea continues to be the main cause of morbidity and child mortality. More than 10% of the admissions to children's hospitals are due to intestinal infections caused by water-borne disease like Shigelia-dysentery.

It is unfortunate that even the National Programme for diarrheal diseases control planned in 1982 under the active support of UNICEF and WHO had emphasised more on curing the disease through oral rehydration therapy (ORT) than prevention of occuring diarrhoea. Though improving water supply services and infrastructural development with regards to laterines have been mentioned in the UNICEF/WHO project, the weightage given to these aspects are minimal compared to the oral rehydration therapy.

The recent outbreak of diarrhoea in the dry zone is a classic example of inadequate sanitary facilities and consuming contaminated river water. An approach such as using rainwater for drinking purposes would have easily prevented the outbreak of diarrhoea to epidemic proportions, even with sub standard sanitary facilities.

The worst period for water-borne disease is the driest months of July and August. Even school attendance have shown a marked decline during the two months due to diarrhoeal diseases. The main cause of diarrhoeal diseases is drinking contaminated water from small water bodies that exist during the dry seasons. This has been adequately proven in the dry zone where chena (slash and burn) cultivation is prevalent. Chena farmers do not have access to safe drinking water, specially during the dry season. They have to consume more water during the dry season, and have no alternative other than to depend on available polluted water in "ara" wells* in the jungles. This habit of drinking polluted water is one of the major factors for the increase of diarrhoea among adult males during the dry season.

Most of the water-borne disease like diarrhoea, Hookworm, Roundworm and Infective Hepatitis can be minimised if rural people adopt drinking rainwater. As such rainwater is considered pure devoid of many infectious microbes and if the collection containers can be regularly cleaned and properly secured preventing sunlight falling into the container, rainwater can be used for a long time without any fear of contacting diarrhoea or any other water-borne diseases.

Expected Outcome of the Project

At the end of the first year, it is envisaged that people of the selected "Udagam village" would have changed their attitude towards drinking stored rainwater. Hopefully, people would be using rainwater for domestic purposes from their own storage tanks. Thus saving valuable time which otherwise would have been spent on fetching domestic water from distant places.

It is expected that the adult males of the village would be adequately trained and experienced in jar/tank construction. Therefore, they would be in a position to help their neighbouring villagers if they too opt for the same approach.

*Naturally occuring small jungle water ways.

By drinking rainwater it is hoped that incidence of diarrhoea and other water-borne disease would decrease and overall health conditions of children in particular would improve.

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RAIN WATER CONSERVATION IN ZAMBIA

HENRY CHIRWA*

ABSTRACT

The Aim of the paper is to assess the need of rain water conservation for Agricultural purposes in Zambia. The paper also looks at the means and ways of rain water harvesting in the Country.

Rain water in Zambia is wholly restricted to the rainy season which is between the months of October and April.

The Eastern and Southern Parts of the Country are most of the year dry with very few perrenial rivers. This has affected Agricultural Development. Hence the other objective of the paper is to examine the drought relief programme introduced in these areas. The paper also looks at whether or not Dam construction which forms a major portion of the programme has been effective. The paper analysis other ways of rain water conservation if they could be good alternatives to the dam construction.

PREAMBLE

Rain Water Harvesting in Zambia has been greatly affected by the nature of climate the country has.

Zambia is a country of contrasting climatic conditions. More than 95% of the precipitation occurs during the period October through May. In the Northern part of the country the precipitation sometimes reaches 1,400 to 1,600 mm per year. In the Southern Province, however the average precipitation is in the range of 750 to 850mm per year with the central province having an average precipitation per year of the range 850-1,300mm. Table 1.1 show the average monthly precipitation and the average monthly mean temperatures (1950-80) of Choma and Kasama respectively. Choma 1,267mm above sea level is located in the southern part of the country and Kasama (1,300mm above sea level) is located in the northern province.

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Table 1.1 MONTHLY MEAN RAINFALL AND MEAN TEMPERATURE (CHOMA AND KASAMA AVERAGE BETWEEN 1950-80)

Month	Town	Mean/Rainfall	Mean/Temperature (^0C)
Jan	Choma	210	21.6
	Kasama	280	19.8
Feb	Choma	180	21.1
	Kasama	233	19.9
March	Choma	90	21.0
	Kasama	245	20.1
April	Choma	30	19.2
	Kasama	70	20.3
May	Choma	8	16.7
	Kasama	9	18.8
June	Choma	0	15.8
	Kasama	1	17.1
July	Choma	0	14.0
	Kasama	1	16.9
Aug	Choma	0	15.5
	Kasama	0	18.8
Sept	Choma	2	22.1
	Kasama	2	21.6
Oct	Choma	20	21.8
	Kasama	23	23.4
Nov	Choma	120	21.7
	Kasama	149	21.7
Dec	Choma	200	
	Kasama	226	20.1
Annual	Choma	860	17.5
	Kasama	1279	19.8

Fig.1.0 is a map showing the average annual precipitation distribution throughout the country. From this map it can be clearly seen that the precipitation in the country decreases from the north to the south, and that the southern part of the country is more likely to be subjected to drought effects than in the northern part.

Fig.1.0 DISTRIBUTION OF ANNUAL RAINFALL

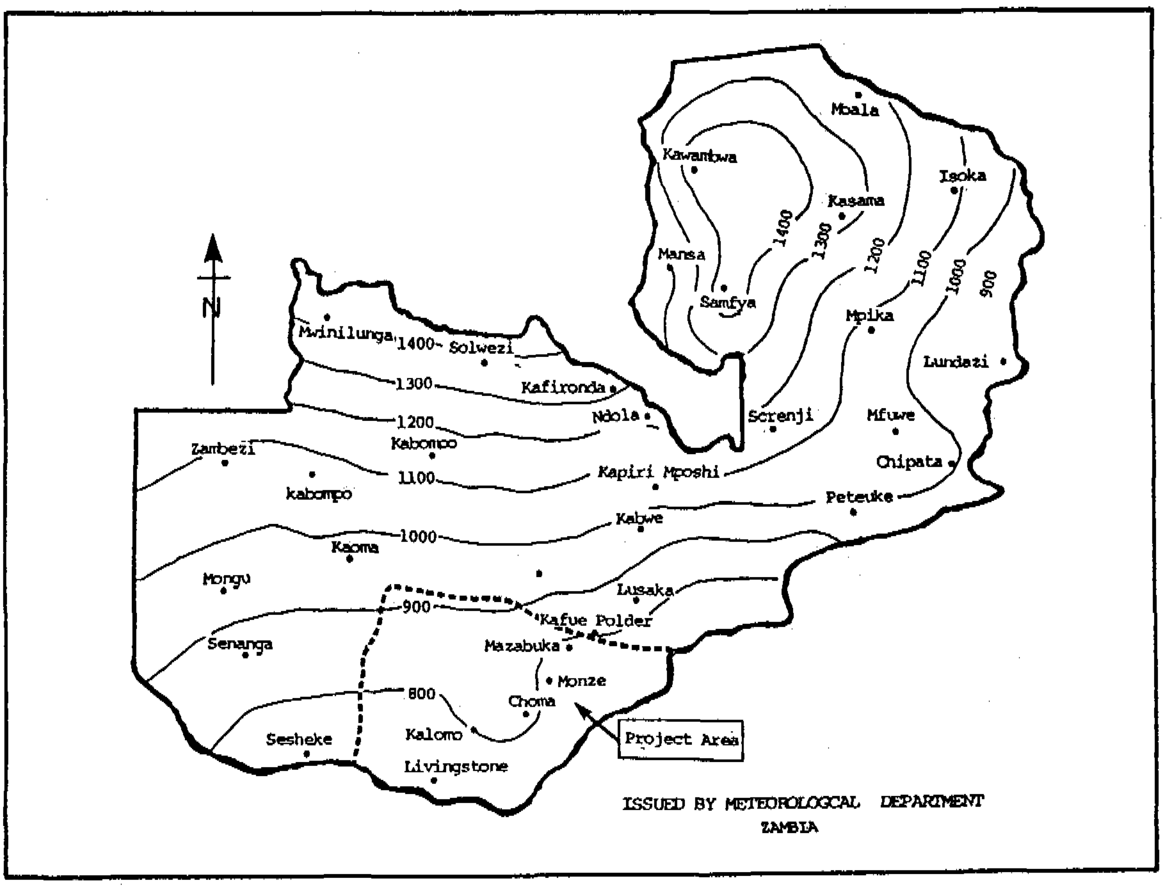

Table 1.2 shows the annual precipitation recorded in the Southern Province. From the table and the figure, it is evident that the recent annual precipitation has been less than the average annual precipitation of the 30 year period from 1950 through 1980.

Table 1.2: ANNUAL RAINFALL IN SOUTHERN PROVINCE

YEAR/STATION	LIVINGSTONE	CHOMA	MAGOYE	KAFUE POIDER
1980/81	953.0mm	918.0mm	890.0mm	1047.0mm
81/82	430.0	556.0	615.0	817.0
82/83	787.0	628.0	629.0	549.0
83/84	436.0	539.0	589.0	500.0
84/85	603.0	827.5	748.6	639.0
85/86	641.7	1047.7	721.9	768.5
86/87	503.2	711.9	682.3	643.4

2. SUMMARY OF OBSERVATIONS

Since Zambia is in the region of wet and dry tropical climate with 4.5 to 7 humid 7.5 to 5 arid months, climate has a great and important effect on the availability of water resources for both domestic and Agricultural Development especially in the Southern part of the country.

2.1 AVAILABILITY OF WATER DURING RAIN PERIOD (OCTOBER-APRIL)

- Being in the tropics this is the time during which Zambia receives all its rains.
- It is calculated that on average Zambia receives between 5.6175×10^{11} and 1.0486×10^{12} cubic meters of water. And about seventy percent of this amount flows away to the Indian and Atlantic Oceans.

Table 2.1 SUMMARY OF RAIN WATER USE IN ZAMBIA

Average Total Rain Water Per year(M^3)	Used for Agriculture Domestic	Reserves Ground and Surface (M^3)	Wasted (M^3)
8.05175×10^{11}	0.805175×10^{11}	1.61035×10^{11}	5.64×10^{11}

- Availability of water during rain season in wholly dependant on rainfall for both Agriculture and Domestic uses.

- Twenty percent goes to the ground reserves and or surface reserves and only ten percent is put to crop and domestic use in a season.

2.2 AVAILABILITY OF WATER DURING DRY SEASON

- During the dry season availability of water is very critical in the country. It becomes worse as you move from north to south.
- In the Southern part of the country for instance, during the months of July to October when most of the streams have dried up there is a great water starvation for both people and animals. people and animals have to track long dist-ances in search of water.
  On average women cover distances of at least ten(10) kilometers to collect drinking water. It is worse for animals as they have to cover kilometers for water.
- In the South ninety seven percent of the steams and rivers are seasonal while in the Eastern part it is ninety-eight percent. The Northern part has three percent seasonal streams.

CONSEQUENCES OF DRY SEASON

- The death rate of cattle in the southern province increases from three (3) percent in the rain season to twelve percent in the dry season.
- Very little Agricultural Production takes place in the dry season and this is evidence by non existence of certain types of fresh crops like pumpkins, fruits, green maize etc.
- There is very little food for animals (see picture 1,2 and 3) during dry season.
- There is a critical shortage of food in certain parts of the country and hence the Government has created a section dealing with Drought Relief in the Ministry of Agriculture.

2.3 DROUGHT RELIEF PROGRAMME

- Due to the problem experienced during the dry season especially hunger and thirst Drought relief programmes was started in 1987 as an emergency water supplies programme for southern part of the country.
- This programme was introduced because the southern part of

the country was badly hit by a severe drought in 1986/87 Agricultural season.

- Some areas did not receive a singly rain and so causing serious shortage of water for both human beings and animals.
- The Government asked for help from the Dutch Government, Canadian and U.S.A. Government. In panic as a result of no proper planning that season 90 water bouser where purchased positioned in villagers for emergency water supplies.
- This exercise was too expensive to operate and manage. The exercise was stopped and started a programme of rehabilitation of old dams and boreholes.

  The merits of this rehabilitation programme are that:
- Water from dam is used for domestic purposes.
- Land catchment areas are being protected from soil erosion.
- Once water is impounded it encourages ground water recharge.
- Used for irrigation and fish farming.

From 1988-1990 there have been 285 boreholes rehabilitated, 60 dams rehabilitated and 42 new dams have been constructed.

- This programme is community based.
- However, this programme has not been successful so far because of lack of plans. It was initiated without any prior planning and as such it has been discovered that;
- There is no staff to run the programme.
- It is very expensive as the Government can not afford such a big community based programme.
- People have not understood it and as a result they don't take part.

2.4 DAM CONSTRUCTION

- As stated earlier this has formed a major component of the Drought relief programme of the dry southern part of the country.
- However Dam Construction came as a result of panic due to the drought which hit the country between 1980 and 1986 when in some places of the country there were not even a single drop of rain.
- The objectives of this programme were:
- To harvest rain water and trap it in the reservoirs.
- To collect run off from the areas surrounding dams and pond in the reservoirs for livestock.
- To use the impounded water for irrigation and so enhancing agricultural development.

- To caustion the drought situation which had hit the country.
- To recharge the underground water and rise the water table in the surrounding areas.
- To convert some of seasonal streams to perrenial ones.

But these objectives have not been achieved because there has not been any serious thought about the rain water conservation programme in the country. There is no section of the Government Machinery which deals with conservation of rain water. As such when the situation came that most streams dried and livestock and people were dying of hunger and related diseases there was panic for dam construction programme brought as a contingency measure.

- As a result the programme has so far failed because of the following:
- The programme is considered a political one and people consider it as such. It is a Government Programme.
- The 45 dams which have been constructed since 1987 only 2 have filled up so far, 23 are already silted up and the rest (20) have not filled and 10 of those 20 have already collapsed. This has been due to the fact that these dams were not planned and designed by skilled personnel. There was no qualified staff involved in the planning, designs and construction of the dams.
- It was thought that since the dams are earth dams' there would have been no need for qualified staff to take part. And this assertion has contributed to many programmes failing.

2.5 REHABILITATION OF BORE HOLES

The characteristics of geology and aquifeus distributed in the southern part of Zambia are shown in Table 2.2

The Table shows the water table in each rock stratum, the thickness of each weathered rock stratum and ground water pumping rates based on data of the bore holes constructed by the Department of Water Affairs during the 1975-84 periled in the southern part of Zambia.

- From the table one may understand that the major aquifers are the fissure zones of the base rocks that are located further below the weathered rock strata.

Table 2.2 GROUND WATER CONDITION IN RESPECTIVE LITHOLOGY IN THE SOUTHERN PART

Lithology	Drilled Depth (M)	Static Water Level (M)	Thickness of Weathered Zone (M)	Aquifer Depth Upper Limit (M)	Aquifer Depth Major Part (M)	Pumping Rate per Borehole (L/MIN)
Geneiss	46	15	14	25	38	70.4
Schist	51	16	15	29	41	74.6
Granite	53	14	26	23	34	58.0
Basic Rock	51	17	26	27	33	45.0
Quartzite	34	14	13	20	28	144.0
Calucious Rock	49	13	25	25	31	112.8
Basaltic Lava	46	26	20	14	42	156.0
Sedimentary Rock	55	16	26	25	46	142.5
Alluvial Strata	40	19	-	25	28	60.0

The static water levels, except in basalt are at about 15m from the ground surface. From this fact it is appropriate to judge that ground water exists even in the weathered rock strata. As a matter of fact, groundwater in the weathered rock strata is obtained from hand excavated wells that are about 10m deep.

- Table 2.3 shows groundwater pumping rate from each rock stratum. since the pumping rates of the hand pumps which are and will be installed in wells for the rural water supply are at most 15 L/MIN.

  their pumping water levels do not exceed 18m from the ground surface.

Table 2.4 SUMMARY OF GROUNDWATER CONDITION IN THE SOUTHERN PART (AVERAGE 51 BOREHOLES)

Borehole Depth (M)	Static Water Level (M)	Pumping Rate (M^3/day)	Specific Capacity (M^3/day/M)	Pumping Water Level (30 L/MIN (M)
60	16	216	18.9	18.6

- However this programme has not also been successful because at the most pumps operate for 2 years. After that most of the times seals are worn out, some parts of pumps are broken and the equipment are rendered non operational. This is profoundly because users don't participate in the initiation and implementation of projects.

3. CONCLUSION AND RECOMMENDATIONS

3.1 It is already shown that southern parts of Zambia do experience critical water shortage during dry season. Most streams and rivers run dry.

One also concludes that most of the rain water is just wasted and if this water was conserved then it would alleviate the problems which occur during the dry season. The Government of Republic of Zambia has not paid enough attention to the programme of rainwater conservation, the Government only realized after the heavy droughts which hit the country in the 1980s. Due to the fact that the programme was initiated in such a hurry and the resulting panic , no plans were done. There was no proper coordination of the drought relief programme which was in a way an attempt to conserve rainwater. As such dam construction programme has had ninety percent failure and borehole programme has also failed due to non availability of spareparts.

The programmes have also failed because of non participation of recipients. Villagers never got involved, they were only asked to use the facilities which resulted in not caring for the facilities. There were no people to run and maintain these facilities as a result after sometime they just got run down.

3.2 RECOMMENDATION

It is a well known fact that modern water supply without pumps or pipes is possible and I recommend, that this should be the fact to be exploited. Since the broad based programme has failed I recommend that emphasis now should be put on family based programmes and this should involve the exploitation of less complicated catchment systems. The systems which are capable of supplying water to the house or for livestock and development of agriculture but need no fuel, no sparepart and very little skill. The systems which save family's money and the country's foreign exchange. Systems which do not permit the breeding and spreading of diseases associated with rural water supply.

3.2.1 DOMESTIC WATER SUPPLY

For an average rural Zambian family of 8 persons a roof catchment is the most suited. It has been found out in Kenya that from a roof of ordinary size in a dry region you can collect 37 tonnes of clean water in an average year. That is rain water collected from the roof to a tank and then it is drawn from there. If more water is required for domestic use the roof can be extended and or a rock catchment can be included. In areas of mountains, like the Gwembe Valley, it is possible to catch rain water from these structures. It can be done either from the mountain or water can be fed to a storage tank situated nearer the house. And for livestock and fish farming, water can be collected from the compound surrounding or roads leading to your house. It has also been found out that if your attach ment area is well sloped and hard surfaced you can collected by ditch to the tank in the ground. depending on the slope, the water can be used for irrigation.

For Zambia condition, I also recommend hand dug wells using chain and bucket.
The advantage of these catchment systems is that people can do them themselves with minimum cost and supervision.

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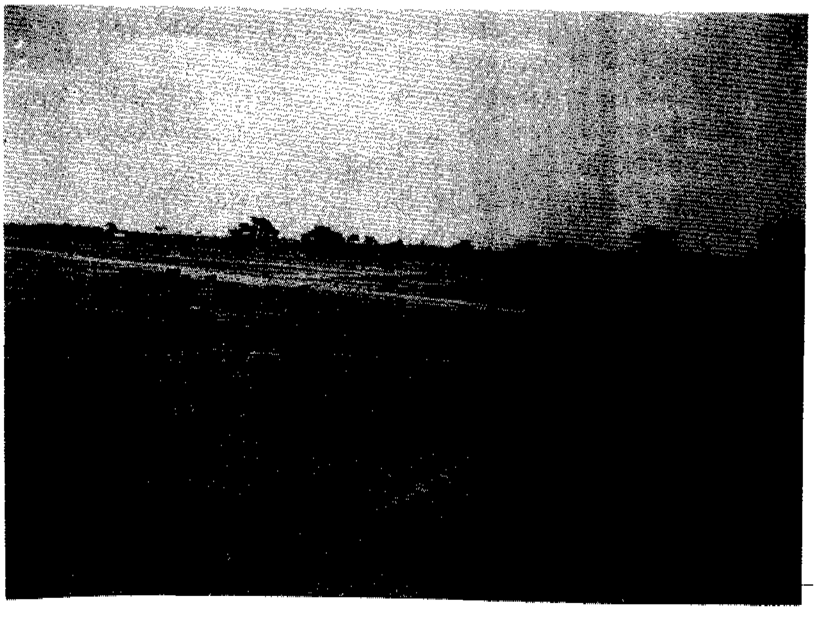
PHOTO 1

TYPICAL
RANCHI IN
SOUTHERN ZAMBIA
DURING DRY
SEASON



TYPICAL
STREAM BED IN DRY
SEASON IN
SOUTHERN ZAMBIA

PHOTO 3
SEASONAL STREAM
IN GWEMBE
(SOUTHERN ZAMBIA)

UTILIZATION OF RAIN WATER IN TANZANIA

Datius G. Rutashobya*

ABSTRACT

Rain water has been in use in Tanzania for ages, but not as a significant source of rural or urban water supply. Being a poor developing country, it is faced with a number of problems which renders services like water supply difficult to achieve satisfactorily.

This paper looks at roof top rain water harvesting as a relatively cheap and appropriate technology that can either solve water scarcity problems or at least reduce them in Tanzania. It traces the historical background of rain water harvesting in Tanzania and points out why the method has or hasn't been adapted in different parts of the country. It looks at the present situation in Tanzania as pertaining to the availability of water for various uses, both in the rural and urban areas. It further highlights on the research efforts being currently undertaken in the country in the area of rain water catchment. The paper attempts to justify the need of popularising the utilization of rain water in Tanzania, in order to supplement the conventional water supply endeavours by the government.

Finally, the paper points out the problems that have rendered the technology unpopular in some parts of the country and why it is not widespread as a major water source.

Chapter 1 : INTRODUCTION

1.1 Background Information

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Tanzania lying between latitudes 1°S and 12°S and longitudes 29°E and 42°E, is a tropical country on the East African coast, occupying an area of 937,062 km^2. It has an equatorial and sub-equatorial climate, modified by elevation. Mean temperature varies, ranging from below 20°C to above 30°C. Annual rainfall lies between 500 mm and 700 mm, but there are areas which receive below 400 mm and those with over 2,000 mm. The national population is about 25 million people , about half of which is under 15 years of age. The average life expectancy is 53 years. Over 60% of the total population, which is predominantly rural, is concentrated in less than 20% of the total land area.

Tanzania is counted among the least developed countries in the world and has a per capita income of US $ 270, derived from mainly agricultural production.

1.2 Historical Background of Rainwater Harvesting in Tanzania

In Tanzania, the practice of harvesting rain water for various uses has been in existence for many years, though in its rudimentary form. However, it has not developed to be a potentially usefull tool in the development and management of water resources. Water authorities, including international donors involved in water development, have not favoured this technology but have, instead, mostly applied sophisticated machineries to develop both surface and underground waters.

Nevertheless, rainwater has been put into use in different parts of Tanzania by individuals, single households, a collection of households, and institutions like missionary centres, schools and hospitals.

The degree of use of rain water has always been uneven in the country due to a number of reasons. Firstly as mentioned in chapter one, the annual rainfall varies from location to location, so that areas with higher rainfall amounts have had the tendency to harvest more rain water than those with less rainfall. Hence, whereas rainwater is harvested in the northern, southern, southwestern and coastal areas of Tanzania, it is rarely harvested in the dry central areas of the country. Secondly the types of roofs, from where the rainwater is mostly harvested, has always had an influence on the practice. Households with corrugated iron sheet roofs do practice rainwater harvesting, whereas those with thatched roofs don't. Thirdly, in the past years, institutions like missionary centres, hospitals and schools were not evenly distributed in the country, such that areas with such institutions were the ones where rainwater catchment was practiced. Some tribes in the country don't like to use rainwater for various reasons, mostly hinged on beliefs.

With development , both socially and economically, spreading throughout the country, people building better houses ,more schools, hospitals, missionary centres spreading in every corner of the country, rainwater harvesting is gaining more and more popularity, even though at a slow pace.

Chapter 2 : PRESENT SITUATION IN THE COUNTRY

The situation of water availability for domestic, industrial and other uses in Tanzania is presently not satisfactory. Most urban areas are experiencing water shortage problems arising from either old and/or mulfunctioning water supply systems or higher water demand due to the higher urban population and industrialization. Unemployment in the rural areas has resulted into rural-urban migration which is currently estimated at 6 per cent. According to the Bureau of Statistics, Tanzania has the highest urban population growth in Africa. The population, both rural and urban, has outgrown the infrastructural and social expansion. Services like transportation, communication, education, health, sewerage, power, water supply and many more are deteoriorating with time, due to the rising demand , that the government cannot afford to meet. To cite an example the daily water demand for the city of Dar es Salaam stands at 86 million gallons per day but only 50 million gallons are supplied by the city's three water supply systems.

The rural population, alike, is experiencing the water shortage problem due to a number of reasons, among which are the higher rural population growth and the drying up of traditional sources due to deforestation and lack of care of those sources. Some sources have been depleted.

It is clearly evident that new and cheap water sources are necessary in Tanzania in order to arrest the present unfavourable water supply situation. One of such sources would be rainwater harvesting. Presently a research on "Rainwater Harvesting in Tanzania" is being conducted and the author of this paper is a Principal Researcher. The overriding objective of this research is to review the current knowledge, practices and attitudes with regard to rainwater harvesting techniques and systems in Tanzania with the aim of improving and popularising such techniques and methods. Specifically the research will dwell on the following aspects.

* Conducting a socio-cultural study of the nature and extent of rainwater collection and usage in two study areas in

Tanzania.
* assessing the economic viability of rainwater harvesting systems and methods in comparison with other small scale water supply schemes.
* reviewing the existing rainwater harvesting technologies and assessing their applicability to Tanzania.
* reviewing and assessing the water quality aspects related to longterm astorage of rainwater.
* establishing design criteria of three different rainwater harvesting techniques or methods which will be best suited for use in Tanzania.

On completion and conclusion of this research it is expected that the findings will form the basis for improving the existing rainwater catchment methods and popularising them where they are presently not used benefitably.

Chapter 3: NEED FOR RAIN WATER UTILIZATION IN TANZANIA

Far before the United Nations General Assembly declared, in 1980, the "International Drinking Water and Sanitation Decade, 1981-1990", Tanzania had, in 1970, launched a 20-year National Water Supply Programme which would ensure that by 1991 every Tanzanian would be supplied with clean and safe water within a walking distance of 400 meters from his residence. The overall objective of the programme was to bring about accelerated development by using water as an essential input. A lot of valuable time, particularly in the rural areas, is spent on walking long distances to fetch water; hence the time saved through walking a shorter distance would be devoted to , among others, socio-economic activities designed to improve the villagers' living conditions and standard.

The programme has experienced a number of crippling constraints such that the realization of the set target is now far below anticipation. There has been an acute shortage of technically trained personnel of various cadres needed to plan, survey, investigate, design , construct and operate and maintain water projects and schemes. In view of the vast area of the country, poor accessibility, lack of basic conveniences, the scattered nature of the water resources, absence of all-weather roads and inadequate posts and telecommunications networks, transportation of men and materials has been a staggering problem. Also disturbing has been a fact that the water from a large number of wells and boreholes has an undesirable high content of fluoride. Non-availability of construction materials has been a great snag. As mentioned earlier Tanzania is one of the least developed countries and like any other developing country, sensitive development programmes like health, water , agriculture, ect., have necessarily to compete with one another for funds which are scarce. Hence , the water programme has had to face a critical shortage of funds, particularly the foreign ones, which have been mostly derived from loans, aids and gift programmes of friendly countries.

A combination of all the above mentioned problems and constraints and those not mentioned has made it necessary to push the targeted year of achievement of the water supply Programme from 1991 to 2002. Moreover, the present water position in the country calls for a review of the programme with a view to provide water service through , among others, technologies which are simple, effective and beneficiary-participatory. One such technology is rainwater catchment systems. In Tanzania there are areas where open water surfaces like rivers, streams , lakes, etc. are bacteriologically polluted such that the only alternative for safe water is rainwater. Again there are areas whose nearest water sources are far away to the socio-economic disadvantage of the people fetching water. There are cases whereby people walk more than ten kilometers a day to and from the water sources. In Urban areas, sometimes, water systems fail due to ,among other things, operational and maintenance problems and , innevitably, some residents have to fall back to unsafe waters from polluted sources. With rainwater harvested and conserved through appropriate technology the consumer can be rescued from missing safe and reliable water.

Before it can be put into domestic and industrial uses surface water needs treatment. The way things are, conventional water treatment schemes are well suited to urban areas and mostly not suitable for rural areas. And , on account of the ever increasing water demands, particularly in urban areas, new water sources are needed to supplement the existing ones. Rainwater, if harvested in sufficient amounts and stored appropriately, could be used as a supplemental source of water for urban areas and as a major source for rural areas where rainfall is available in sufficient amounts.

Chapter 4 : CONSTRAINTS AND PROBLEMS

For many years now Tanzania's economy has been suffering unprecedented setbacks due to , among others, unfavourable world trade, oil price surges, unclement weather and regional/national upheavals. This state of affairs has caused problems in supplying sufficient water to the people, as already mentioned in the previous chapters.

As regards the utilization of rain water there are constraints that are socio-cultural in nature. Some of the more than one hundred tribes in the country have negative attitudes towards rainwater as a result of their traditional and cultural beliefs. Yet other tribes which would be willing to put rain water into maximum use don't have houses with roofs suited to proper rainwater catchment. The majority of houses in rural central Tanzania have thatched or earth roofs that are not useful for harvesting clean, hygienic rain water. And in those locations where rain is harvested, people have commonly insufficient storage facilities. The rain water is usually stored in small-capacity utensils like buckets, earthenware pots. calabashes and medium sized drums. As such the water so harvested is only enough for a day or two.

For the harvested rainwater, be it in small or large quantities we have a serious problem attributed to hygiene. You find very often that the utensils used to store the water are not kept clean. Alternatively, the stored water is rendered unhygienic by the tools and utensils used to draw water from the buckets, pots, drums etc. These practice are a result of lack of sufficient knowledge on hygiene, on the part of the rain water harvesters and users.

Chapter 5 : SUMMARY AND CONCLUSIONS

In chapter 3 an attempt has been made to ellaborate on the situation in Tanzania as regards the availability of water ,both in urban and rural areas, for various uses. It has been made evident that the situation is far below anticipation and desire. In chapter 4, efforts made by the government of Tanzania to effect water supply to her inahabitants, have been mentioned, together with the constraints rendering the different programmes to be only partly successful. And in chapter 5 it has been shown how various problems made it difficult for the people to utilize rainwater in sufficient amounts and in hygienic conditions.

It can be concluded, therefore, that rainwater harvesting systems, being a cheap and appropriate technology, stands as a useful potential and supplement to the conventional water supply systems in Tanzania, if the technology is popularised and some obstacles to its application ironed out. Rainwater utilization can therefore be a solution to water supply problems in various parts of Tanzania.

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RAINWATER CISTERN ITS USES IN NEPAL - PROBLEMS, PROSPECTS AND PROMOTION

Ajaya Dixit*, Shivajee Upadhyaya**

ABSTRACT

Experience of construction of few rain water cisterns in Nepal shows that the approach could be a viable water supply system in the country. The system has more relevance in settlements in ridges, spurs, river terraces and generally water critical pockets at different climatic zones. Of the several factors, cost of the storage tank appears to be the major constraint in the way of wider uses of the system. In order to make it attractive, storage system need to be built at lesser cost, when the system would be more affordable. Prototype of a tank that used plastic lining has been developed and is being installed in field situations, whose performances need to be evaluated. For wider promotion of the system, an action oriented approach is being pursued. The feed backs would be useful in further promotion of the rain water cistern system in the country.

Physical Setting

Nepal lies between the Tibetan plateau and the Gangetic plains along the southern belt of the Himalayas. The country's area stretches for 800 km along east west, while the average width along the north south is 140 km. For a country having such a small area, Nepal possesses spectacular landscape with rich biological diversity.

The topography is made of varied but distinct ecological zones; the Tarai, Churia and the Siwalik, the middle hills, and the northern Himalayan region. In the south, lies the Taral, an extension of the Gangetic plain, which has the elevation of 60 m to 200 m. Underlain by a fertile soil, the region is the country's breadbasket.

Adjacent to the Tarai, and in its north abruptly rises the Churia range or the Siwalik. At places, the ranges reach the

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altitude of 1800 m, but the elevations generally are between 300m to 500 m. Within this formation lie the fertile and heavily cultivated inner valleys like Chitwan and Surkhet. North of the Churia lies the Mahabharat mountains of rugged terrain that rise up to 3500 m. The region is characterized by high ranges, steep slopes and deep valleys cut by the mountainous rivers. It is within this ranges, valleys like Kathmandu and Pokhara are located. The middle mountain region is heavily populated where the villages are dispersed all over the slopes. At many places, more than 30 degrees slopes are cultivated using traditional methods. On the north lies the Himalayan range with elevation above 4000 m and occupies about 15% of the country's land area. The physical setting of the country is shown in Fig.1.

Climate Rainfall and Water

The physical setting has dominant influence on the country's climatic condition. In the southern Tarai, the summer is hot where the temperature reaches more than 40 degrees celcius. The northern Himalayan region is extremely cold and chilly. In the middle mountains, the winter is cold while the summer is warm.

Although, the country is under the dominance of the south west monsoon, rainfall is variable with respect to both space and time. About 80% of the mean annual rainfall of 1500 mm falls during the four monsoon months of June to September. Remaining rainfall occurs during winter months. In some of the northern regions, that are on the rain shadow of the Himalayas, rainfall is sparse. The rainfall at different selected stations of the country is summarized in Table 1.

Table 1: Mean Annual Rainfall at Selected Stations (1961-1980)

Station	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Surkhet	242	424	380	170	56	4	16	24	32	38	20	62	1468
Syangja	599	756	658	430	165	18	11	23	44	42	163	344	3153
Kathmandu	272	371	297	163	69	5	8	15	18	34	50	97	1399
Dhankuta	199	256	131	105	75	11	10	14	13	20	66	114	1014
Dipayal	168	372	279	46	8	3	27	14	33	109	44	107	1240
Jomsom	26	43	38	32	31	16	3	7	9	20	15	8	248

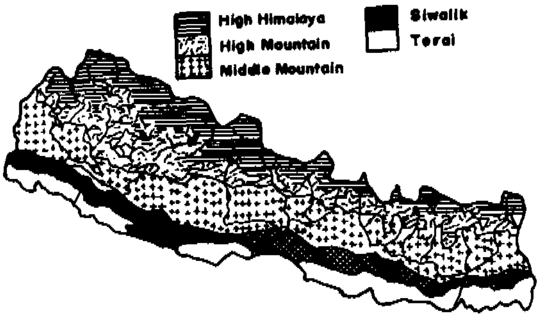

Fig.1: Physical setting of the country

The precipitation in the country is drained by three major river systems; the Kosi, Gandaki and Karnali which respectively drain the country's eastern, central and the western areas. In addition to these, other smaller rivers are the Bagmati, Kamala, Kankai and the Rapti. The total annual runoff from these river is estimated to be about 200 billion cum.

Human Setting

Nepal's current population of 18 million is increasing annually at 2.6%. Population distribution is non uniform in the mountain, Tarai and the hill divisions. The country is one of the most populated in region that supports 1 person per 0.12 ha land in the hills while that at the Tarai is 0.21 ha per person. In the recent times, migration from the hills to the Tarai and from rural area to the urban centers are gradually increasing. However, only 7% of the total population live in 33 urban settlements, whose population by the end of 2000 is expected to reach 2.3 million. At its current growth rate, the population is expected to reach 21 million by the end of the century.

Water Supply Scenario

The relationship between mountain territory and economic marginality is remarkably evident in Nepal which is among the 11 countries with sizeable mountain territory that are poor according the 1990 world development report. The diverse physical setting and environmental factors coupled by the population distribution have severely hampered the efforts of providing basic services to improve the people's life.

One indicator of the poor condition is reflected in the health sector. Even with the continued efforts to bring about changes, progress has been slow. Most of the population living in the rural communities suffer from diarrhoea, hepatitis, gastro-enteritis and parasitic infection. The problem is created primarily by absence of potable water and lack of education. The direct suffers are the women folks who share the most of the daily household burden, and the children. Nepal has a infant mortality rate of 35 per 1000 (Unicef 1990).

In order to improve the situation, the government pooled resources from both bilateral and multilateral supports during the water decade to extend the coverage of potable water by constructing water supply systems. In the ten year period little more than 4% of the annual budget was allocated to the sector (Unicef 1990) for supply improvements. This emphasis did bring about changes and by the end of the decade in 1990, 34% of the rural and 81% of the urban population making 38% of the total population were provided with improved water supplies by gravity as well as pump systems (Unicef 1990). In 1980, only about 10% of the population living mostly in the urban areas had access to piped water.

That only 38% of the population has access to piped water supply reflects on the level of efforts that would be needed to extend the coverage to whole of the population. This coverage figure also hides the disparity in supply that genuinely is available to the population. Problems are created by two factors; inadequate operation maintenance of the completed water system and water quantity. In the late 1970s, a study of 70 completed water systems showed that more that 50% of the schemes were non functional and had major flaw (New Era 1977). Similarly in central Nepal, another inventory found more than 70% of the systems built earlier non operational (Ommen 1982). The situations can be considered to be representations of the whole country.

While this has been the story of extending water supply coverage by getting supplies closer to homes, in the rural areas quality aspects are addressed by selecting mostly uncontaminated sources, springs or even rivers with less likelihood of encroachment. Beyond this, quality is still secondary consideration in these regions. Even in urban areas where treatment facility exist, poor quality water causes frequent public outcry and infections due to water borne diseases are widespread. This is particularly magnified in the capital city kathmandu, where water quality issues are the most contentious conflict between the consumers and the state corporation.

The situation calls for an approach to improve coverage by installing new systems, rehabilitating non-operational ones and finding answers to the water quality questions. The problems become rather serious during the rainy season when rivers become muddy and water supply pipe lines get washed by landslides. It is particularly severe on the communities situated on river terraces that rely on rivers as water sources, or higher settlements where improved water systems are still to be built. In such cases women have to wall down long slippery mountain trail for a pitcher of water.

In the dry seasons, problems are further compounded because the nearby water sources dry up exacerbating the hardship. This situation is severe in the settlements at ridges, spurs and the Siwalik region (Fig. 1) which is a water critical area. Even pockets in the Tarai and peripheries of the urban areas face hardships. As the country prepares for new initiatives, all the options need to be effectively undertaken to minimise drudgery on women and save people from contaminated water.

Rain Water Uses

Use of rain water and its storage for drinking purpose was not practiced in Nepal probably because of the prevalent practice of regarding stored water as impure and flowing water as pure (Campbell 1973). However, local system called, panyalo, made of bamboo mat, and clothes piece laid horizontally on four bamboo supports, to harvest rain water for only livestock were used (Dixit 1991). These traditional methods, today have become extinct as piped water supply have come in as the easy alternative.

Rain water harvesting and its storage for drinking is feasible in the country as the available rainfall input is well in excess of the demand (Dixit 1989) and the technological choices are available. Only exceptions are the regions in the Himalayan rain-shadow. Development of rain water useless in these regions would need larger catchment area for the same storage than in other regions to compensate for lesser rainfall. for an average household with six members, when only the water requirement for drinking at 10 lpcd is considered, a total volume of 10.85 cum water would be needed for the non monsoon months (Dixit 1989). Wider use of Rain Water Systems however, depend on dissemination of the method and its acceptance by the users as an supplementary water source that could be built at affordable cost.

Nepal's first rain water tank was probably built at Pokhara hospital twenty five years ago. In recent years, series of rain water cistern systems have been built (Chindaprasit and Upadhyaya 1988), (Severinghause 1991). The details of the systems built and their location are given in Table 2.

Table 2 : Built Rain Water Cisterns

Year	Location	User	Capacity cum	No.	Cost per cum
1988	Pokhara	School 400	12	2	1000.00
1988	Ramnagar	Residence 8	6	1	1500.00
1989	Ramnagar	School 200	7	1	1500.00
1990	Bharatpur	Residence 8	8	1	1500.00
1991	Manthali	Health Post	5.5	1	1860.00

All the systems used ferrocement tanks. The experiences of building the system at Pokhara have been compiled in the form of a working manual (PC N 1989), while the systems at Ramnagar and Bharatpur were built during the in-service training of Peace Corps volunteers. All tanks were constructed using bamboo mat form work which was placed on the putside, wrapping the chicken wire mesh and plastered from inside. The tank at Mantanli also used bemboo mat form work but from at the inner face while it was plastered from out side. Users actively participated in the development of the harvesting systems.

Enquiry with the users at Ramnagar has revealed that the tank was useful at critical times, both in the dry months when the city supply was inadequate, as well as the rainy season. During the rainy season it was useful not only for the family but also others in the vicinity. As the city system supplied murky water, primarily because the washed off sedimentation tank is yet to be repaired, the cleaner rain water preferable. At both the schools in pokhara and Ramnagar students use the water and find it handy. But the management of the system was found to be unsatisfactory. The problem was created because no particular individual was assigned to look after the tanks as both the schools are located away from the households. The tank at Bharatpur would be stored only in the coming monsoon and its performance as well as the experience of the family would be monitored. Stored water from the tanks at Pokhara and Ramnagar were tested on two occasions which showed no contamination except for growth of mold.

This limited experience has shown the prospects of Rain Water Cistern Systems in supplementing water supply improvement in Nepal. While their construction posed no difficulty, shortcomings in the components and the construction methods have been identified (Dixit 1991). These related to the gutters, the pour flush system, the drainage, overflow and the water inlet system, one of which had to be repaired at a later date (Dixit 1990). The installation of the cisterns nevertheless, have indicated their utility.

In order to extend their uses on a wider scale an attempt is made to identify, on a macro scale the potential areas where the system could be installed. This is needed to locate users who face greater shortages of water and where the system would be more beneficial. The regions can be classified into four categories as follows.

(a) Dispersed households at ridges, spurs where generally water sources are far away.
(b) Settlements along the river terraces that depend on river water and face problem during the rainy season.
(c) The region along the Churia belt.
(d) Water scarce pockets in city peripheries.

Interventions in these areas are desirable as the impact would be more evident. This would then pave the away for more systems to be built and provide a sustainable water system. In addition, rain water cistern could be also taken up to lower the cost of developing gravity water systems. In far west Nepal for example, schemes designed to cover a village development committee that included several communities ranging from a cluster of five to five hundred households has the per capita cost as shown in Table 3. In some extreme case of isolated communities, where water has to be brought from large distance, the per capita cost has been found to be more than Rs. 3500.00. These options are the matters that need to be analysed, in the subsequent phases when rain water storage option gains little more acceptance. At present, such analysis would be only academic because people still have to be accept the system.

Table 3: Cost of Gravity Flow Water System at Far Western Region

Scheme	District	Per Capita Rs./Head	Cost per total storage Rs./Lit
Malatikot	Accham	1147.25	21.68
Santada	Accham	1185.74	28.26
Alital	Dadeldhura	1859.42	29.83
Mastabandali	Doti	2003.77	38.82
Mandu	Dadeldhura	1309.72	28.80

(Source: Reports prepared by Taec Consult 1991)

Even while more and more new gravity systems get designed and built, the difficulties of managing the systems for proper operation and maintenance with users' participation is yet to meaningfully evolve assuring functional water scheme at the village levels. In this

background, Rain Water Cistern systems can be brought in to supplement and support the piped water supply systems.

The cost per capita of the rain water cisterns built so far compare with that of the gravity flow systems. Its cost per liter (rain water cistern) is also found to be lesser than that of a gravity flow piped system. For an average Nepalese family however, the cost of the rain water system is still prohibitive. Even the ferrocement tanks that otherwise are cheaper than the bulky masonry tanks are not affordable. The cost of the ferrocement rain water tanks built at Pokhara, Ramnagar and Bharatpur were influenced by the easy accessibility as the sites were located along main highway. At remote and inaccessible areas, the cost could be very high. For example, in the Far Western Region, the cost per litre of the ferrocement tanks of 6, 8, 10 and 12 cum sizes are obtained as Rs. 7.65, 6.06, 5.52 and 4.68 respectively (Taec 1991). A 10 cum tank needed to store just drinking water would then cost almost Rs. 55000.00. Cost becomes the major factor that would cause its unacceptance. Promotion of Rain Water System in the country hence needs more concentrations on methods to lower cost.

One way this could be achieved is by using doubled layered continuous plastic sheet barrels (average cost Rs. 15.00 per meter). The sheets can be used for lining underground tanks. Suitable for sloping areas generally in the hills, water stored in the underground tank can be supplied by gravity to a point lower than the tank, close to the household. The roof of the household serves as the catchment surface. Two such systems are being installed in Kathmandu that would store water of the 1991 monsoon. One of the systems would be used for irrigating vegetable, while the other would be used for drinking purpose. A tank prototype with storage of 2.5 cum has been built at a cost of only Rs. 250.00 using locally available PVC sheet. The details of the approach and the process of construction (Dixit 1991) including the schematic (Fig 2) of the system is discussed below.

The prototype consists of a underground tank three feet deep and three feet in diameter. It is brick lined with 1:10 ratio cement sand masonry. A plastic barrel sheet having three feet diameter and 8 feet long is taken and divided into two length wise sections. The upper section is placed inside the tank such that the barrel sheet sticks to the brick wall forming the outer layer of the tank. The remaining portion of the plastic at the bottom is coiled until it became about four inches in diameter. The turned plastic is taken upwards through the 4 inches grove provided at the side of the tank as shown in the figure. At the top, the masonry wall is raised one feet above the ground to prevent runoff water from getting into the tank and to provide a base over which a tank cover can be placed.

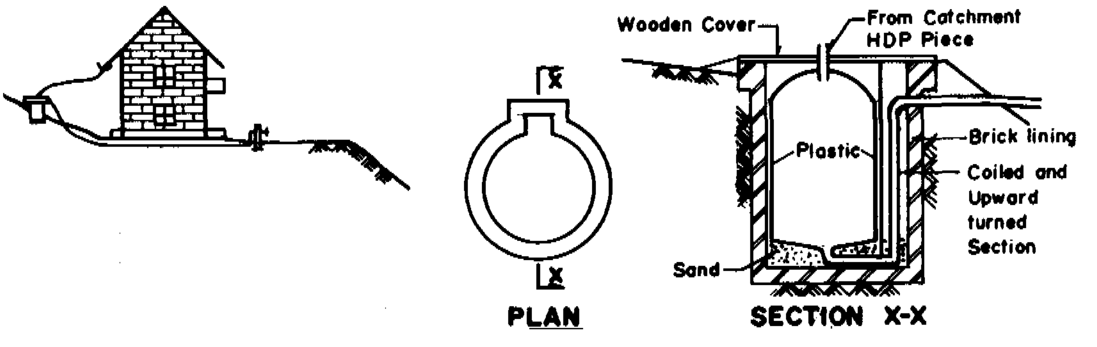

Fig. 2: Plastic Lined Underground Rain Water Collection Tank

The coiled plastic, is brought up, to be used as overflow of the system, and taken out of the tank at the top. This is done to facilitate drainage of the potential high flow likely to get into the tank from the catchment and avoid the need for making more openings. Use of a larger one sheet, eliminated its tearing and hence the need for sealing which require good workmanship to prevent leakages. The upper edge of the plastic tank supported by the brick wall is joined to a HDP piece, to which the inlet pipe from the catchment would be connected.

The supply outlet pipe in the storage is fixed by first making a hole at the bottom end of the plastic. A GI nipple is put in the hole which is then tightened from both the sides of the plastic by jam nuts after putting rubber gaskets. This ensured a waterproof joint. The upper portion of the tank is covered by wooden plank placed on the top of the masonry. As the tank has been designed for a sloping land, suitable connection to the nipple would be made and the tap taken to an appropriate site for uses.

The performance of the prototype in a field situation would be tested during the coming monsoon. Several important issues such as durability, handling difficulties, replication and ease of construction have to be evaluated. The performance of the tank with respect to its integration with the inlet pipe system and other specific and technical details also have to be monitored. This should be followed by evaluation of how the system is used and whether it is accepted by the users or not. This implies a two looped (one within the other) cycle for promoting RWCs in the country as shown in Fig. 3.

In order to promote the system at different ecological zones and different target groups, preliminary discussions have been held with a number of NGOs active in rural areas. The promotion should be pursued in a household approach till a sound basis and understanding

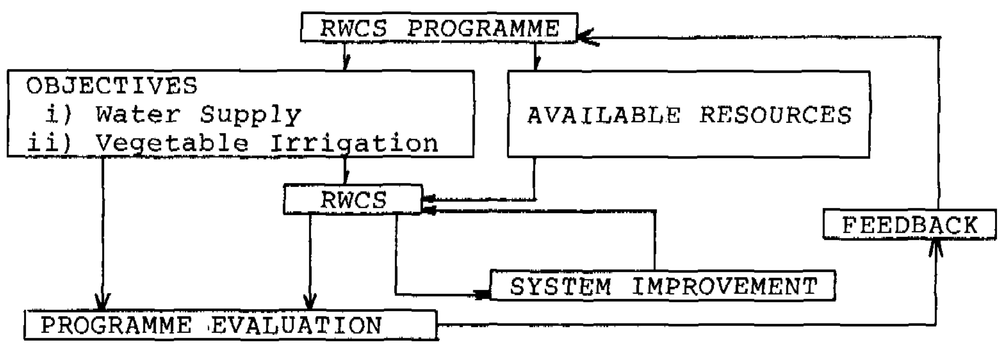

Fig. 3. RWCS Promotion Cycle

for wider uses of the cisterns are established. The approach should focus first on the four regions identified in the earlier section, because it is at these places the usefulness would be more apparent. Attempt should be made to install the system by actively involving the users in the process. Further actions would be based on consolidation of the experiences gained.

Conclusion

This paper has discussed the prospects of Rain Water Cistern uses in improving water supply situation in Nepal. The feed backs obtained from the few tanks built are limited to completely understand all the issues, yet give reasons for optimism. Of the several constraints, cost of the tank is the major factor. Low cost methods have to be developed. Past experiences have enabled development of a low cost prototype, whose performance is being tested through actual installation of the system in a field situation.

Rain water harvesting and storage is a viable option in Nepal particularly at water scarce communities, regions where people are forced to use muddy river water and where the existing sources are contaminated. Its promotion needs more tanks to be built at household levels when the usefulness would be more discernible. Use of Rain Water cisterns can provide people with a better quality and sustainable water source, which also offers opportunities of enhancing the agricultural outputs at micro levels. The prospects are there, the need is to pursue its promotion through action oriented programs.

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HAFIRS IN Sudan

Ahmed Ayoub El Gaddal*

ABSTRACT

The HAFIR is an underground reservoir designed for storing rain water carried by streams and used for domestic water supply and for agricultural purposes in rural areas in the Sudan.

Hafirs are usually constructed where there is enough rainfall and where there is no underground water.

It is usually big enough to cater for the needs of the villagers and their live-stock for a whole season.

The Hafir is surrounded by earthen embankments and protected by barbed wire fencing from animals.

The shape of the Hafir is like a trunkated frustum of a pyramid. The average capacity of a Hafir varies from 15,000 to 250,000 M3.

There are different types of Hafirs e.g.:-

(1) Conventional HAFIRS

(2) Lined HAFIRS

(3) Overground storage HAFIRS

Maintenance of HAFIRS depends on:-

(a) Removal of slit

(b) Cleaning of water pipes

(c) Cleaning of canals-stilling bowels, inlets and outlets.

(d) Compaction of eroded embankment.

INTRODUCTION

The Sudan is about one square miles. It lies between latitude 3°N. and 22°N. and longitude 23°E. and 38°E.

It is traversed by two rivers, the White and the Blue Niles which meet at Khartoum and continue Northwards across Egypt to the Mediterranean Sea as the River Nile.

These rivers are the main source of water for hydro electric power generation, irrigation, domestic water supply and for industrial purposes.

Rainfall increases from North to South, the Northern part of

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the Sudan is dry, the Southern part has heavy rains. The average annual rainfall in the South is about 700 mm.

The Western as well as most of the Eastern part of the Sudan depend on rain water for cultivation, and hence forth, most of the HAFIRS are concentrated in those areas.

(A) WHAT IS A HAFIR

It is an under-ground reservoir designed for storing rain water carried by streams and used for domestic water supply and for agricultural purposes in rural areas in the Sudan.

Hafirs are usually constructed in areas where there is enough rainfall and where there is no ground water due to the presence of the basement complex strata or salinity of the ground water.

Excavation of HAFIR is done by heavy machinery like Buldozer D8-D9 and scrapers.

The HAFIR water is surrounded by earthen embankment and protected from animals by barbed wire fencing.

(B) SHAPE AND SIZE

The shape of a HAFIR is like a trunkated frustum of a pyramid with side slopes 1:2 and 1:4.

It is fed by rain water running in seasonal streams (Khors) or down hills (Jebels).

14" A.C. or P.V.C. pipes are used to let in water from the stream, stilling basin, to the inside of the HAFIR.

The water flows from the HAFIR to the outlet well through 4" or 6" A.C. or P.V.C. pipes. if no treatment is done to the water, it is pumped to an elevated tank and then distributed by pipes to the consumers.

It is usually big enough to cater for the needs of the villages and their live stock for a whole season.

The average capacity of a HAFIR varies from 15,000 to 250,000 M3. The depth is governed by clayey soils and it may vary from 5 to 12 metres unless a permeable stratum is encountered.

HAFIR'S water for towns and bigger villages is usually treated through pressure or slow sand filters. It is chlorinated, sometimes, and then raised to elevated storage tanks for distribution through pipes. (Fig. 1-2-3)

(C) TYPES OF HAFIRS

There are different types of HAFIRS; the design is governed by technical as well as environmental factors.

(1) Conventional HAFIRS;-
These are the commonest traditional HAFIRS which are dug in favorable clayey soil fed from khors or Jebel catchment area.

(2) Lined HAFIRS:-
These are usually constructed in areas where there is no clayey soil (North Western Sudan - Kordofan). The soil is usually sandy. After the excavation of the HAFIR, it is lined with polythene membrane to stop the loss of water through the sand. The polythene might be affected by termites or boring insects and animals.
The lining is sometimes done by the addition of clayey soil to the base of the HAFIR - compaction is usually done before and after the addition of the clayey soil.
Asphalt has been tried for lining the HAFIR; but it did not prove successful.

(3) Overground Storage HAFIRS;
These are constructed in shallow clayey soil - less than 5 metres deep; the HAFIR is surrounded by high and well compacted embankments to impound extra water above ground level which is raised by pumping from a reservoir.

(4) NILOTIC HAFIRS;
Such HAFIRS dominate in irrigated areas where canal water, which is usually polluted, is available. In such areas a treatment plant is usually attached to the HAFIR.
The water is drawn from an irrigation canal to an excavated low lying area for storage. Then it is filtered and may be chlorinated and after that raised to an elevated water storage tank for distribution through pipes.
Water is sometimes drawn from an outlet well by a hand pump or buckets. It is transported for human consumption, or poured on troughs for animal watering.

(D) MAINTENANCE:

The main problems encountered are siltation and breakage of embankments. The maintenance is usually done when the HAFIR is dry. Sometimes there are more than one HAFIR in one area; this is to ensure the presence of water in one HAFIR while maintenance is done in the other HAFIR.

The usual maintenance can be summarized in. the following points:-

a) Cleaning of canals and stilling basins.
b) Compaction of eroded parts of embankment.
c) Maintenance of inlets and outlets.
d) Rectification of barbed wire fencing.
e) Construction of new structures and wing embankments when necessary.
f) Removal of deposited soil from the base of the HAFIR (by excavation).

(E) DISEASES TRANSMITTED THROUGH HAFIRS:

In ideal HAFIRS, which are well guarded, men or animals are not allowed to come in-contact with the water in the HAFIR. If there is no proper fencing, animals can enter to the HAFIR and drink and wade in the water. The same happens with human beings. Usually the children swim in the water leading to its pollution.

Such exposed HAFIRS lead to the transmission of diseases, e.g.

a) Schistosomiasis:
Snails, the intermediate host of schistosomiasis, are available in most of the HAFIRS. Birds carry snails or snail eggs from polluted canals to the HAFIRS. Also snails are carried to the HAFIR on the hooves of animals (cattle). If not properly protected, children might polute the water with eggs of schistosomiasis. Children or man who wade in the water get infected with schistosom -iasis.

b) Giardiasis:
Is common in some HAFIRS; specially if the water is directly taken from the HAFIR without treatment.

c) Typhoid:
Some cases of typhoid were reported from unprotected HAFIRS.

d) Guinae Worm:
It happened recently that an epidemic of Guinae Worm took place in Mazmoom area. The source was a HAFIR which was open to man and animals.

e) Malaria:
Some HAFIRS may be the source of mosquito breeding leading to malaria transmission in the area.

Wad Bugul Proposed Hafir

Scale 1:5000

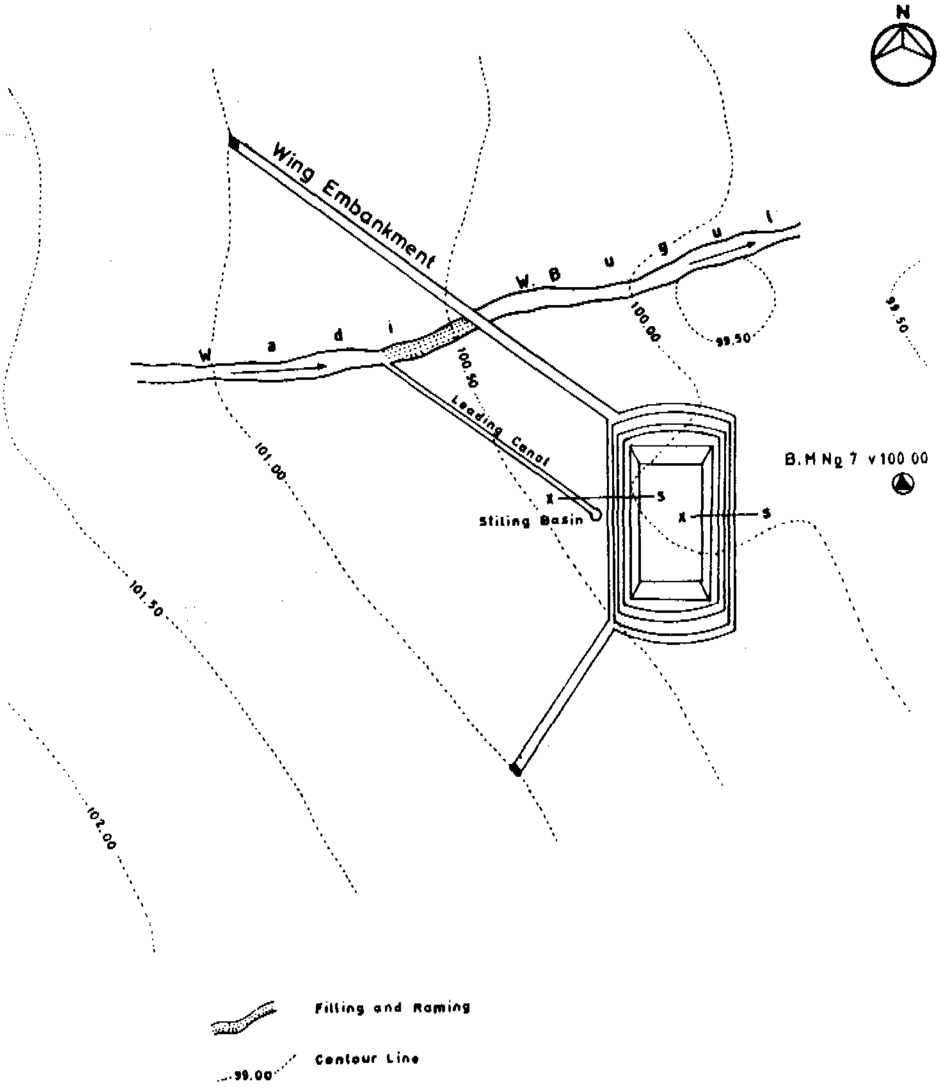


Figure 1

Name Of Hafir : Wad Bugul

Province : Gazeira

Rural Coun. : Tamboul

Dimensions : 150.92 X 75.46 / 114.92 X 57.46

Capacity : 40 000 M^3

Depth : 4.5 M.

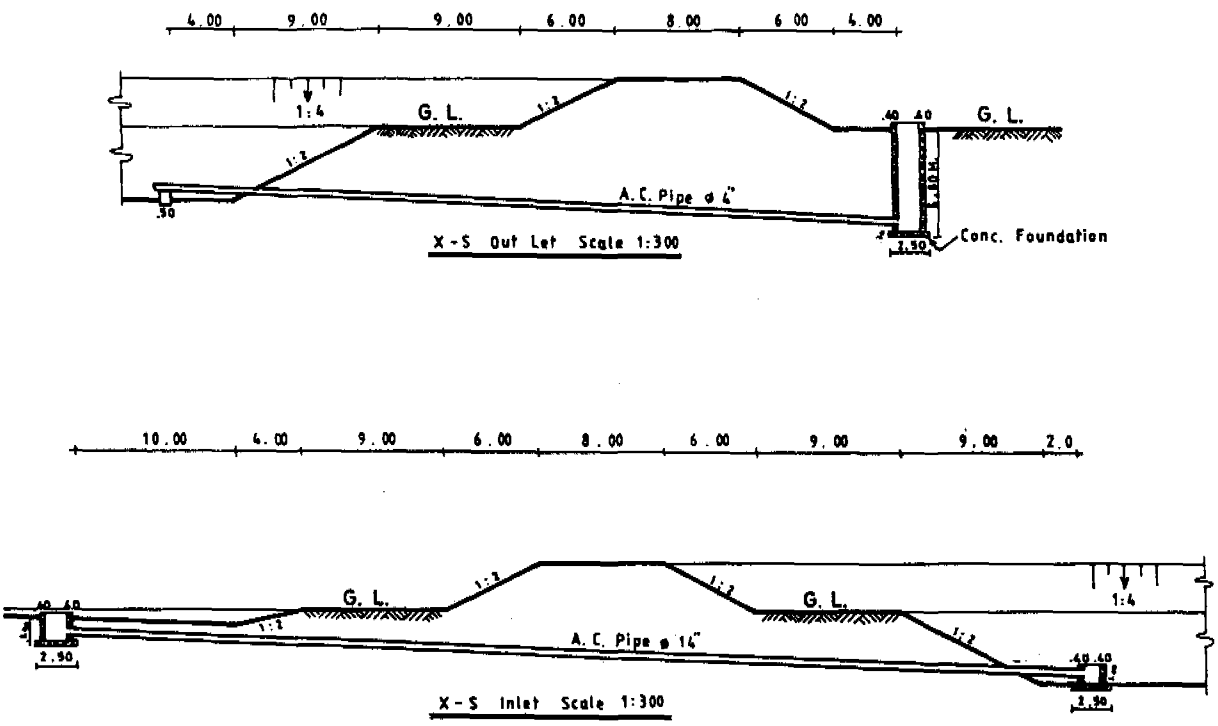


Figure 2

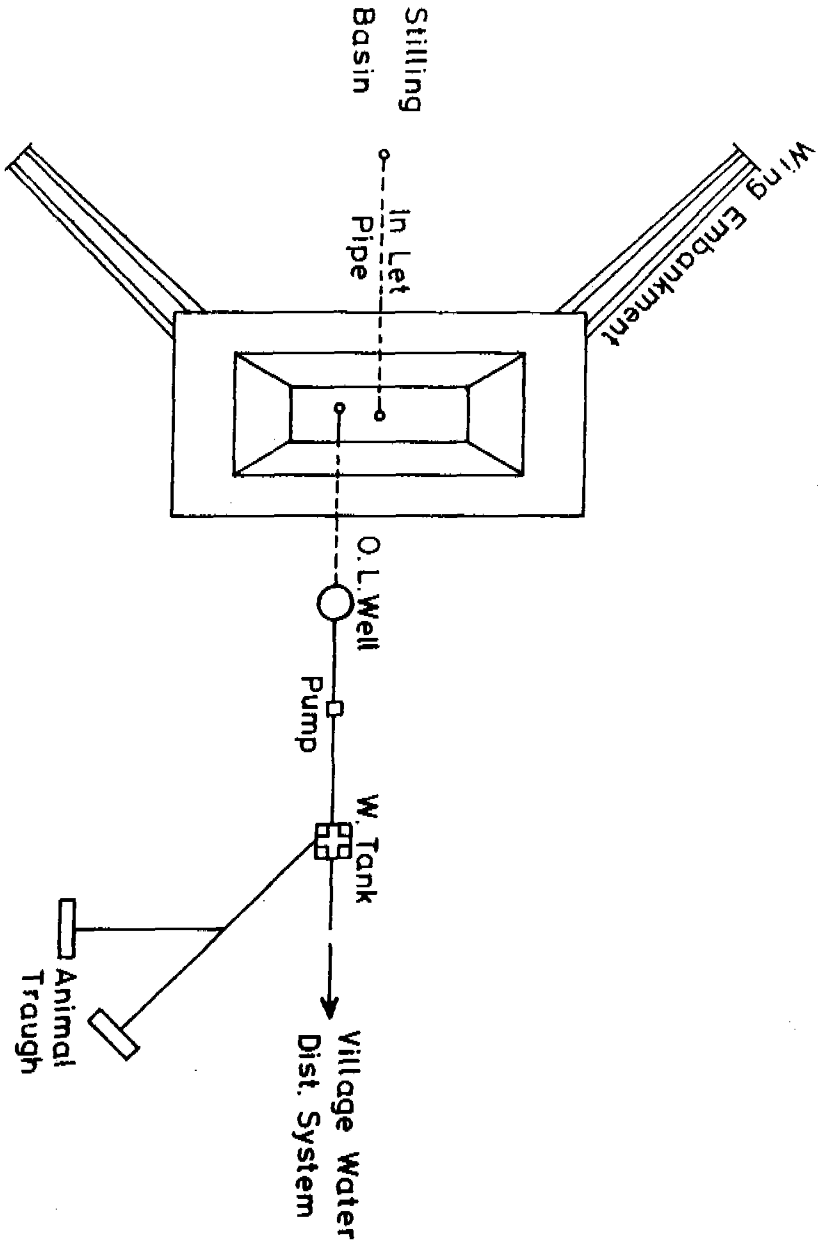
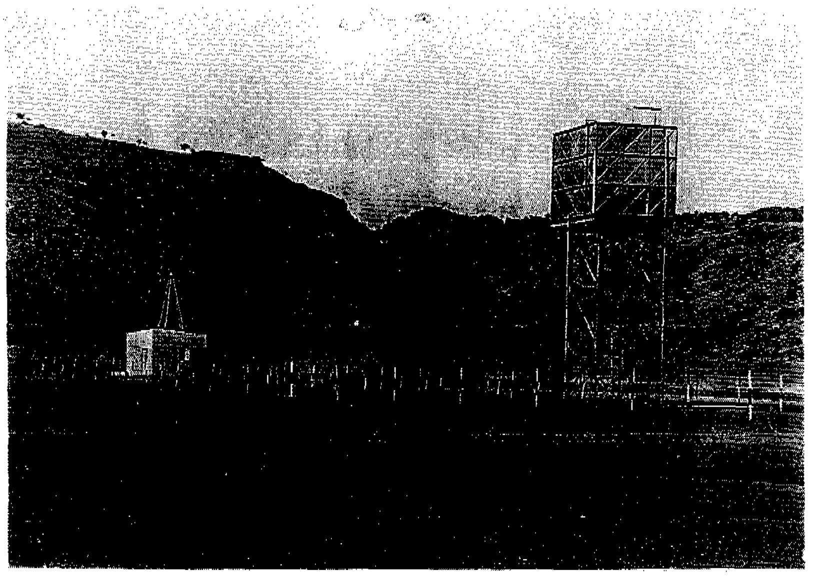
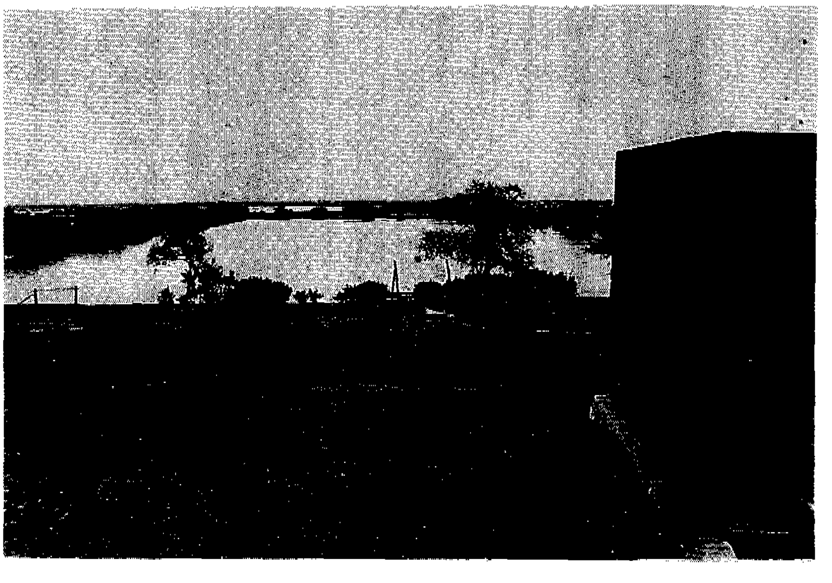


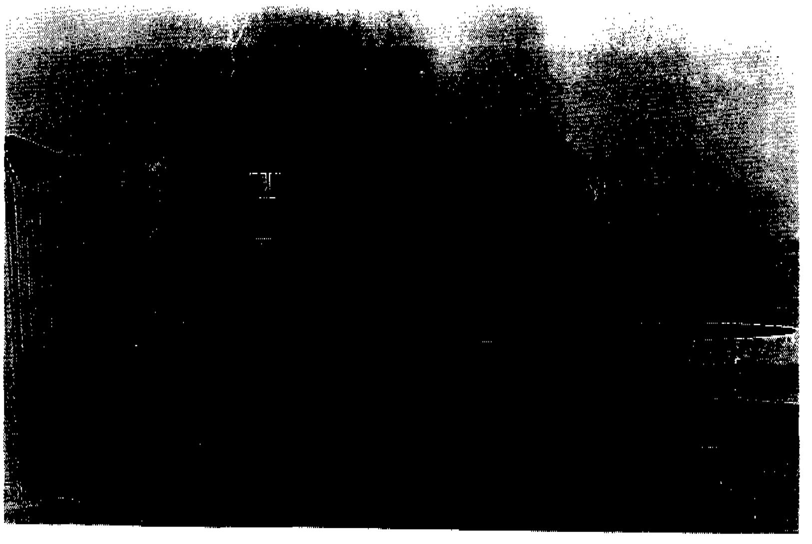
Figure 3
Site plan of an ideal conventional HAFIR



Standard conventional HAFIR with pump house, elevated tank, barbed wire fencing and Jebel catchment area.



Twins HAFIR full of water with tank placed on embankment of HAFIR with barbed wire fencing.



HAFIR water is treated via slow sand filters then pumped to the elevated tank and distributed by pipes to consumers.

Sometimes the water is pumped from the outlet well of the HAFIR to the animal troughs, and to water barrels transported by donkeys for human consumption.

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RAIN WATER HARVESTING IN SARAWAK AND BRUNEI : PROGRESS OF ITS IMPLEMENTATION AS PART OF THE RURAL WATER SUPPLY DEVELOPMENT

K.C. GOH*

Abstract

Piped water supply to homes definitely has a better coverage in Brunei Darussalam than in neighboring Sarawak. Nevertheless in some isolated villages where no reticulated system exists and where shortages from natural streams during dry spells occur, rain water harvesting has been introduced. In Sarawak the problem of developing rural water supply is much more difficult as the population is widely scattered in the coastal swampy plains and the interior. In the coastal plains concerted efforts have been made by the government to introduce rain water cistern systems as a viable means of potable water supply to the more than 500 village settlements of varying sizes. This paper examines the rain water harvesting plan in Brunei Darussalam and in particular Sarawak, and the extent of success of its implementation to date.

Introduction

The governments of Brunei Darussalam and Malaysia are anxious, for obvious reasons, to provide as complete a coverage of potable water supply to their populations as possible. However, for unavoidable reasons such an objective cannot be attained within the short term. While urban areas are still favored with good water supply system ,the rural communities tend to be less privileged in this regard. Nevertheless, in the past five years, considerable progress has been made to ensure that wholesome water reaches rural homes and in this respect Brunei Darussalam has achieved a higher percentage of coverage compared to Malaysia (Tables 1 and 2). Obviously the much smaller population base, areal extent and the greater per capita resources of Brunei Darussalam are factors that account for the favorable and quicker attainment of the water supply development goals. In Malaysia the percentage of population with

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piped water supply in 1988 was 74.6% : 94.8 per cent and 61.6 per cent for urban and rural populations respectively. However, in the thirteen-state federation of Malaysia, Sarawak ranks as one the least developed as far as rural water supply is concerned. Nevertheless in both Brunei Darussalam and Sarawak, or any other country for that matter, a complete coverage of piped water supply is impossible to attain. Reasons such as isolation of communities, very dispersed nature of house locations and the absence of basic infrastructural network preclude the extension of the existing reticulated systems to such areas. Because of these reasons it is imperative that alternative supplies be planned and provided. This paper examines rainwater harvesting as the most favorable option proposed and which the Sarawak government in particular has adopted for scattered rural communities along the coastal plain. It also seeks to assess the extent of success of its implementation to date.

Topographical and climatic considerations

Brunei Darussalam and Sarawak are situated on the west coast of Borneo and they are adjacent to one another. The coastal areas of both states are low lying with an average elevation of less than 10 m and mangrove and peat swamps predominate. Further inland the land is undulating to high reaching an elevation of more than 2000 metres along the border. In the rather broad coastal area numerous streams and rivers, heavily laden with sediments, cut the land into numerous islets as they take their sluggish course towards the sea. These rivers are very much influenced by tidal effects and for some distance inland. Communication along the coast, particularly in Sarawak, is almost wholly by water as the terrain does not favor the construction of roads.

Both states share similar climatic characteristics. The climate is equatorial and rainfall regimes are very much dictated by the monsoon winds which influence the resultant areal rainfall distribution. Certain rainfall characteristics are evident. The coastal rather the inland region shows a greater variation in annual and monthly rainfall distributions. It also experiences greater effects of dry spells than the rest of the states. In Sarawak dry spells during which the total rainfall of the preceding 30 days was less than 100 mm have been observed to occur. The periods increase in frequency from about once a year in the relatively non-seasonal interior to about three or four per year on the coast (Brunig, 1969). In Miri,a coastal station north of Sarawak and relatively close to Brunei, there are days when the running 30-day rainfall total falls to 60 mm (Baillie, 1976). Brunig has also shown that the frequency of months with less than 51 mm of rain varies from 4 at kuching (71 years of record) and Baram (22 years od record) to 10 at Miri (31 years of record). Dry spells of 36 to 59 days without any day having rainfall exceeding 5 mm have been known to occur in Brunei and Sarawak (Goh, 1990).

In spite of the relative abundance of rainfall as seen from Figure 1 , regions of water stress occur in the coastal areas. The greatly diminished flow of fresh water in streams during dry spells, the lack of storage facilities and surface saline intrusion make the coastal areas particularly susceptible to water deficiency.

Yet by reason of easy communication by boat and the ease of obtaining a livelihood from the sea, many villages have sprouted along the coastal areas and hence the population tends to be largely rural (Figure 2). A recent survey of the areas shown in Figure 3 indicated that there were more than 500 settlements with population sizes varying from 50 to 2000 people. These settlements are generally isolated and the population density of the whole area is less than 25 persons km^2. The provision of potable water supply for largely small but dispersed rural communities becomes a daunting task to water engineers and planners in Sarawak. The provision of piped water from existing system to these outlying areas is out of the question for both reasons of economy and resource availability. By 1988, the rural population of Sarawak without any safe water supply at such locations was 190,000 or some 12.5% of the total state population.

In Brunei Darussalam, the main belt of population distribution is within a ten-kilometer coastal stretch where more than 80% of the state's population is found. In the interior the population is sparse. Availability of salaried jobs in towns has caused most people from the interior to move to urban areas. Besides, the predominance of oil and gas in the Brunei's economy has taken the pressure off the land and led to the highly urbanized nature of its population. Nevertheless, communities in the interior do exist and which as yet do not receive proper water supply. Sources of water supply are rivers, shallow wells and rain water.
However, as alluded to earlier, the numbers involved are small.

Rain water harvesting

Concern for the welfare of these rural communities in both states has been translated into some concrete plans in the provision of potable water supply. In sarawak a Master Plan Study was commissioned in 1986 by the state government to investigate the socioeconomic aspects of the villages, their existing sources of water supply, potential water resources in their localities and the projected consumption up to the year 2005. To complement the survey, demonstration water schemes were established to determine the viability of the raw water sources and to assess the feasibility and practicability of the various recommended methods and water treatment technologies. Possible alternatives of water supply included shallow and deep ground water sources, peat swamp ground water as well as roof runoff. Of all these alternatives, rain water harvesting from roofs and in ponds was thought to be the most appropriate for most of the communities in the coastal plain.

In order to explore the potential of adopting the rain water harvesting a detailed investigation to fulfill several objectives was required first. The investigation included the examination of critical parameters affecting the performance of rain-harvesting schemes. There was also the need to select the appropriate dimensions of the rain water harvesting schemes for a range of community sizes. Computer-based calculations were carried out and parameters used in the analysis included frequency of failure, catchment area, storage volume, consumption rate, rationing and evaporation loss. Computer-aided calculations were useful in providing the proper indications of the rainwater harvesting schemes to be designed. However, simplification to the final designs was deemed necessary. Two types of rain water cistern systems were finally proposed and implemented in the study area. These were:

1. individual household tanks for drinking and cooking only fed by rainwater caught on individual house roofs.
2. community tanks with a roof catchment over them in which both the tanks and the roof catchments are so sized as to tide the community over the annual dry season.

For larger village communities of between 500 to 1500 people, in the absence of groundwater or reliable surface sources, open storage ponds recharged by direct rainfall and/or surface runoff were proposed as a viable option (Figure 4).

The Sarawak Master Plan for rural water supply development envisages various levels of service for the villages with varying sizes of populations (Table 3) from the various water supply types i.e. surface sources, ground water ,peat aquifer and rain water. The viability of such schemes and the levels of service was thoroughly examined taking into consideration factors such as population size, the villages' ability to be grouped together, assessment of costs and feasibility of source.

Rainwater Cistern System Designs in Sarawak

a. Household tanks

In any design of tanks, whether household or communal, several factors must be taken into consideration. These are per capita consumption, average household size, roof area, collection efficiency and the length of dry spells catered for. Analysis of the storage sizes for these two types takes into consideration the following assumptions:

a. Average per capita per day consumption of 25 litres.
b. Average household size of 6.
c. Minimum roof catchment size of 33.4 m^2.
d. 85 % collection efficiency.
e. Average recurrence interval of dry spells of 1 in 25 years.

With regard to the last factor, analysis of daily rainfalls for the determination of length of dry spells of 1 in 25 year average return period resulted in the delineation of the coastal areas of Sarawak into three regions namely regions with 30,40 and 60 days of storage (see Figure 3). Tank sizes in these three regions were designed to cater for these storage requirements.

b. Rainwater Harvesting Ponds

As ponds would provide larger amounts of water than tanks, they were envisaged to provide continuous supply of water throughout the year. Thus in the design of the ponds analysis was based on three different consumption levels - 25, 50 and 150 lpd. For economic reasons the catchment area for ponds is kept to the minimum and a practical ratio of pond area to catchment area of 0.5 was derived. In addition other assumptions were incorporated which included runoff coefficient of 0.7, runoff coefficient of the pond area/direct interception of the pond area of 1.0, evaporation of 4.5 mm per day , zero seepage, and total supply losses of 30 %. Different depths of 1, 1.5 and 2 metres were incorporated in the calculation.

Water Quality of household and community tanks

Chemical and bacteriological analyses of water samples taken in the dry period of 1989 were carried out for both household and community tanks and for different roof types (Table 4 (a) and (b). While more analyses have to be carried out before a more definite conclusion can be made, these results nevertheless give some indication of the quality of the water harvested. As far as chemical analyses are concerned, with the exception of pH the water quality meets WHO Aesthetic Guidelines for Drinking Water Quality. The type of roof materials bears no relationship with the chemical parameters and the water collected in all cases is potable.

As the number of samples analyzed for bacteriological properties was low, the results shown were rather tentative. However, based on the results obtained the water collected was not bacteriologically safe for drinking without some form of disinfection or boiling. Zinc roofs apparently showed more cases with lower Ecoli counts as compared to other types of roofs.

Progress of implementation

Roof runoff has been collected by people in the rural areas of Sarawak and inland Brunei Darussalam for a long time. The only difference is that in the past harvesting of rain water had not been done in a systematic way. Rain water was used for drinking and other incidental purposes as a supplement to either well or river water. Containers used were mainly household basins.

Under the government's development plan, rainwater harvesting is encouraged in areas where other sources of water are not available and where the community size is small. Based on the investigations alluded to above, two types of designs were introduced in Sarawak: household tanks and communal tanks constructed in corrosion free high density polyethylene (HDPE) or glass reinforced plastic (GRP). Rainwater ponds are limited to locations where impermeable clays exist to prevent leakage. Since 1986 the Ministry of Health has installed 23,116 HDPE household tank units of 529 1 each throughout the state of Sarawak. In addition the government under the Public Works Department has installed 17000 1 and 22500 1 HDPE and GRP communal tanks.

While the household tanks of capacity 2368 1 were able to meet household requirements for most months of the year, during the dry spell, these will become empty for a period of up to 60 days. During such dry periods, reliance on communal tanks is essential. In communities where houses are scattered, communal tanks prove unsuitable and large household tanks of 7500 l are provided.

In the process of implementing some of the water supply schemes, a reassessment of large household and communal tanks has been made. A plan was drawn out showing regions where 30,40,60 day storage capacities are required to maintain supply at a consumption rate of 25 lpd for droughts of 1 in 25 years.

Altogether 23 rainwater schemes (communal and large tanks) serving 28 villages have been identified and the water supply system implemented. By the year 2005, these villages will contain an estimated population of 6009 people. However, these schemes do not include 11 small isolated villages of less than 70 people. For these small isolated villages, smaller tanks will be provided.

In villages where other sources of water supply are of lower quality and the quantity unreliable, rain water tanks are recommended for conjunctive use.

It appears that the provision of rain water cistern systems in the rural coastal areas of Sarawak is rather costly when compared to the total population envisaged in the year 2005. If the estimated cost is anything to go by, the expenditure per person would be in the region of M$1,500 (approximately US$650).

It is recognized that the provision of rain water cistern systems in the rural areas of Sarawak cannot be sustained and the benefits enjoyed by the community cannot be maintained for long without the active involvement and participation of the communities right from the start. The element of trust and confidence between the government agencies and the people has to be nurtured. There is a need to convince and impress upon the people that rain water system is as good and reliable as piped water system which due to one reason or other has always been regarded as the ultimate' in water supply. Once the system is accepted, then the people could be convinced to manage the systems themselves. The many and dispersed schemes would make it very difficult if not costly for government agencies to play any degree of direct maintenance role. It was thus envisaged that basic skills in operation and maintenance of the systems be imparted to local operators who will maintain the systems when situations warrant. Also, the use of standard designs using simple and appropriate technology compatible with local capabilities is emphasised. The overall management of all the systems would demand some king of organizational structure both at the village level and at the government administrative level in order to oversee and coordinate operations and maintenance of completed schemes. A team of supervisors and technicians would provide the technical know-how as well as the backup services required. In the implementation of such schemes the government will provide the initial capital outlay but the subsequent costs of maintenance must be borne by the community. In order to make this workable a sound revenue collection system was proposed.

The revenue collected will ensure and safeguard continuity of operation. At the moment it is too early to be able to gauge the extent of success of community involvement and participation in this matter of revenue collection or even the rain water harvesting scheme as a whole. In Sarawak, the ministry of health is also involved in the development of sanitary facilities within the same villages and the need to coordinate water supply development with sanitary facilities is vital. So also the need to educate the people in improving their hygiene and general well being.

In Brunei Darussalam , rain water cistern system is more appropriate for households which are located in the interior such as in Ulu Belait, Ulu Tutong and in the inland parts of Temburong. In such areas longhouses rather the individual houses predominate. Each longhouse is built on stilts and in some cases may be 100 metres long and it can accommodate as many as 100 to 200 people in 10 or more families. Each family is housed in a family compartment but with a common frontage. Such houses may have total roof areas of between 1500 to 2000 m^2. While no concerted effort has been made to construct and implement rainwater cistern systems commensurate with such large roof areas, the viability of harnessing such large catchments is unquestionable. Large tanks or concrete-lined ponds could easily contain this large roof runoff and serve the water requirements for the entire longhouse. However, no such steps have been taken so far. What has been implemented was the provision of 1 m^3 alluminium tanks to each individual family. During normally wet seasons the water in this tank is used for cooking and washing of plates as water used for bathing and washing of clothes is obtainable from nearby streams. However, during prolonged dry spells when the streams dry out, this rain water tank is inadequate to provide the potable water requirements. In order to increase storage volume families supplement it with other containers or large oil drums.

Conclusion

In most considerations of rain water cistern systems in the tropics, the rationale for their design and implementation is invariably related to climate, in particularly the need to provide potable water during droughts or prolonged dry spells. In the humid tropics, RWCS should be encouraged not so much because of prolonged dry spells but more so precisely because of the abundance of rainfall which means that RWCS can be adopted on operational basis to meet household water supply requirements throughout the year. Unfortunately in Malaysia generally rain water is not regarded with the same kind of respect' as piped water which is regarded as modern and wholesome.

The above discussion has shown that at least a start has been made to implement RWCS as a viable and wholesome water supply system in the rural areas of Sarawak in particular and in Brunei to a limited extent. The fact that the state government of Sarawak has been convinced of the efficacy of this system shows that RWCS has gained recognition as a viable and respectable form of potable water supply which hitherto has been regarded as primitive'. A systematic investigation of the needs of the rural areas for RWCS and their proper designs to meet those needs in other areas would go a long way towards meeting the government's objective of providing wholesome water supply to the rural areas. It now remains to be seen whether what has been implemented will be sustained by the communities themselves.

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Table 1 Estimated level of water supply services, 1985
(estimated population: 225,000)

District	No. of Houses	Percentage of Houses served			
		Piped water	Well/Spring	River	Others
Brunei-Muara	22,640	98.1	0.3	0.8	0.8
Tutong	4,360	83.9	6.1	8.3	1.7
Belait	11,610	90.3	0.7	3.1	5.9
Temburong	1,160	65.6	0.1	19.6	14.7

Table 2 Rural water supply coverage of Sarawak, 1985-90

	1985		1988		1990	
	Persons	%	Persons	%	Persons	%
Sarawak	414,447	33.0	495,430	37.0	662,673	47.3

Table 3 Level of service

	Service Level	Criteria
a.	Unrestricted reticulated supply (fully treated)	For populations above 1500
b.	Unrestricted reticulated supply (partially treated or untreated)	For populations between 500-1500
c.	Unrestricted reticulated supply (untreated non-mechanical)	Source is unlimited For populations between 100-500
d.	Restricted communal standpipe supply (untreated non-mechanical)	Source is limited For populations between 100-500
e.	Rainwater storage supply	
	- individual household tanks	For populations between 70-500
	- communal tanks	For drought relief For populations between 70-500

(Note: 70 people refers to the size of an <u>isolated</u> community)

Table 4 Water quality of household and community tanks

(a) Chemical Properties

Parameter	Household tanks				Community
	Zinc	Atap	Shingle	Zinc/Atap	Zinc
pH	6.2-6.9	5.7	6.1-6.3	6.4	6.1-6.3
Chlorides	2.0-4.5	6.0	1.0-4.5	1.0	1.0-3.0
Total Solids	5.1-8.0	13.3	2.4-8.0	6.0	3.2
T. Dissolved Solids	3.0-41	1.0	2.0-4.0	4.0	2.0-3.2
Suspended Solids	1.0-5.0	14.3	0.0-4.0	2.0	0.0-1.2
Conductivity	4.0-5.5	25.0	2.0-4.0	5.5	3.0-5.5
Total Iron	Trace	Trace	Trace	Trace	Trace
Soluble Iron	Trace	Trace	Trace	Trace	Trace
Soluble Manganese	Absent	0.04	Absent	Absent	Absent

(b) Bacteriological properties

		Presumptive Coliform	E-Coli	Plate Count
Household Tanks				
Zinc roof	(11 samples)	0-180	0-50	88-6000
Atap roof	(5 samples)	50-180	3-160	1050-3200
Shingle roof	(3 samples)	90-180	3-50	1000-3400
Zinc/Atap	(4 samples)	8-180	0-180	2100-3040
Zinc/Ac	(1 sample)	25	0	9600
Community Tank				
Zinc roof	(4 samples)	90-180	0-25	480-5500

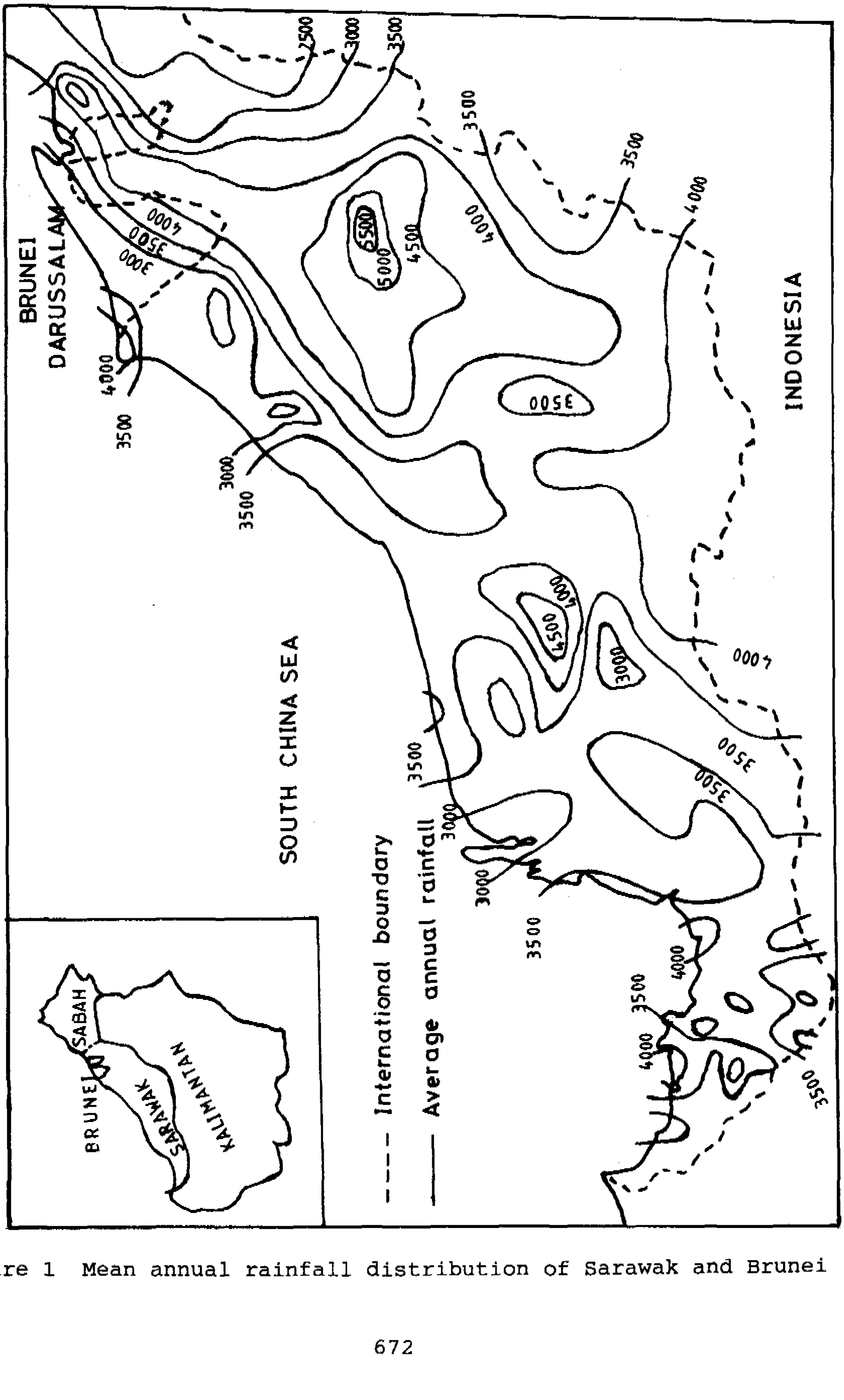

Figure 1 Mean annual rainfall distribution of Sarawak and Brunei

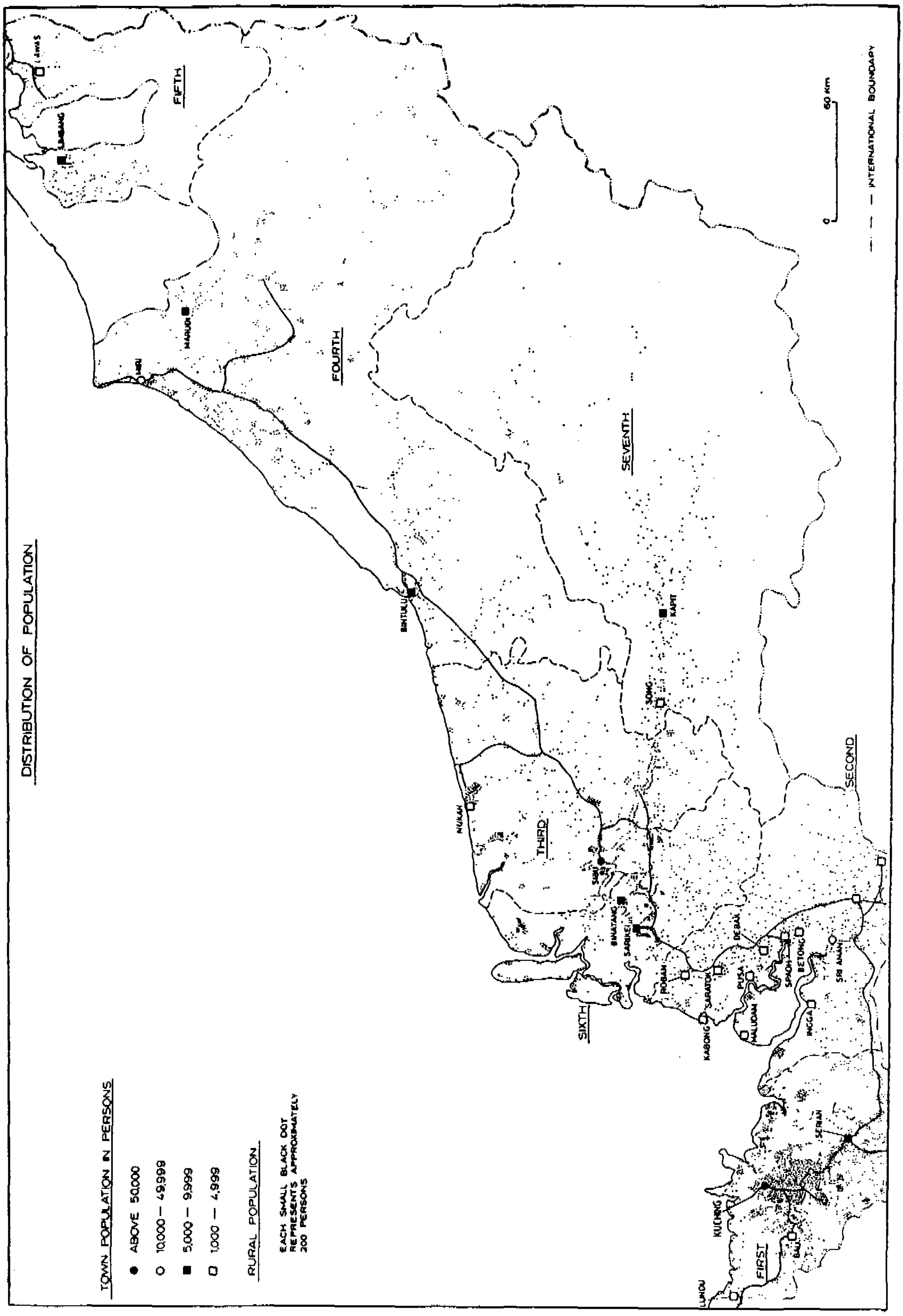

Figure 2 Distribution of population in Sarawak

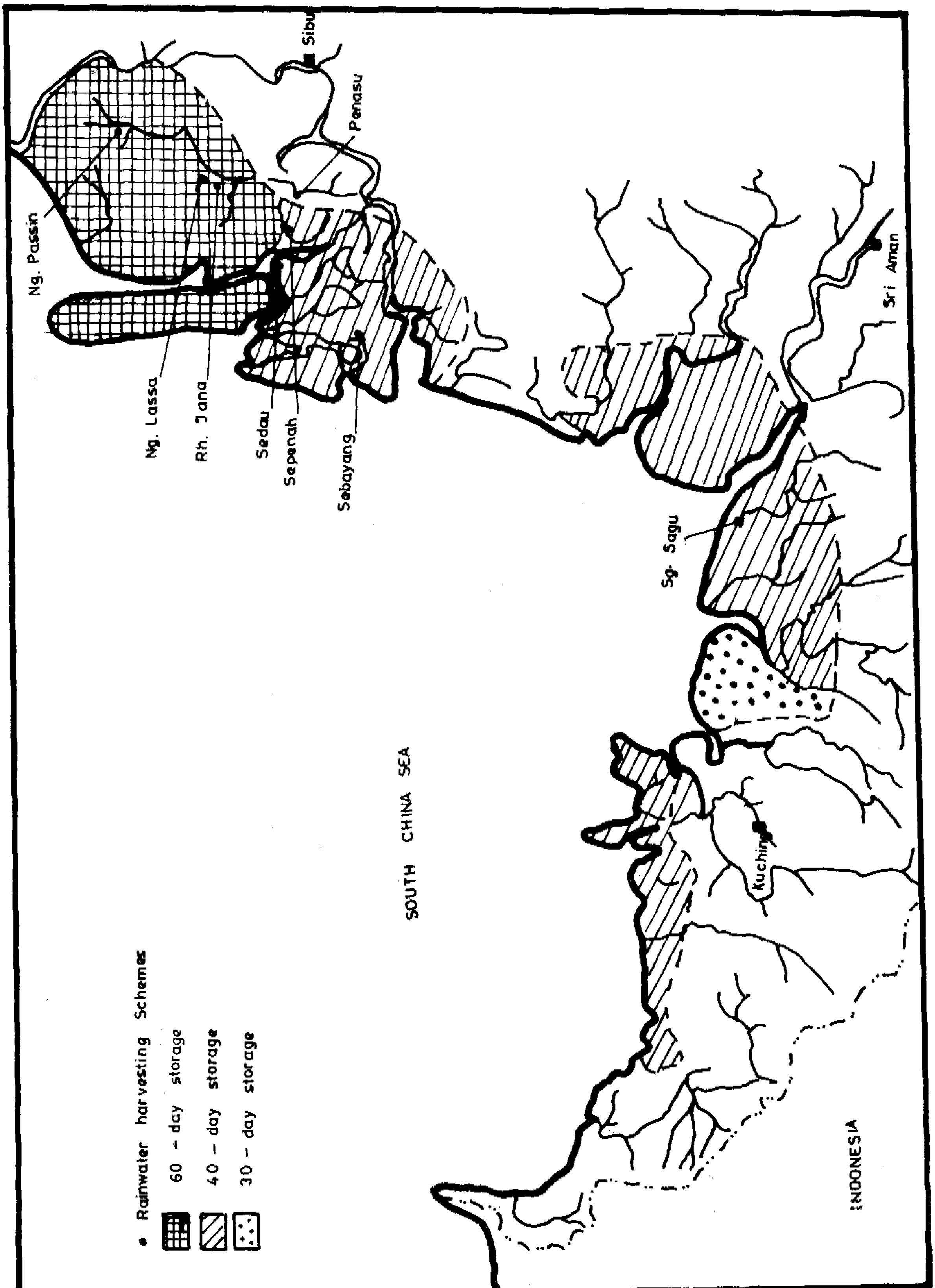

Figure 3 Rainwater harvesing schemes in the Sarawak Coastal region

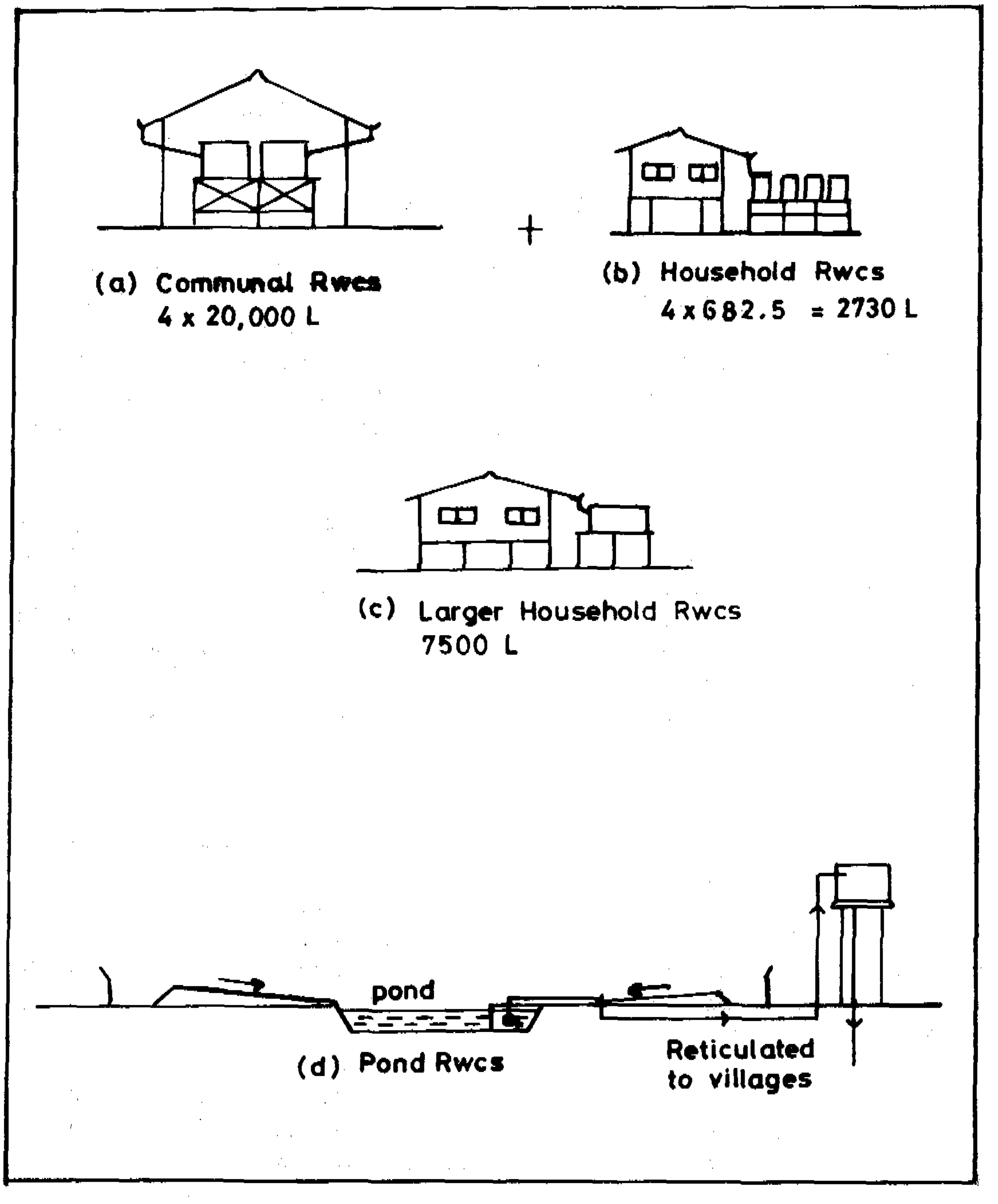

Figure 4 RWCS designs in Sarawak

RAINWATER CISTERN SYSTEM IN MALAYSIA RECONSIDERED

Uzir bin Abdul Malik*, Hamidon bin Othman**

INTRODUCTION

It has been almost a decade since an attempt was made to examine the policy and practice of rainwater cistern system (RWCS) in Malaysia(1). The main aim of this paper is therefore to review the development of RWCS over the past decade and consider its future prospect. This is especially in view of the massive rural water supply programme undertaken by the government particularly during the second half of the decade(2).

It has to be mentioned at the outset that RWCS in Malaysia is essentially a rural water supply system. There has been no attempt on the part of any agency related to water supply to introduce the system in an urban environment and attempts by private individuals to utilize this source of supply can be said to be minimal. The urban areas has been entirely dependent on the potable system provided by the various water supply agencies and the folly of this over-dependence has been clearly demonstrated by the recent failure of the Malacca water supply system(3).

Other than private efforts which are largely uncoordinated, the only programme on RWCS in the rural area is under the purview of the Ministry of Health. However, to quite an extent it could also be said that the RWCS programme of the Ministry of Health at the State levels is largely uncoordinated, This is illustrated by the absence of any clear guideline on programme implementation at the policy as well as technical level.

Malaysia has a population of about 17.4 million. Out of this about 8.0 million or 45% live in the rural areas. Table 1 gives the population breakdown of the rural population as sell as the number

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of households in accordance to the various States in Peninsular Malaysia as well as Sabah and Sarawak, the two Malaysian States in Borneo.

Almost 100% of the urban population in Malaysia have potable water for drinking as well other domestic and industrial purposes. The number of those receiving potable water in the rural areas are also relatively high, about 73.5% as shown in Table 2. The potable systems are being provided by the Ministry of Health and other agencies such as the Public Works Department, Water Authority, Estates and Mining Companies. The Ministry of Health provides untreated water supply through its environmental health programmes. Among the systems used are protected shallow wells, gravity feed system, mechanical pumps and rainwater catchment system(4). As indicated in Table 2, supply of potable water varies from one state to another. By comparison the states in the west coast of Peninsular Malaysia have better access to potable water compared to the states in the east coast. This is partly explained by the fact that the west coast being more developed has better infra-structures compared to the east coast and this include piped water supply. According to the Economic Report of the Ministry of Finance there has been an impressive increase in the population's access to potable water over the past decade. In 1980, only 43 per cent of the rural population has access to potable water compared to about 67 per cent in 1990.

RAINWATER CISTERN SYSTEM- 1980-1989

Since it was first officially introduced in 1968 rainwater cistern system (RWCS) has been largely the undertaking of the Ministry of Health. It was launched in the late 1960s as part of the Rural Environmental Sanitation Programme (RESP). RWCS was one of the water supply systems introduced in the rural areas. The water supply system was closely tied to proper excreta disposal system in order to ensure sanitary environment in the rural areas. This programme requires total community participation not only to minimize costs but also to ensure contineous support. The twinning of these systems at various levels is best described by the following programme strategy:

Table 1: POPULATION DISTRIBUTION AND NUMBER OF HOUSEHOLD IN RURAL MALAYSIA, 1989[1]

State	Population	Number Of Households
Perlis	141,909	34,174
Kedah	845,605	175,997
Pulau Pinang	422,790	79,699
Perak	738,166	151,677
Selangor	433,353	77,519
Negeri Sembilan	326,562	68,746
Melaka	316,784	65,502
Johor	771,516	135,271
Pahang	607,226	119,042
Trengganu	523,324	110,336
Kelantan	954,714	203,792
Peninsular Malaysia	6,081,949	1,221,755
Sabah	908,719	151,631
Sarawak	1,996,059	158,808
MALAYSIA	7,996,059	1,532,294

1. Figures based on census carried out by Helath Officers in their areas of operation.

Source: Laporan Tahunan 1989, Kementerian Kesihatan Malaysia, Ogos 1990.

1. Figures based on census carried out by Helath Officers in their areas of operation.

Source: Laporan Tahunan 1989,Kementerian Kesihatan Malaysia, Ogos 1990.

Table 2: NUMBER AND PERCENTAGE OF RURAL POPULATION RECEIVING POTABLE WATER SUPPLY AS OF 1989

	Health Ministry		Other Agencies		Total	
State	Population	%	Population	%	Population	%
Perlis	5,823	4.1	84,619	59.6	90,442	63.7
Kedah	187,383	22.2	396,763	46.9	584,146	69.1
Pulau Pinang	2,191	0.5	356,193	84.2	358,384	84.7
Perak	94,769	12.8	519,373	70.4	614,142	83.2
Selangor	3,014	0.69	355,957	82.1	358,971	82.8
Negeri Sembilan	6,276	1.92	280,523	85.9	286,799	87.8
Melaka	1,929	0.61	293,951	92.8	295,880	93.4
Johor	32,608	4.2	579,145	75.1	611,753	79.3
Pahang	48,318	7.9	434,067	71.5	482,385	79.4
Trengganu	63,126	12.1	217,723	22.8	280,849	34.8
Kelantan	151,031	15.8	326,292	34.3	477,323	49.9
Peninsular Malaysia	596,468	9.8	3,844,606	63.2	4,441,074	73.0
Sabah	346,939	38.2	302,644	33.3	649,583	71.5
Sarawak	548,740	54.6	240,875	23.9	789,615	78.5
MALAYSIA	1,492,147	18.7	4,388,125	54.9	5,880,272	73.5

Source: Laporan Tahunan 1989, Kementerian Kesihatan Malaysia, Ogos 1990.

> "Promotion of construction and use of sanitary water supply and excreta disposal systems through the provision of technical assistance for the design of such systems using technology appropriate and acceptable to the communities and supply of equipment and materials for the construction of these systems and facilities by the communities on a self-help basis to ensure acceptance, utilisation and maintenance by the communities"

Since its inception this programme has benefitted 1.13 million rural households through its water supply provision and 1.27 million households through the provision of sanitary pour flush latrines.

Under the Ministry of Health rural water supply programme, RWCS is still regarded as a scheme of last resort. Priovities are still given to the gravity feed or handpump systems where situations permit. Only when these sources are not available would RWCS be considered. The construction of RWCS over the last ten years is shown in Table 3. In many states construction only begins in 1983 or 1984. In Peninsular Malaysia the system is only significant in a few states namely Perak, Perlis and Johor. Overall, the system has been most developed in the state of Sarawak. The states which have significant numbers of RWCS are generally regarded as having more areas considered to be at risks, namely rural, riverine, squatter and isolated population. This is in fact very true in the case of Sarawak where there are large numbers of isolated communities.

Over the last ten years the number of sistems have increased about three fold. But this does not reveal the whole picture because no data has been collected on the number of households that require or would benefit from the system. The Ministry in many instances have to reject applications for participating in the RWCS scheme because of unsuitable roofing materials of the houses or the absence of gutters. In the former case the houses normally have thatched palm roof which could contaminate the rainwater. Zinc or corrugated iron roof are normally preferred. In the latter case, the Ministry sometimes also subsidize the purchase of gutters for the participating households.

Table 4 illustrates the number of RWCS units constructed and the associated costs over the period considered. It also indicates the number of population served. The total cost of the scheme has generally increased throughout the period although the cost per capita has fluctuated depending on the number of people participat-

Table 3: THE CONSTRUCTION OF RAIN WATER COLLECTION SUSTEMS BY STATE AND YEAR (1980-1989)

State	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Perlis	0	135	44	55	60	75	116	103	75	87
Perak	0	0	0	0	63	239	747	261	313	359
Negeri Sembilan	0	0	0	0	0	3	6	0	0	0
Selangor	0	0	0	0	0	0	0	0	0	28
Johor	0	0	0	1	39	124	122	183	187	348
Pahang	0	0	0	0	0	0	0	0	0	64
Kelantan	0	0	0	0	0	2	0	4	7	54
Sarawak	1,759	2,696	2,510	3,971	3,939	4,134	2,935	3,610	4,417	6,708
Sabah	104	579	120	16	0	0	0	0	0	0
MALAYSIA	1,863	3,410	2,674	4,043	4,101	4,577	3,926	4,161	4,999	7,648

Source: Ministry of Health, Malaysia.

Table 4: THE CONSTRUCTION OF RAIN WATER COLLECTION SYSTEM IN MALAYSIA (1980-1989)

Year	No. of Units Constructed	Population Served	Total Cost	Cost Per Capita
1980	1,863	6,189	$250,503.20	$40.48/cap
1981	3,410	16,292	$502,881.28	$30.87/cap
1982	2,674	8,229	$409.505.00	$49.78/cap
1983	4,043	13,032	$489,546.00	$37.56/cap
1984	4,101	15,702	$743,657.35	$47.36/cap
1985	4,577	15,639	$622,073.35	$39.78/cap
1986	3,926	14,580	$863,207.96	$59.20/cap
1987	4,161	13,669	$733,688.16	$53.68/cap
1988	4,999	16,699	$1,381,902.47	$82.75/cap
1989	7,648	25,820	$1,615,464.00	$62.57/cap

Source: Ministry of Health, Malaysia.

ing during the particular year. The cost of RWCS varies from one state to another depending on sheme implimentation. The scheme that utlizes community efforts at all stages of construction tends to be lower in costs.

RWCS DESIGN SYSTEM

Since it was first reported in the first RWCS conference in 1982, there has been very little change in the design of the RWCS in Malaysia. The design criteria is still based on an average family size of 6 and per family water consumption of 9 gallon or about 40 litres per day. This is mainly for consumptive purposes i.e drinking and preparation of food. The storage tanks which are constructed using reenforced concrete vary from one state to another. Generally each storage tank is 4 feet in diameter but can be 2 feet or feet in height (see plate 1). The former are generally supplied by a successful tenderer, while the later are generally built in-situ. Each system normally consists of two tanks of 4 feet in diameter and 8 feet in height. This will give a capacity of about 5688 litres and could last a family for about 4 1/2 months.

There are, as indicated above, slight variations in some states. In one particular state of Perlis the design criteria is based on the requirement of a family size of 8 and a consumption level of 5.8 litres per day. Each tank then is estimated to have a capacity of 1256 gallon (5712 litres) and could last a family for about 4 months. In order to participate in the RWCS programme in the district, a house should also a minimum catchment size of 28 feet and 10 feet normally of currugated zinc. This in fact is the general requirement in most states. It can easily be deduced that this requirement has some welfare implications. It means that the really poor who normally uses thatched palm leaves as their roofs would be automatically out of the programme. In a few states this problem is overcome by extending the subsidy scheme to include part of the roofing materials.

In an another area called Parit Buntar in the state of Perak the design criteria is for a family of 5 and a consumption level of 5 liters per day. The storage tanks here are of a smaller size, i.e 3 feet in diameter and 2 feet high. These cement cylinders are also provided by a tendered supplier. The choice of a smaller size tank component is to facilitate transportation and construction. Since construction works are mainly undertaken on a communal basis, the larger size tank was found to be rather cumbersome. In this particular case a system which is made up of 4 cylinders could store about 350 gallon (1539 litres) of water and last about 45 days.

Plate 1

SYSTEMS COSTS

The RWCS of the Ministry of Health is largely a community based system and largely subsidised by the Ministry. Generally the Ministry of Health requires each household to contribute M$20.00 towards defraying part of the material costs. Construction costs vary markedly from one state to another and from one construction site to another depending on the materials used, the transportation costs involved and the size of the available labour force. Table 5 gives the approximate per capita construction costs for the different type of water supply projects sponsored by the Ministry of Health.

The rainwater storage system as shown above is relatively cheaper compared to the other systems. However, the overall system cost Varies from one state to the other depending on the system design, availability of required materials and the number of suppliers in the area. For example in the state of Perlis a rainwater catchment system with a capacity of 5688 litres costs approximately M$508.00. On the basis of six members per household, the per capita cost is around M$85.00. The costs as shown in Table 6 comprises of storage tank and its foundation, gutters and pipes for house connection. A participant is also normally required to contribute M$100.00 to purchase the items necessary for connection to the house.

Another estimate in Table 7 shows a more detailed costing of the RWCS. This estimate also assumes that labour is voluntary and that the house has adequate gutter system. However, as will be indicated in a research undertaken, there are other factors that need to be considered in assessing the financial feasibility of a rainwater storage system. Since storage costs can be considered the most expensive element, the most important factor would therefore be the adequacy and regularity of supply. This is of course largely determined by the rainfall pattern of an area and the mode of consumption.

PRIVATE RAINWATER COLLECTION SYSTEM

It has to be admitted that rainwater usage in the rural areas is more extensive than that provided by the scheme under the Ministry of Health. Private individuals and households have utilized rainwater since vary early days, although it was mainly used for non-consumptive purposes. Only with the introduction of zinc and iron roofing materials and earthernware containers does rainwater be used for consumptive purposes. Plate 2, 3 and 4 show the various sizes of earthernware containers used and the typical roofing materials used as catchment areas.

In addition, rainwater has also been used for public purposes such as schools, mosques and community centres. However, except for vary remote areas such uses are quite rare. This is largely due to the fact that most public buildings are normally constructed using government funds and provision of potable water is usually standard procedure. Plate 5 shows an elevated rainwater storage system used by a school.

Table 5: APPROXIMATE PER CAPITA CONSTRUCTION COST FOR MOH RURAL WATER SUPPLY

Type of Project	Material	Labour	Total
		Costs: M$	
Gravity scheme with house connection	30	15	45
Sanitary well with house connection	25	13	38
Sanitary well without house connection	6	5	11
Pumped water supply with house connection	30	15	45
Hydraulic ram with house connection	35	15	50
Rainwater stroge	20	10	30

Source: Ministry of Health

Table 6 : ESTIMATED COST OF RAINWATER CATCHMENT SCHEME PER HOUSEHOLD IN PERLIS

Item	Quantity	Price Per Unit	Total Cost
A. Storage Tank and Foundation			
1. River sand	5 cu feet	$18.00	$90.00
2. Bricks (3/4")	21/2 cu feet	22.00	55.00
3. Bricks (11/2")	1 cu feet	20.00	20.00
4. Cement	101/2 bags	9.20	96.00
5. Steel B.R.C. No. 10	48 x 6 1/2'	0.91	43.68
6. PVC pipe	2 feet	2.11	4.22
		Total	$309.50
B. Gutters			
7. Zinc (0.oooz(ft^2) x 61/2	30 feet		123.00
8. Down pipe outlet	15 feet	4.10	61.50
C. House Connection			
9. PVC pipe 1/2"	25 feet	$0.16	$ 7.17
10. PVC Elbero 1/2"	4 pieces	0.42	1.68
11. PVC 1/2" Foucet Socket	1 pieces	0.46	0.45
12. 1/2" Brass Socket	1 pieces	4.90	4.90
		Total	$ 14.21
		GRAND TOTAL	$508.21

Source: Department of Health, Perlis.

Table 7: ESTIMATED COSTS PER UNIT OF RAINWATER CATCHMENT PROJECT

Name Of Material	Quantity	Cost/Unit	Total Cost
A. <u>Expenditure by the Ministry of Health</u>			
1. Base Covered Cement Mould 3'	1	$25.00	$25.00
2. Uncovered Cement Mould 3'	3	$20.00	$60.00
3. Cement	3	$10.00	$30.00
4. Bricks	1 ela	$35.00	$35.00
5. Sand	1 ela	$ 7.50	$ 7.50
6. "Bakau" timber	5 batang	$ 3.50	$17.50
7. PVC/Pipe 13/4	2 batang	$ 7.28	$14.56
8. PVC/Pipe 1/2"	4 batang	$ 2.44	$ 9.76
9. Gutter	4 batang	$ 6.91	$27.64
10. End Stopper	2 pcs	$ 1.66	$ 1.66
11. Down Spout	1 pcs	$ 8.53	$ 8.53
12. Joiner	3 pcs	$ 1.27	$ 3.81
13. Elbow (EL)	2 pcs	$ 5.56	$11.12
14. Down Spout Joiner (DSJ)	1 pcs	$ 1.87	$ 1.87
15. Mitre Joint (MJ)	2 pcs	$ 5.23	$10.56
16. Down Spout Pipe	1/2 lenght	$13.86	$ 6.93
17. Gutter bracket	15 pcs	$ 1.21	$18.15
18. Solvent cement	2 tin	$ 3.80	$ 7.60
		Total	$297.19
B. <u>Expenditure by Householder</u>			
19. Faucet 1/2"	2	$ 5.30	$10.60
20. G.I 'T' 1/2	1	$ .80	$ .80
21. Valve Socket 11/4	2 pcs	$ .70	$ 1.40
22. Valve Socket	2 pcs	$ .60	$ 1.20
23. Elbow 11/4"	2 pcs	$ 1.30	$ 2.60
24. Gate Valve 11/4"	1 pcs	$ 6.00	$ 6.00
25. Elbow 1/2"	2 pcs	$ .40	$ .80
26. Jam Nut 1/2"	1 pcs	$ .70	$ .70
27. Solvent taoe	1	$ 1.50	$ 1.50
28. Mosquito net			$ 3.00
		Total	$ 28.60
		GRAND TOTAL	$325.79

Plate 2

Plate 3

Plate 4

RESEARCH ON RAINWATER CISTERN SYSTEM

Very little research work has been conducted on Rwcs in Malaysia. This is largely as indicated earlier due to the lack of emphasis on this system of providing water supply even in the rural areas. As a result there has been little improvement in both the technical and institutional aspects relation to the system.

An attempt, however, was made in the late eighties to study current knowledge and practices of RWCS in peninsular Malaysia(5). It also attempted to investigate the socio-cultural and economic aspects of rainwater usage. The study was based on surveys of sellected areas where there were no supply of potable water and due to certain characteristics of the area, RWCS was considered appropriate.

There were a number of findings from this study. In all the three areas covered by the survey it was established that rainwater was an important, although generally treated as a supplemantary source of supply. It was foud that more than 90% of the households use rainwater mainly for domestic purposes. Another important finding is that in all the study areas, the rainwater catchment system of most households was grossly inadequate. And although most houses have what can be considered as acceptable catchment areas mainly made of corrugated zinc, many do not have adequate gutter as well as storage facilities. This was largely due to lack of information especially regarding rainfall pattern and also partly due to lack of fund. The setting up of a rainwater catchment system with adequate gutter and storage facilities would require substantial capital outlay especially after a house has been constructed.

The study also revealed that rainwater is generally acceptable both for consumptive as well as non-consumptive uses. Although most systems did not have proper filters, very few complained its use on health grounds.

Finally, the study also indicated that most respondents prefer to locate their storage tanks near the kitchen for easy access. The aesthetic considerations of the tanks in terms of size, shape and materials used seemed to be of rather low priority.

Plate 5

FUTURE PROSPECT OF RWCS IN MALAYSIA

The future prospect of RWCS is very closely tied to the construction of other rural water supply systems. In general it could be said that the independent rural water supply systems including RWCS are going to be phased out and replaced by the fully treated raticulation system. This has been the objective of the government since the beginning of the last decade.

In line with this objective the Ministry of Health, the agency responsible for the non-centralized rural water supply systems, have reduced the number of systems to be implemented during the current year and also the year after. As shown in Table 8, the Ministry has agreed to construct only 894 RWCS in the current year compated to 1,126 in the previous year. The number of shallow wells as well as the gravity feed system have also been reduced. The reduction in number is largely in response to the availability of areas that still require the services of such systems. Those areas that have been or would be shortly served by the centralised system would not be considered for the independent systems.

Although the number of the independent systems are to be decreased, the distribution in some states could show otherwise. This may be due to the slower development of the centralized systems within such states. Table 9 gives the distribution of the rural water supply systems to be implemented in the curreht year.

It is interesting to note that the construction of RWCS for the current year tend to concentrate to the more developed states of Johore, Perak and Selangor. But overall the rural water supply systems of the Ministry of Health tend to serve the less developed states especially those in the east coast of the Peninsular.

CONCLUSION

Rainwater collection systems are still quite extensively used in rural Malaysia. Although the large majority of them do not any more used" ... pans, jars and tubs", but earthenware of various sizes and proportions, With the massive extension of the urban-type raticulation system one would suspect the usage to have generally declined during the last decade. However, based on the figures of RWCS constructed with the aid of the Ministry of Health one gets an opposite impression because the number has in fact increase quite substantially over the period. There are two possible explanations:

Table 8: TYPE AND NUMBER OF SYSTEMS TO BE IMPLEMENTED IN 1990-1992-AND POPULATION SERVED

Water Supply System / Year	1990	1991	1992
1. Shallow wells	1,798	1,697	1,339
2. Gravity feed system	210	191	142
3. Rainwater catchment system	1,126	894	1,030
Total population served (cumulative)	1,177,089	1,600,000	1,625,475

Source: Ministry of Health, Malaysia.

Table 9: TYPE AND NUMBER OF SYSTEMS TO BE IMPLEMENTED IN 1991

Water Supply Systems / State	Perlis	Kedah	Pulau Pinang	Perak	Selangor	Negeri Sembilan	Melaka	Johor	Pahang	Trengganu	Kelantan	Sabah	Sarawak	Total
1. Shallow wells	8	332	4	35	4	38	0	27	120	268	349	144	10	1,339
2. Gravity feed system	0	2	0	10	3	0	0	1	8	1	12	45	60	142
3. Rainwater catchment system	68	25	0	180	100	0	0	305	160	0	9	100	83	1,030
4. Total pop. served	76	359	4	225	107	38	0	333	288	269	370	289	153	2,511
5. Total population served	6,200	207,383	2,270	98,769	4,014	7,076	2,000	39,608	58,318	73,127	191,031	386,939	548,740	1,625,475

Source: Ministry of Health, Malaysia.

1. Many areas are still out of the reach of the national rural water supply programme and therefore are dependent on other water supply sources.

2. The RWCS under the Ministry of Health has so far met the demand of only a small proportion of the rural households that need rainwater collection systems. If the policy continues the number could still increase in the near future.

As far as the policy maker is concerned, RWCS is still a source of last resort and its official programme will be phased out with the extension of the potable water supply system. This explains the lack of research and development works on RWCS. Without governmental support there is unlikely to be much progress in this area.

The future prospect of RWCS in Malaysia is not bright at the present juncture. However, the failure of the raticulation system in Malacca should be a lesson to the national authority on the folly of depending on just one supply source. Furthermore the development and operational costs of such systems are already increasing. The development of alternative water supply including RWCS has many hidden advantages. Its extensive use will releave some pressure on raticulation system development and this means savings in costs and allowing supply source for other uses especially recreational uses which would have higher value in the future.

1
A status paper was presented at the first Rainwater Cistern System Conference in Honolulu, Hawaii in 1982.

2
The government has committed more than MR 1 billion during the last decade of development for rural water supply . This is mainly in the from of extensions of urban systems as well as construction of treatment and raticulation facilities in the rural areas.

3
A major water crisis struck the state when the Durian Tunggal Dam, its main water supply source dried up during early January this year. The people have to resort to all supply sources including old wells and rainwater.

4
The terms rainwater cistern system, rainwater catchment system and rainwater storage system are used interchangeably here.

5
The study was a spin-off of the RWCS conference in Hawaii and was funded by IDRC of Canada.

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RAINWATER HARVESTING AS SUPPLEMENTAL SOURCE FOR THE TRADITIONAL AND MODERN WATER SUPPLES FOR FORMING FAMILIES IN MALAWI

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(Agric. Engr.)

ABSTRACT

Rainwater harvesting simply means collecting rain water in some suitable reservoirs.

To achieve this simple phenomenum a systematic process has to be followed. This involves provision of an ideal surface area, referred to as catchment area and the receiving tank or reservoir referred to as cistern.

The family rainwater harvesting system is expected to provide water for all their needs, drinking, cooking ,washing, irrigation etc. But there are several limiting factors that regulate the volume of water collected. The natural factors are the potential annual rainfall and the duration of the dry season. The adjustable factors are the collection surface (roof) area or catchment area and the cistern capacity. The most important limiting factor is the FUND.

INTRODUCTION

This paper will try to highlight the approach adopted in the project Agrometeorology/Data Processing MLW/84/016, towards implementing rainwater harvesting as a means of supplementing the traditional and modern sources of water supplies for the farming families in Malawi.

The prime objective of this programme is to provide the rural farmer with some drinkable water and help farmers survive the short dry spells which make his crops to wilt away or suffer a yield

WMO/UNDP PROJECT MLW/84/016 (Agrometeorology/Data Processing)
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reduction before harvest. Apart from rainwater harvesting some other cultural practices have been introduced to the farmer in this programme but will not be discussed here.

The trial run was conducted in 1989 when about 300 farmers participated in the programme in Lower Shire area but this year 1990 we have covered more grounds in the Lower Shire and Blantyre ADD and hopefully we shall get across to more than 1500 farmers. This pilot programme is expected to end in 1991.

Malawi is one of the landlocked countries in Central Africa, South of the equator. Geographically it is dominated by its enormous lake, the Africa's third largest and word's twelfth.

Malawi has three seasons, the day, the cool and the wet. From May to August it is cool and dry. July is the mid-winter month with maximum and minimum temperature of about 22 and 12 in the capital city. From September onwards it is hot and dry, with October and November the hottest months recording mean temperatures of 29 .

The rainy season extends from November to April. Annual rainfall varies between 600 mm in the Lower Shire Valley in the South to 3000 mm in the highland areas (National Atlas of Malawi). See figure 1.

The rainy season is usually punctuated by dry spells and in some cases the duration of the dry spells is about a week or more (van der Velden, 1979).

As of 1986, the Government of Malawi estimated that about (4.5 million people) 72 percent of the population collect water from traditional sources (hand-dug wells, rivers, streams). The remaining 28 percent get their water from improved (modern) sources (boreholes, gravity fed pipes, urban water system).

CATCHMENT SURFACE:

The initial survey carried out indicated that few farmers have adequate roofs, made from Iron sheets the ideal surface for rainfall harvesting. Most roofs are thatched and too loose to effectively hold water or not strong enough to hold a gutter in place (the gutter is a conduit for easy flow of water into the cistern).

In such a situation, a sturdy but simple open-air locally sourced woven bamboo-mat shed of 2.0 m x 4.0 m in dimension was recommended. This usually cost little to nothing ($3.00) as the materials for construction are village sourced and made by the farmer. In some cases the farmer makes use of his existing thatch roof but the designated section is covered with polythene sheet. See Figure 2.

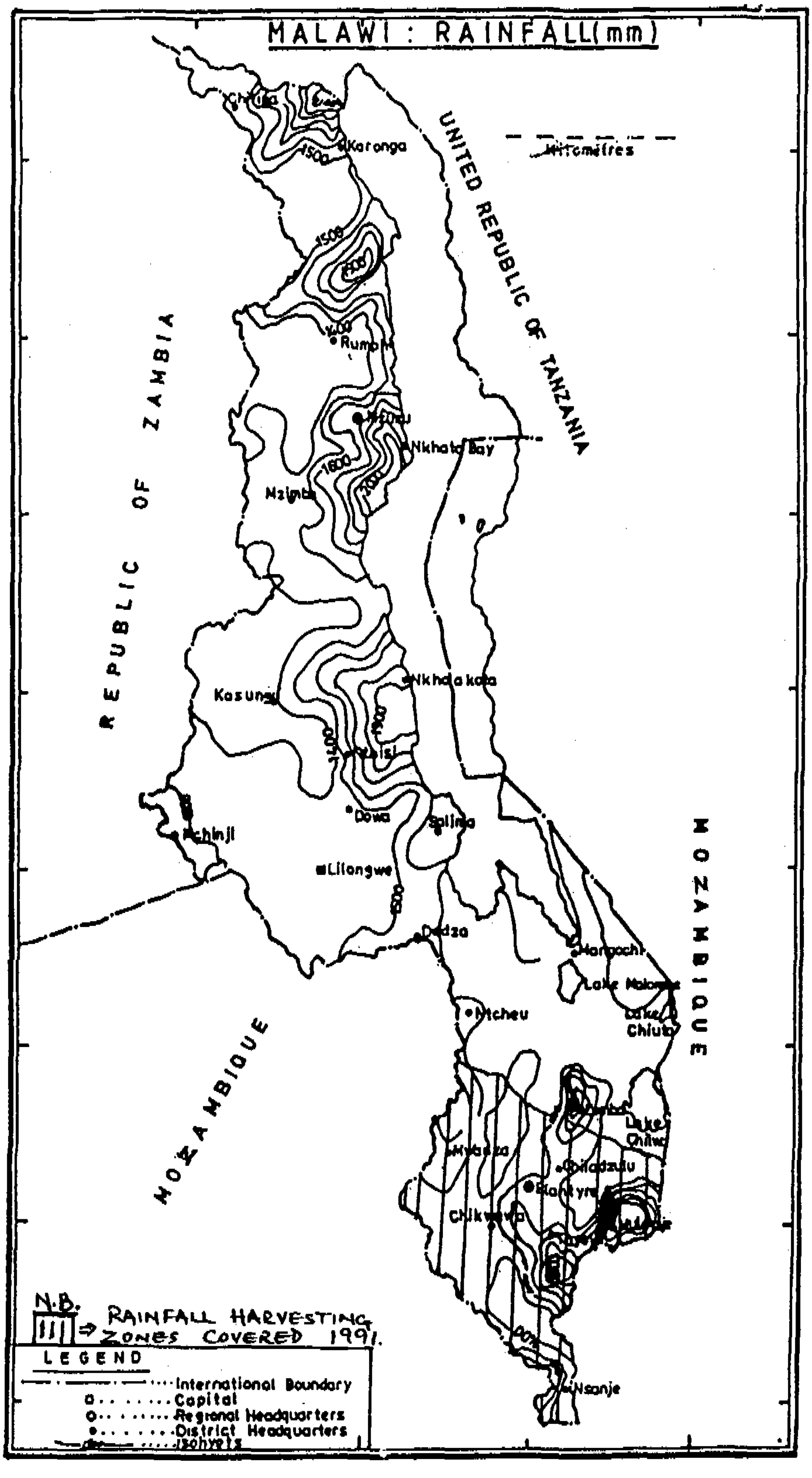
MALAWI : RAINFALL(mm)
UNITED REPUBLIC OF TANZANIA
REPUBLIC OF ZAMBIA
MOZAMBIQUE
MOZAMBIQUE
Kilometres
Karonga
Rumphi
Nkhata Bay
Mzimba
Kasungu
Nkhotakota
Dowa
Salima
Mchinji
Lilongwe
Dedza
Mangochi
Lake Malombe
Lake Chiuta
Ntcheu
Lake Chilwa
Mwanza
Chiradzulu
Blantyre
Chikwawa
Nsanje
N.B. → RAINFALL HARVESTING ZONES COVERED 1991.
LEGEND
International Boundary
Capital
Regional Headquarters
District Headquarters
Isohyets

Fig. 1

- Roof (woven mat ≃ 2m x 4m).
- Gutter (woven reed or Bamboo)
- Cistern (Nkhokwe lined with Plastic)
- Raised platform

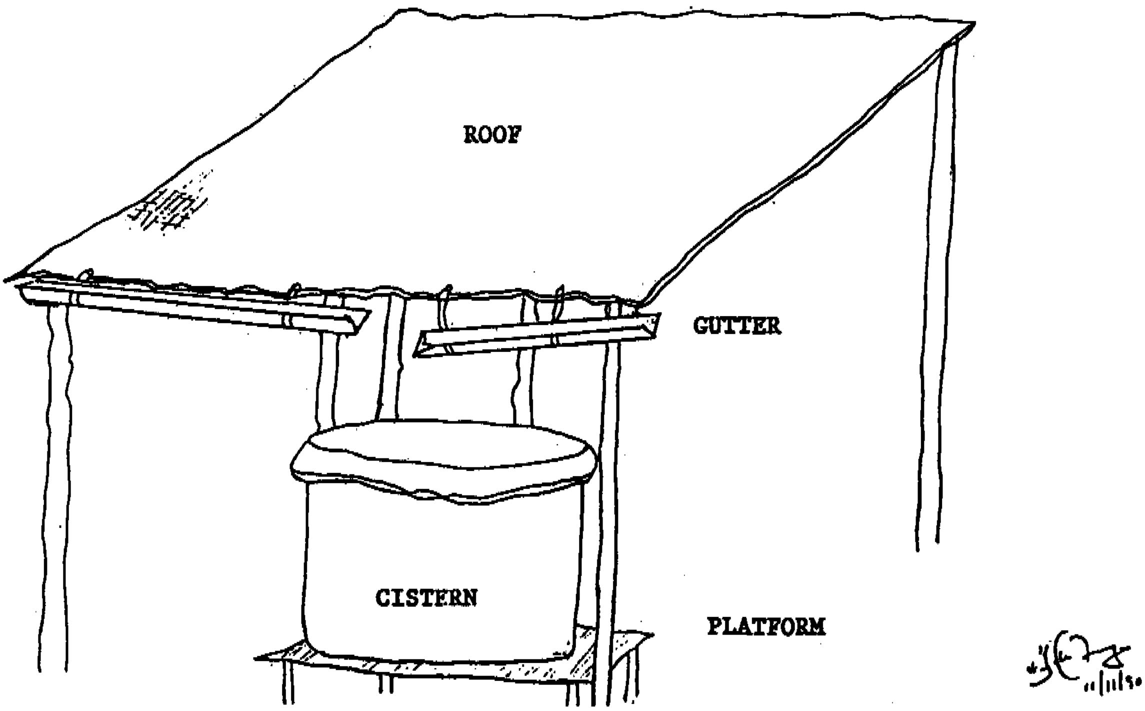

Fig.2 TYPICAL RAIN HARVESTING ASSEMBLY:

- made from woven bamboo strands or twigs
- dimension of 1.5m high and 1.0m diameter
- plastered with clay both inside and outside
- lined with 250 microns plastic tube
- must be covered always

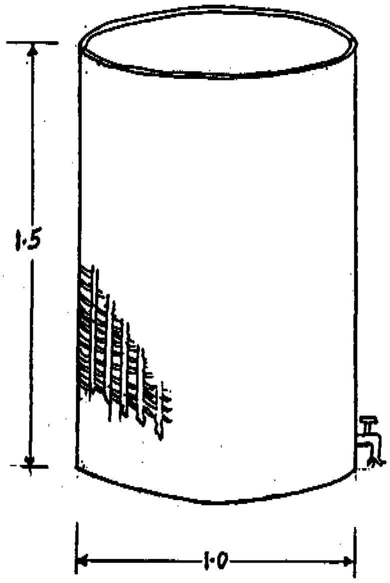

Fig. 3 CISTERN-(Nkhokwe)

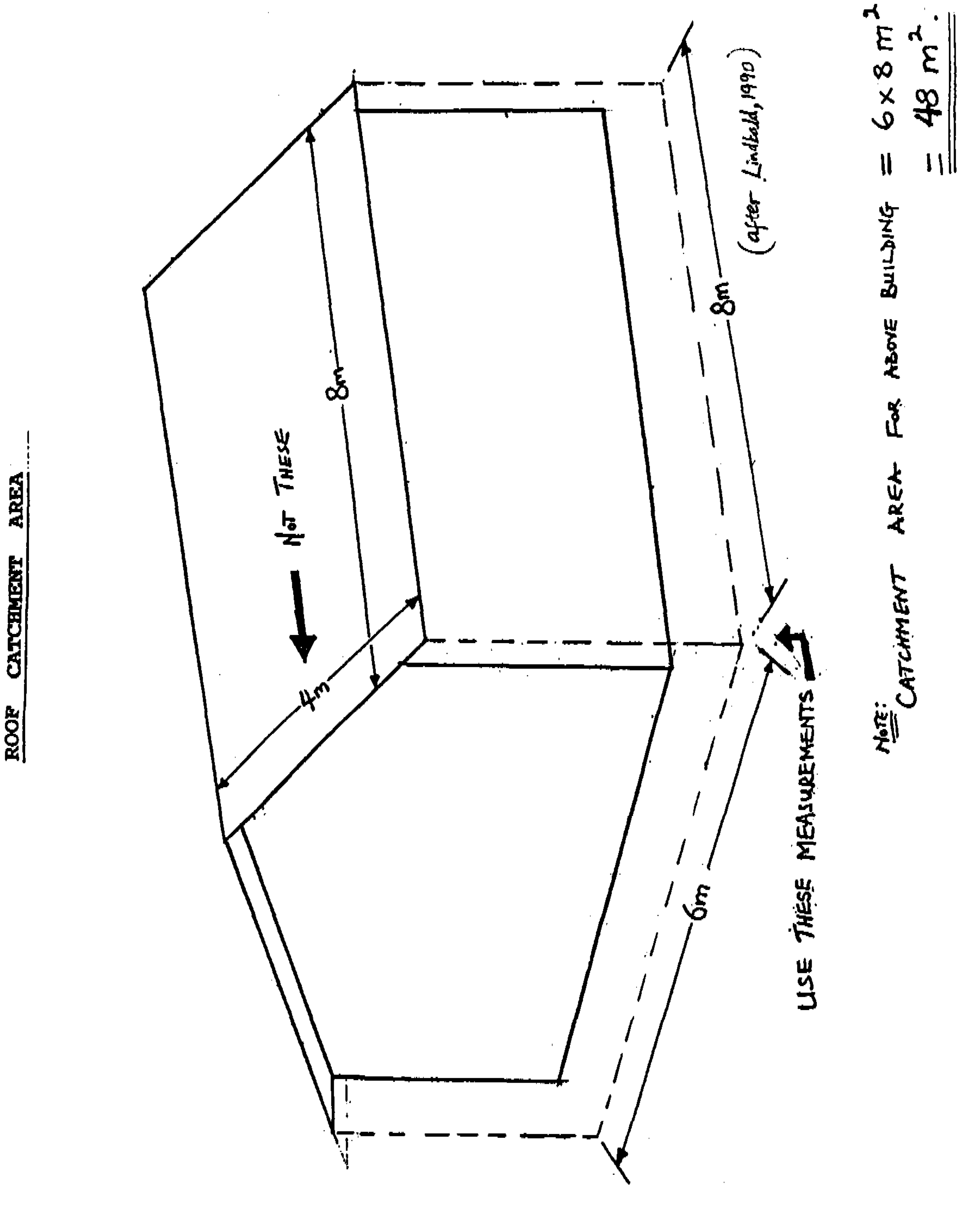
ROOF CATCHMENT AREA
NOT THESE
8m
4m
8m
6m
(after Lindskld, 1990)
USE THESE MEASUREMENTS
NOTE: CATCHMENT AREA FOR ABOVE BUILDING = 6 x 8 m².
= 48 m².

Fig. 4

The gutter in most cases is made from horizontally splitted bamboo or woven reed which is lined with polythene sheet. The affluent farmers of course uses corrugated iron sheet for both the roof and gutter. Runoff water from most common materials such as tiles, iron-sheets, and brick pavements is chemically safe for drinking (Hofkes, 1981).

The catchment area for a house is the measurement of ground surface covered by the roof. The roof surface is never measured thus whether the roof is flat or slope is not important in the calculation (Lindblad, 1990). See figure 4.

Experts have advised that rainwater harvesting calculations be based on the lowest rainfall in eight or nine of the past ten years. These figures are available with the Meteorological Department.

Since the potential rainwater (runoff) collected from a designated roof of identified size is a product of the catchment area and the annual rainfall figures, then the larger the surface area covered by the roof the greater the amount of rainwater harvested and the bigger the cistern required for storage.

In this project about 30 percent of our identified farmers collect rainwater from thatched roofs. Most thatched house farmers are reluctant to participate because of the brown-colour associated with water from such roofs.

CISTERN

The rainwater harvesting potential of a collection surface depends wholly on the natural factors such as the potential rainfall and the day season duration for the place in consideration .

In this programme the cistern structure chosen is based on the traditional grain basket (Nkhokwe) made from either bamboo strands or twigs and lined inside with polythene tube. The polythene tube is to make the structure waterproof and the water hygienic for drinking.

While constructing the structure effort is made to make the internal surface free of protrusions and sharp edges that may perforate the internal lining of polythene tube and thus render it useless.

In some cases banana leaves or mats are used to cushion the walls of the Nkhokwe cistern before incorporating the polythene tube. But an ideal procedure is to plaster the Nkhokwe in-and-out with clay material. This has been found to prevent termite attack and prolong the life of the structure. See Annex 1.

For stability, it is either placed on a raised wooden platform or buried in the ground to about 15 centimeters depth. The present standard size in use is 1.5 metres high and 1.0 metre diameter. Such size could hold about 1200 liters of water conveniently. The polythene tube is 1.36 metres in diameter and 3.0 metres long. If fully utilized it can hold about 4.0 cubic metres of water but we took care of safety in usage, thus the relatively smaller cistern size. The system of taking water from the cistern is either by siphon, a bucket or a carefully installed water tap at the base of structure. See Figure 3.

FAMILY WATER REQUIREMENT

The potential rainwater (runoff) collected annually from a designated roof of identified size is a product of the catchment area and the annual rainfall figures. Thus the monthly rainwater harvesting potential of a collection surface is the product of the ground area covered by the roof and the probable monthly rainfall figures for that location. Consequently, knowing the dry season months gives one the idea of total water deficit, then one can design a relatively large cistern to store enough water to sustain the family through the dry period. But there are problems such as:

(1) <u>Cost</u> : Larger cisterns usually cost more per volume due to the more sturdy construction required as water pressure increases with water volume.

(2) <u>Materials</u>: Materials for sturdy structures can not be locally sourced in the villages and when available (such as cement for concrete structures and corrugated iron sheet for roofing) the cost is usually outside the farmers reach.

The structures design is therefore centered around least cost for collecting adequate rainwater to last for a period of 2 to 8 weeks depending on intensity of usage.

Domestic:

The minimum daily drinking water requirement for an average person is 5 liters. And total daily water requirement for an average man is 30 liters or more per day.

At the optimal minimum of 5 liters per day a family of 10 would need 50 liters per day.

Monthly water needed by the family will be
50 liters x 30 days = <u>1500 liters</u>

For a dry season of 6 months the family require
1500 x 6 months = 9000 liters

From above our present cistern can sustain the family for one month after which they can use it for storage of water from other sources.

Supplemental Irrigation:

Even the driest part of Malawi have enough seasonal rainfall to produce at least one good maize crop or another every year. But rainfall intensity higher than soil infiltration rate results in low rainfall absorption by the soil, high runoff and soil erosion. Seedlings die before the next rain. Dry spells in flowering stage of crops severely reduce crop yield. Two to four week supplemental irrigation in the whole growing period can insure crop production. Through rainfall harvesting, all rainfed farms can have supplemental irrigation.

A 400 m^3 reservoir (such as 18.2 m x 13 m top , depth of 3 m and slope of 45 degrees) can irrigate a quarter-hectare of rice or three-quarter hectare of row crops e.g. water melon during the critical periods for water. The existence of critical periods for water in the development of crops make supplemental irrigation technically feasible. The critical periods include seedling establishment, flowering , and yield formation. If water is limited it is better to use it during the flowering stage. Water shortage at that time can reduce yields of maize, for example, to only 30 percent of potential. Only water left, should be applied at yield formation stage, as planting is normally done when the soil is moisture laden (Baradas, 1988).

Most farmers in the rural areas crop about 0.4 hectare (1.0 acre) of land.

Using the above parameters we can obtain the amount of water required for supplemental irrigation:

0.75 ha of row crops require 400 m3 of water

then, 0.4 ha of row crops will require $\frac{400 \times 0.4}{0.75} \frac{m^3}{1}$

$= \underline{213\ m^3\ \text{of water}}$

Thus , about 213 m^3 of water is required for the total supplemental irrigation of 0.4 ha of row cropped farmland per season.

Considering the existing structure in relation to the cropped land, e.g. at Ngabu which has Mean Annual Rainfall of 803 mm (0.803 m) :

	Annual Water Collected	
	Structure	Farmers land
Catchment Area available (Average) :	2m x 4m = 8 m^2	0.4 ha = 4000m^2
Total Rainfall Harvested per Annum :	0.803 m x 8 m^2 = 6.424m^3	0.803 m x 4000m^2 = 3212 m3
1 m^3 contains 1000 Litres of Water :	= 6,424 litres of water	= 3,212,000 litres of water

The above comparison confirms that although enough water is available the structure is not big enough to harvest adequate water to totally supplement the water requirement of the farmland. Some partial effort is achieved. But construction of clay or polythene lined reservoir is highly recommended. See Annex 2.

FOUL FLUSH

Rain water falling on a roof at the beginning of the rainy season is usually contaminated with accumulated dust, leaves, bird droppings, soot etc. that have accumulated there after the last rains.

The first few minutes of rainfall should be depleted from the cistern by moving the spout away from the cistern or covering up the cistern during this period of polluted discharge. This is referred to as Foul Flush.

FILTER SYSTEM

In a thatched roof house positioning of a filtration system (about 3 centimeter layers of gravel, charcoal, coarse sand, placed in a perforated container) between the gutter and cistern will help to :

(1) screen the water entering the cistern free of broken leaves.

(2) eliminate the brown coloration of soot usually associated with the cookings done in a thatched roof house.

WATER SOURCES

It has been observed that during the rainy season families tend to rely on the traditional water sources that are close by and in relative abundance for domestic use. The cistern water is conserved until the nearby water sources become depleted especially in the dry season when the cistern is used until that supply is exhausted. Thereafter women return to carrying all of their family's water.

The sources are usually a reasonable distance making the collection process extremely time consuming and exhaustive. Some modern sources include the Boreholes (e.g. Ngabu) which are few in number and could be more than two-kilometers from a farming family. Sometimes it may take two hours to get a bucketful and some remain dry for a reasonable part of the year. Another is the Piped water sources (e.g. Mulanje). Some of these pipe lines get blocked and remain unserviceable for a reasonable time.

There is another group that live far from the traditional water sources. In this case the cistern is used as their central focus of immediate water source. They virtually rely on it for domestic water supply throughout the year. And all they do is to go out and fetch water from far away sources in the dry season and store in the cistern.

In both cases above, the cistern serves as an immediate reservoir of water for the farming family during the dry season , thus saving the woman some valuable time for other home or farm duties. The long run effect is improvement in quality of life. The fact that the cistern is in use throughout the year either as rainwater collecting tank or as water storage tank are pointers to its acceptance and importance to the farming families.

Not surprisingly therefore most farmers pose the following:-

(1) that the cisterns and catchment surfaces are too small and want a larger, robust and more permanent models.

(2) wishes to have more than two cisterns which means supply of more polythene tubes (each cost $10.0 estimated).

(3) wants to know whether the supply of the polythene tubes would continue indefinitely or not.

FUTURE TREND

The present rainwater harvesting operation (both domestic and agricultural usages) is on a pilot programme level and if we are to give positive response to above questions then we shall go out of our scope of operation.

The reality here now is that the awareness has been created. The farmer now knows (in the areas covered) that he can collect rainwater during the rainy season for use in his farm or at home as the need may be.

The project (Agrometeorology and Data Processing: MLW/84/016) in its efforts at tackling one aspect of the farmers requirements that is, augmenting the water need of the farmer to nurture his crop through the rainy season till harvest has by so doing been confronted with the survival of the farmer in the aspect of his domestic water requirements . To be able to handle the water need on a broader scope more fund would be required to modify the design and construct bigger and ideal catchment surface area as well as, larger more robust cistern or reservoir for the adequate collection and storage of hygienically suitable rainwater to sustain the farmer and his family through the dry season period of about 6 months.

In this regard the Department of Meteorology and others should deem it fit to address at this juncture the inadequacy of this rainwater harvesting programme and recommend to the higher authorities, as well as the donor agencies (WMO, USAID, UNICEF and UNDP especially) the need to have this programme on a larger and more comprehensive scale such as had been done in some other sub-Saharan countries e.g. Togo, Botswana, Kenya and Mali. The possibility of a joint financing should be exploited.

CONCLUSION

Providing rural dwellers or farmers in general with the materials and know-how to own their rainwater collection structures has proven to be one way of solving two prong problems:

(1) to provide water for supplemental irrigation of crops during the short dry spells within the crop growing period; and

(2) to increase the urgently lacking supplies of safe drinking water for the farming families.

There is no doubt that supporting such programmes can add succor not only to the farmers meager income but to the national crop yield potential and bring about great improvement to public health as well as, relieve for womenfolks in the farming families by serving as an alternative to distant or polluted water sources.

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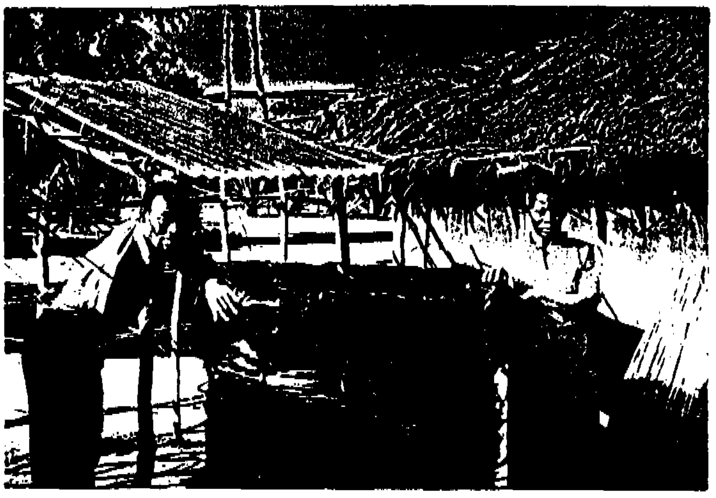
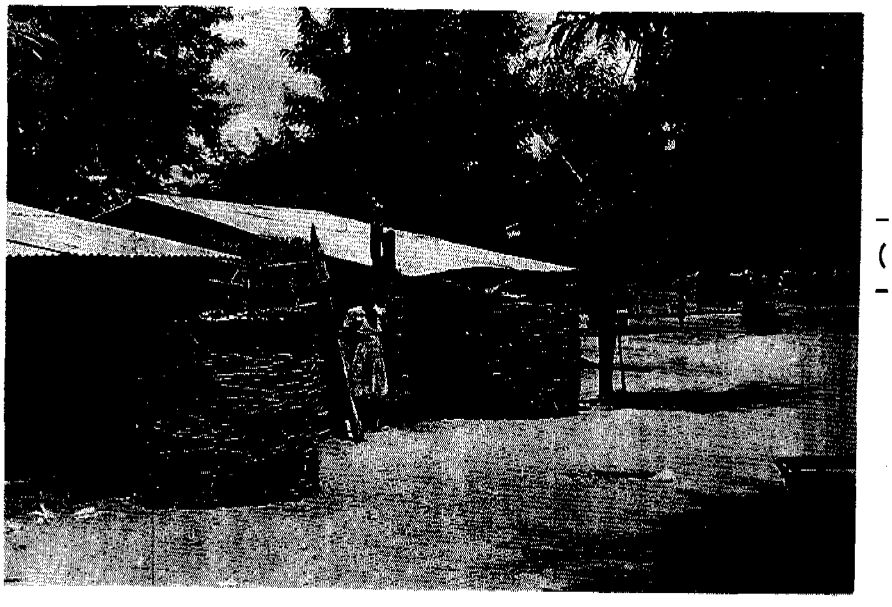
Annex 1



Note:
- The catchment areas
- The cistern(Nkhokwe)

Note:
- The catchment area
- The Gutter
- The Filteration system
- The Cistern lined
  with the polythe



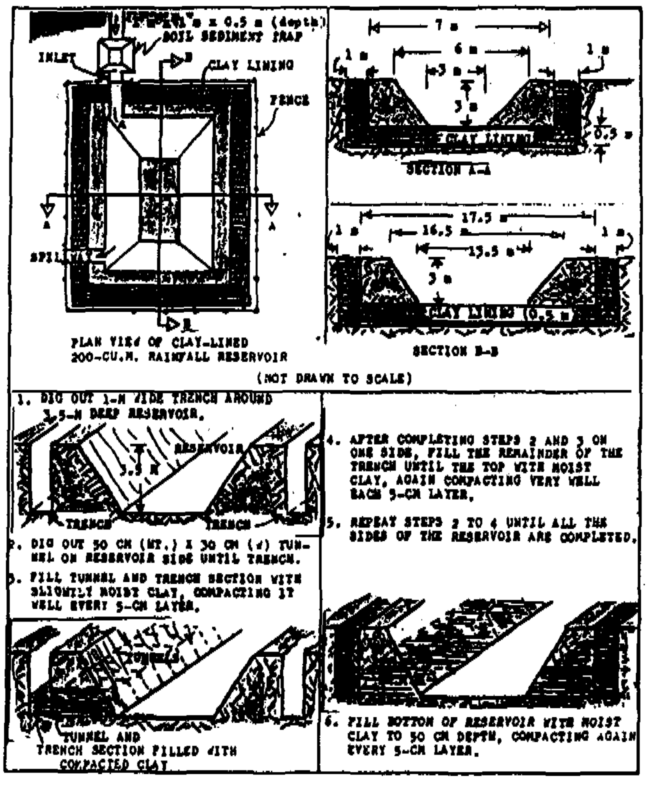
Note:
- The Catchment area (iron sheet roof)
- The Cistern (Nkhokwe)

Note:
- The Cistern(Nkhokwe plastered with clay).
- The water tap.

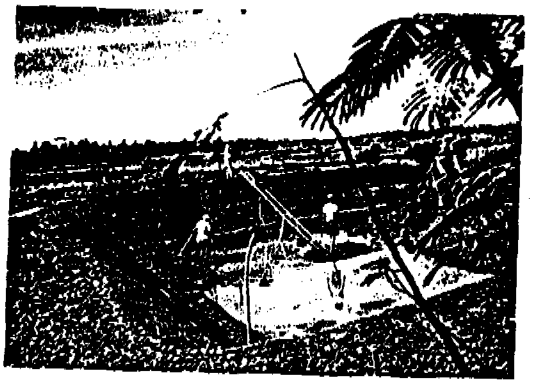
Annex 2

CLAY LINING AND COMPACTING SIDES AND BOTTOM

CLAY LINING IS CHEAPEST WAY TO REDUCE SEEPAGE FROM RESERVOIRS. SEE DIAGRAM BELOW FOR PROCEDURE.



IT IS EASIER TO DIG OUT SMALL FARM RESERVOIR THAN TO RECLAIM A SILTED BIG DAM.



INLET/SPILLWAY CONSTRUCTION
USE NYLON SACKS PILLED WITH SOIL TO
STABILIZE GROUND AT INLET/SPILLWAY.

COVER/FENCE/TRELLIS CONSTRUCTION
COVER RESERVOIR TO MINIMIZE EVAPORATION.
FENCE IT FOR SAPETY. HAVE TRELLIS OVER
RESERVOIR FOR GROWING VINY VEGETABLES.

For further information contact

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(Agrometeorology/Data Processing)
August 1988

MALAWI
10 DAILY TIMES, MONDAY OCTOBER 8, 1990

AGRICULTURE

Farmers to harvest coming rains

"... will save the woman rigours of going to the river every time she needs water and could use the time saved for other activities."

SOON rain will be in full bloom and farmers will be busy in the fields. But nature is unpredictable and uncontrollable; it is possible to have a shortfall in the rainfall pattern.

The World Meteorological Organization (WMO) in conjunction with the United Nations Development programme (UNDP) drew up a programme under the auspices of the Meteorogical Department of Malawi to advise farmers through the agricultural extension officers on a number of approaches by which the rural farmers can combat the shortfall in the rainfall during the planting season.

The programme is called 'Rainfall Harvesting and Management'.

According to a UNDP staff attached to the Meteorogical Department, Mr. Alfred Osunsanya, the programme started last year with the Lower Shire as the pilot area and this year, it will be extended to the areas within Blantyre Agricultural Development Division. It is expected to gradually spread to other parts of the country.

Mr. Osunsanya said rain harvesting can be for both domestic and agricultural purposes.

By Rankin Nyekanyeka

Most rural farmers, especially women, have been known to travel long distances collect water from rivers or streams for their consumption.

In the usually dry regions, when the rains come, they usually come in torrents and only last for a short while. The rural farmer out of mere ignorance stays in the protective cover of his house and allows this water falling on his roof to flow away as erosion. Later on, he follows it to the river to bring it back for domestic use at home.

To save him this trouble, the programme devised a tank from locally available material for collection of the rain water from the roof for storage. This structure is made from the grain storage basket (*nkhokwe*) of about one and half metres high and one metre wide lined with polythene plastic. This could conveniently hold 1,300 litres of water which an average human being can use for a period of 40 days.

The extra requirement to the nkhokwe structure is a gutter made of a half-split bamboo pole tied to the roof edge. In the event of rainfall, the water will flow from the roof through the gutter and into the nkhokwe tank. In this way, the farmer harvests rainfall which can be used in the home.

"This will save the woman the rigours of going to the river every time she needs water and could use the time saved for other needy activities," Mr. Osunsanya said.

Last year, 300 farmers in the Lower Shire participated in the programme. They received the polythene plastics which are supplied by the UNDP.

On the agricultural use, the first method is that the farmer is asked to construct terraces or bands across his land if it is sloppy or on a hillside.

In this way, he controls soil erosion and at the same time increases and improves water infiltration. Since the rain water is prevented from flowing downhill but aided to go into the soil where it will be available for crop use, the farmer will have therefore harvested rainfall.

The increased water infiltration becomes very helpful when dry spell occurs especially during the flowering stage. As more water is retained in the terraced soil, the system encourages relay cropping (planting another crop before the present crop is harvested).

The second method under the agricultural use is the construction of reservoirs or dams. As this constitutes a large investment not within the reach of rural farmers, the programme suggests the making of trenches by farmers, which could be lined with polythene plastics. The trenches can irrigate some rows of crops beside it in case of a short dry spell.

Another innovation is pot farming. During the dry season, most farmers idle away their time when they could embark on vegetable farming with the scheme of pot farming.

Earthenware pots (*Mnyai*) are buried in pulverised rich garden soil at about one metre apart with some water in them. Vegetables are planted around them and the water inside is replenished every five days.

Using nkhokwe and polythene plastics, farmers can combat shortfalls in the rainfall by harvesting rainwater. Picture: World Meteorological Organization.

Exotic plants adorn Israel's arid south

HARDY drought-resistant decorative plants from Australia, Baja California, and Chile now flourish all over Israel's arid south as a result of research conducted by a team at Irael's Ben-Gurion University (BGU) of the Negev.

Every year, as summer comes around and Israel's water reserves drop to dangerous levels, consumers are cautioned to use water sparingly, and, above all, not to waste large quantities of the precious liquid on watering their gardens.

In response, BGU researchers propose gardening with decorative plants which require little or no irrigation, and/or are salt-tolerant.

For two decades Yossi Ben-Dov (picture), Meir Forti and Professor Dov Pasternak of BGU's Institute for Agriculture and Applied Biology have been introducing hundreds of varieties of plants from arid areas, particularly the Australian desert, into Israel.

The Australian imports include *cochia sedifolia*, a fodder plant.

THE NAKURU C.P.K. RAINWATER HARVESTING PROJECT

John Mbugua*

ABSTRACT

The above programme started in 1984 with a goal of introducing sustainable affordable, replicable and acceptable water supply projects within 6 1/2 administrative districts which are Nakuru, Nyandarua, Narok, Baringo, Samburu, Kericho and part of Laikipia. During this period of 6 years a number of target groups have been identified and mobilized. To date the programme has over 150 active groups made up of 90% women who are also responsible for their group management. Total number of tanks constructed are over 3,000 and sizes vary from 500 gallons capacity to 30,000 gallons. This means over 30,000 people and hundreds of cattle have safe water supplies at their homes. Challenges have been in areas of research, documentation, quality monitoring and promotion of rainwater cathment system in other areas other than domestic such as agriculture. The programme with assistance from UNICEF hosted first IRCSA workshop which attracted over 55 participants from over 20 organization including 4 ministries. There were also participants from Botswana and Tanzania.

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3. Overview of RHW projects in Kenya
4. Introduction
5. Rationale
6. Implementation
   I. Non Technical Aspects
   (a) Institutional options
   (b) Main target (the poor)
   (c) Labour
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   II. Technical Aspects
   (a) General
   (b)Gutters criteria

*International Rainwater Catchment Systems Association National Representative for Kenya

(c) Tank efficiency
(d) Quality
    (i) General
    (ii) Quality analysis
    (iii) Treatment
(e) Monitoring and control
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7. Research
8. Workshop
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An overview of RWH projects in Kenya.

Rainwater in Kenya is widely practised. There are thousands of individuals who have built stone tanks and others have built tanks through help of many organizations like government of Kenya ministry of health or multilateral organization eg UNICEF and bilateral such as Danida, SIDA and many private volunteer organizations such as AMREF, Kenya Institute of organic farming, Kenya energy non governmental organization (KENGO). Help children Canada Canadian hunger foundation children fund, life water and many religious groups in Kenya, such as C.P.K., Catholics, Action aid, Care Kenya.

There is very high enthusiasm in developing various tank designs and it comes out clearly in the number of tank designs in the market. Many organiation report of success in their designs which others report is a failure in their locations. During the just concluded IRCSA workshop Ghala tanks were reported to be doing poorly but another organization defended it. Tim Holmes of CPK diocese of Maseno West has designed a 2.4m^3 reinforced cement water tank. (1) Catholic diocese of Machakos are actively involved in building 3,000 gallon ferrocement tanks for a long time now. (2) While AMREF in Utooni and Tigania build 2,700 gallons and 2,000 gallons respectiely. In Kapenguria sand/cement blocks are used to build 1,000 gallon tanks. (3) In Muka Mukuu ferrocement tanks using old G I tanks plus chicken wire and fencing wire is being done, the tanks are 2,000 gallons and below. (4) Kamujine ferrocement plus weldmesh and chicken wire and mabati roof 1,600 gallons. (5) In Kitui water jars using bags filled with saw dust and capacity 750 gallons.(6)

The problems of lack of appropriate roof eg getting water from the grass thatched roofs may be overcome by making the group more flexible such that the group finances G I roof as part of its objectives. (7) In Kenya an organization called shelter Afrique is doing just this. Its rainwater programme includes housing.

The other solution is to take on surface catchment instead of roof under this category the CPK RWH programme is practicing surface catchment. In Kenya too certain big trees have holes which are developed into a tank.(8)

In Kenya a number of methods of financing the tanks are practised.

1. "Merry Go round" contributions by each member and then money is given to members in turn.
2. The group calls a general fundraising called in Kenya "Harambee.
3. Joint community and external agency.
4. Individual funding.
5. An individual contributes labour and some materials and outside agency give the rest.
6. Income generation eg GI tanks.
7. Grants from agency may build tanks on demonstration.

Kitui integrated development programme through Erik Nissen Petersen has developed 46 cu.m. cylindrical water tank with dome.(9)

Also developed by Asal rainwater harvesting through Erik is a hemispherical underground tank of ferrocement which is extended above ground level with a cyclindrical wall of either blocks or stone masonry and roofed with iron sheets total volume is 78 cu.m.(10) See figure 1.

The Nakuru diocese (CPK) is promoting similar tanks but the difference is that the tank lining depends on the soil background so that the lining is not uniform.(11) This makes tanks cheaper as some soil do not need any lining for seepage control but may be light lining for beauty. In both cases above, the tanks are fitted with a handpump, sometimes the CPK tanks are unroofed unlike the Kitui tanks which are roofed with G I. Also common in Kenya is construction of small earth dams built by animal traction. The dams are of 500 - 10,000 cu.m. capacities. The banks are of earth not more than 5m high and 60m long. The dams are built by manual labour and animal traction using ox scoops.(12)

This dams are common in Kitui and other places like Nyandarua where tractors are hired. The cost is prohibitative and hence the Kitui approach is realistic. In Kitui, according to Erik and Michael Lee rock catchment dam with a self-closing water tap has proved very useful. Masonry gravity walls can be built in all lengths and sizes depending on the shape of the site where they are built and the size of the reserviour they will hold.(13)

Shallow wells are also common and in some areas are classified under rainwater harvesting, such ones are practised in Kenya. Sub surface and sand storage dams this are seepage prevention structures which are built across sand-river beds to improve the productivity of shallow wells. Such sub-surface dams should only be built if a shallow well situated upstream has shown to produce water for nearly all months of the year. This structures are common in Kitui and Machakos and are being practised by many agents.(14)

Spring protection practices is also practised by many agents in Kitui integrated and CPK Nakuru Diocese. Mbugua 1990, Erik 1990. It has been reported also rainwater for agriculture production has been practised in Turkana and Baringo districts of Kenya with varied success (Pacey and Cullis 1986). The techniques tried in Turkana district include semi circular hoops and Trapezoid bunds constructed through a food for work programme.

Today similar work is going on in Isiolo under CPK Diocese of Kirinyaga as reported by Burgess in the IRCSA workshop.(15) According to International drinking water supply and sanitation decade directory 1987 Kenya levels of coverage varied widely from as low as 4% in the arid zones and average was 15%. This then calls for diversity in approach and rainwater is most dependable for higher coverage levels. February 17th - 20th 1987 at Limuru in Kenya world neighbours and oxfam jointly organised and sponsored a rainwater catchment ferrocement tank workshop. It was attended by 26 participants from organizers own organizations and Care Kenya, Dioceses (Catholic) of Meru, Kitui and Machakos attended. The workshop recommended to call in another workshop and to develop networking and communications between each other. The workshop also recommended that more alternative tanks construction materials and water sources could be included in future workshops. Also recommended is need to invite relevant ministries to attend.(16) This hopes seemed to have been answered by IRCSA workshop which had ministry of water development, ministry of health, ministry of agriculture land ministry of ASAL in attendance. Various potential uses of rainwater and many different tank construction designs and materials were reported.

INTRODUCTION

The Nakuru CPK RWH programme occupies an area which was occupied by former white settlers. The settlers developed various water resources to suit their own interests. The technologies were chosen based on already available operation and maintenance capacity. After independence the lands were bought and cut into pieces which were occupied by new settlers. The systems collapsed because the new settlers found the technologies strange and to some it was a represetive symbol of colonialism. As a result little attention was given to their operation and maintenance.

This situation posed a great challenge that needed critical analysis of social cultural and economic dynamics to determine acceptability and affordability of rainwater technologies. After an year and in some places even two years the projects started and proceeded on to completion.

RATIONALE

Rainwater technology was accepted mainly because of its simplicity offordability and clearly defined individual responsibilities during construction and thereafter during operation and maintenance. Another reason was that individual benefits were clear. This programme was introduced at a time when failure and collapse of many piped water systems was occuring and also at a time when government expenditure on public sector was greatly affected by harsh global economic order of structural adjustment programmes (SAPS) Another benefit that came into picture was that many donors had started accepting role of NGO and their appropriateness at the grassroots.

IMPLEMENTATION

Non Technological Aspects

(a) Institutional options

Through a number of ways villages heard about the rainwater programmes and came for technical advice. Then the programme officials organised a baseline survey and series of community meetings for a dialogue. This then was followed by visits organised to expose members to similar areas like theirs where various activities related to rainwater was going on. Such visits were by far the most effective mobilization strategy. Various trainings were then planned to improve management skills organization, humans resources, and confidence building. During this training sessions role of women in development of rainwater technologies was taught and encouraged throughout project planning and implementation.

(b) Main Target (Poor)
The Nakuru RWH programme has the poor as main target. But this group happen to be also most difficult to deal with because:

(a) The poorest of the poor do not like joining community groups
(b) They lack the required group contributions
(c) They shy away and fail to join others in group activities
(d) Some rich ones stand as barriers to development of the poor
(e) The poor lack confidence in themselves
(f) Communication barriers sometimes exist between the facilitating agent and the poor

Target groups were located in the identified project area. The group gathered members who faced water shortage and could form a cohesive group. The group sizes depended on a number of factors including economic geographical degree of exposure of the villagers and degree of awareness created by the external facilitator. Generally our groups range from 15 to 80 members the eighty member further subdivided into small units of 12 to enable easy labour management.

(c) Labour
The tank construction has skilled and unskilled labour needs. In order to minimize on cost all unskilled labour plus some of the skilled labour is done on voluntary bases. The group then recruits a village artizan who is trained by the programme and is given back to the community for administration and work assignment.

(d) Finance (i) Community
The groups agree on monthly meetings to contribute money and to plan future actions, but the group meet also weekly to work on their projects. Some groups have agreed to meet after construction of 2 or 4 tanks in order to cast ballot papers to find out whose tank will be built next. Some groups have also fixed that when it is a member's turn the member will contribute money about 10 times

monthly contributions to boost the group's account, in order to build more tanks in order to reduce waiting period.

(ii) External Support

The programme in addition to contributions on mobilization and technical help the programme encourages construction by contributing 50% of material needed and cannot be obtained locally like cement and iron sheets etc. This imput is very carefully planned to avoid fights or group collapse something that has happened when too much money has been given without proper planning.

Technical Aspects

(a) General

Tank size, tank material, roof material gutter sizes, gauge, fixing, gutter gradient are all important technical aspects. There are a number of formulae to determine tank sizes but whatever the circumstances careful planning is done so that the optimum size of tank that is cost effective is selected. Tank materials is usually chosen with maximum utilization of locally available material. The programme has used five different tank materials more than ten different tank sizes. Examples are attached and about six different shapes some are built above ground below ground or combination of both.

The need for standadization has become necessary in order to generate quality and to reduce technical supervision. However within our programme, ministry of health. Catholic Diocese are facilitating construction of ferrocement tanks of uniform capacity say 10 cu.m or 20 cu.m or even water jars of 2 cu.m capacity one shortcoming of these projects is rigidity in that even where stones are available ferrocement tanks are still only alternative available from external support agency. In such circumstances sustainability is at risk and participation degree is minimized. The programme under review has approached the community with open approach and technology options so that after a series of meetings the community itself will identify most appropriate tank materials and sizes with a little but adequate technical support from programme officials. In Baringo an area with very hot and dry climates, ministry of health and water development have abondoned ferrocement tanks because of failure and now are doing reinforced stone tanks.

Process of selecting rainwater project is carefully followed during community meetings and dialogue some of main questions we deal with are (1) are rainfall pattern and roof design suitable for rainwater catchment if yes (2) can people afford the storage tanks necessary for rainwater catchment?

The Nakuru RWH programme has dealt with the above questions in a number of ways, construction of large underground water cisterns receiving water from surface run off from roads paths or non cultivated fields. These have adequately responded to the flash tropical storms and lack of adequate roofing among majority of rural poor. However the water collected have limitations in quality and the water is usually used for non drinking purpose like kitchen gardens and livestock. A number of families have also been known to use the same water for cooking and washing after using some well known vegetations or aluminium sulphate to coagulate and then by passing the water through a piece of while cloth. The programme officials advice the community to use the water as tea, coffee or some soup but not to drink water directly.

About the 2nd question of affordability of storage tanks. Care is taken to maximise on villager or family labour and materials nearest to the family. This explains why we have such wide selection of tanks such as masonry, rubble stones, surface or semi underground spherical cylindrical semi spherical etc. see figures in the appendix.

Nakuru RWH programme has adopted the following sizes and shapes for gutters. See Appendix. Although the community has not taken this seriously. It is common to find tanks that were built and for a year there has not been any gutters or only 1/10 of gutters that can be placed have been installed.

(b) Gutters Criteria
The following criteria is followed in the choice of gutters size shape and fixing. It is development based on experience acquired.

1. Gutter must be large enough to channel water from heavy rains without overflowing.
2. The shape should be such that the gutter is not too shallow to allow overflow.
3. The gutter should not be too narrow the water from the roof may shoot over the gutter and be lost.
4. The gutter should be placed at a uniform slope to prevent water from pooling and overflowing the tugger eg 0.8 cm per metre or

1.0 cm per metre about 1%.

5. The gutter must collect all of the water running off the roof during the highlight and heavy rainstorms. To achieve this the gutter should be located so that the roof overhangs the gutter by 1" and the gutter extends beyond th edge of the roof by at least remaining diameter.
6. Number of supports depends on type of materials but should be at least 50-60 cm.

See the figure 2

However optinium gutter sizes will obviously vary with the intensity of local storms and ground area covered by the roof. For our programme area such study would be very useful to provide some guidelines.

It is proposed that before the programme selects standard sizes or materials an external expert will be called in to help in a kind of structural evaluation of various tanks sizes and shapes and engineering of materials.

Roof materials is a great concern. The programme has tried unsuccessfully to tap water from grass thatched roofs or other organic materials. But of even greater concern is a number of brick and painted G.I materials which are being manufactured in the market. Health impact of the pollution from these surfaces is still yet to be established.

(c) Collection Efficiency

The programme has identified that some farmers treat a tank as a symbol of status and therefore forget the purpose. This is evidenced by some farmers who forget to put enough gutters, put gutters of inadequate size and are fixed at poor slopes etc. However this short coming has come out clearly and is currently serious challenge and the water department is working out training strategy to overcome this shortage.

Making the proper gutter sizes in the market is another constraint and the programme is planning awareness creation among the community so that the farmers refuse size of gutters that are not appropriate. Also being done is to introduce various fixing materials to achieve proper gutter slopes.

(d) Quality

(i) General

Both quantity and quality of water supplied to community is of great concern to our Nakuru RWH programme. The programme area has serious shortage of both quality and quantity. While it has been possible to make more water available attempts to improve quality and to maintain high standards has not been easy. However health education to improve kitchen and domestic and even personal hygiene has been inco-operated in the programme. As this touches on culture and traditions care is taken so that cleanliness culture could be inco-operated in our people without interferring with the existing culture.

(ii) Quality analysis

The Nakuru CPK RWH programme a year ago acquired a mobile water laboratory equipment which is capable of analysing over 12 minerals and using its two incubators which run on electricity or 12 volt or 24 volt batteries. This equipment can culture and isolate coliform bacteria E. coli or even streptococci. The results are used to help develop monitoring mechanism and also helps to do water tank disinfection with chlorine.

(iii) Treatment

In several occasions the programme is called upon to help sort out problems such as

(a) Water from the tank producing bad taste and odour.
(b) The water is found to contain small larvae.

The programme then responds by a number of ways that include washing the tank annually to remove settled materials or drawing of water at a higher point to exclude the polluted level and finally chlorine may be is administered.

Chorine Treatment

A solution of 70% chlorine is prepared by mixing 100 gms to a litre. Using a table developed by the programme and based on experience right amount of dose is applied and after an hour a test of residual chlorine is done so that 0.2 - 0.5 mg/l level is maintained. See table 1.

(e) Monitoring and control

(i) General

The Nakuru RWH programme has put up this schedule of activities for its staff to facilitate quality improvements.

Jan - Feb	Cleaning tanks, checking for cracks and repairing faults in gutters or tanks, cutting any trees overhanging tanks or roofs to avoid birds resting directly above the tanks to avail birds droppings.
Mar - April	Clean gutters and roofs, repair them and ensure first flush mechanism are in position and working.
May - June	Evaluate tank performance and catchment effectiveness.
July - Aug	Check water quality by use of laboratory ventilated improved pit latrines maintenances and evaluation.
Sep - Oct	Train on water conservation and usage, water budgeting to avoid loses and wastage.
Nov - Dec	Preparation of water tank constructions.

However in addition to the above the following is adopted by the programme and is practised in areas of rainwater roof catchment systems. (From water and sanitation for health project workshop technical report)

(ii) Maintenance Schedule

(a) The roof gutters ad cisterns should be periodically inspected to identify problems (cavings, cracks and leaks)
(b) Gutters should be replaced when worn out or water proofed when needed or realigned when the shape is altered.
(c) Debris should be swept off roof and gutters when needed.
(d) The cistern water should be inspected for taste and odour.
(e) The cistern should be cleaned periodically (at the beginning of the rainy season or at the end of the dry season)
(f) The environment should be monitored for health hazards such as standing water or animal contamination.

<u>Maintenance check list</u>

1. At the beginning of each rain
   (a) Engage foul flush mechanism
2. At the end of each dry period
   (a) clean debris from catchment area

(b) check gutter supports and repairs

3. At the end of each dry period and weekly During rainy periods
   (a) clean gutters of debris
   (b) check and clean screen at down pipes
   (c) check gutters for leaks and repair accordingly
   (d) check gutters for over flowing and adjust position around tank
   (e) check drainage around tank

4. Monthly throughout the year
   (a) check tank cover and ventilation
   (b) check tank for leakage

5. Weekly throughout the year
   (a) check water quality in the tank and clean out if necessary

6. Annually
   clean out and disinfect the tank

Research

The diocese of Nakuru RWH programme identified research needs of the programme. A nearby Egetron University was approached who jointly with the author developed a research proposal for which finances are still being sought. However with limited funds from the programme a number of samples have been taken and analysed.

Section A Part I

The research proposal intended to carry out some study in areas of social economic conditions of those already practising RWH. This section was to bring in size of household, size of land, production of land and its size.

Part II of the questionare was aimed at obtaining information on group dynamics such as reasons behind the group formation and its social aspects.

Part III was aimed at rainwater technology and questions focussed on type, size and shape capacity of tanks plus its performance.

Section B

Here questions were focussed to obtain answers related to attitudes and awareness.

Section C

This was devouted to water quality, health and agriculture. Questions in this section were focussed to officers in the various ministries and NGOs.

Section D

Here sanitation issues were discussed. So that number of people with form of sanitation those without and how many had improved theirs.

Section E

Finally was devouted to socio-cultural. Questions here were concerned with cultural attitudes and taboo that affect various sources of water and its use.

Workshop

The IRCSA sponsored Nakuru workshop of May 28-29 1991. We received over 55 registered members from all areas of Kenya. Some delegates also came from Tanzania and Botswana. The workshop recommendations included need for information sharing, information and data collection. Workshops were identified as being some very good forums to share and exchange information.

IRCSA Kenya team was asked in the recommendations to organize such workshop annually. It was also suggested that issues of research needs should be addressed and reported in the coming workshops. The 2 days workshop was too short and 6 hours field visit was also too short. It was also commended that group discussions were not given more time. Therefore next workshop will be planned with the above issues in mind.

On behalf of the organizing committee, we are thankful to John Gould for his presence and contributions in management and contributions.

Sanitation

The CPK Diocese of Nakuru RWH programme has integrated sanitation activities. For every tank construction there must be an improvement or construction of a pit latrine. To date out of 3,000 tanks constructed there are over 2,000 pit latrines dug or improved by installing a vent pipe, clearing the compund and path leading to the latrine. Inside the latrine moisture on the slab is avoided by keeping a gallon of ash which is sprinkled around after every use. The ministry of health instead insist on using a concrete slab something that is not compatible with financial ability of most people. Families argue that their own houses are not made of concrete floors and are even grass thatched. But when materials used for latrines is compatible with materials in the houses and owners financial capabilities then latrines are improved. Of equal importance is health education. Full health and economic benefits can only be realized when safe water and adequate supplies are complimented by sanitation facilities, kitchen and domestic hygiene and health education.

CONCLUSION

The programme has achieved most of its objectives. Many lessons have been learnt. Most notable of these is the importance of the non-technicalogical components relating to the sustainable delivery of water servies. For example finance and technology are not the major constraints to acquiring water for all, but rather the social and political dynamics among the target groups. Financial inputs should be administered carefully to avoid a "dependency sydrome." Any intervention should develop self-reliance and confidence. Therefore the choice of technology should be made with extreme care.

Rainwater resources have a great impact on the daily lives of the majority of people in the project areas. Energy and time saved can result in more time for productive activities that help to counter poverty, hunger and disease among the rural communities in Kenya.

Community participation not just lip service is necessary in project planning and must be encouraged. Communities must make a commitment with a view towards accepting ownership and responsibility for the project. Efforts are needed to prepare communities before implementation and to avoid short terms goal fulfilment. Quality not quantity and programme sustainability must be the main objectives.

Community participation through education using the mass media and schools is necessary. Community involvement requires considerable resource inputs (finance and time) and budget must be properly allocated and used. A bottom-up and top down approach should complement each other coupled with institution building. More research is needed in some areas of rainwater technology such as optinium tank sizes, roof materials gutter, sizes, water quality and information dissemination.

Another sad finding is that the current curriculum at Kenya colleges and universities pursue objectives that are not relevant and sensitive to the needs for more applied research, so that those leaving this higher institution of learning come fixed on piped water supplies and big dams design while they have problems in gutter design and ventilated pit latrines. According to Prof. Were such institutions fail if they fail to change with changes. The just concluded workshop came out with similar findings. According to IDWSS decade director Kenyas coverage is about 4% 1986 this calls for serious thought on other sources such as rainwater.

Project appraisal and monitoring are needed to determine if objectives has been met and if projects can be replicated for the benefit of others. Technology application has many constraints which must be identified as they vary with location, needs and resource availability.

Training in improving nowledge skills attitude and confidence building is still a short-coming not only of recipients but also of technical staff involved in implementation. Training must be allowed for technical staff and must where possible, distinguish and include training for decision-making and management as well as hands on training.

Rationing/water budgetting?

Supply of clean and safe water will have only limited health and economic benefits unless adequate health education and sanitation is made part of the rainwater programme. It comes out clearly during visits in the villages that any improvement in water supply equal concern and commitment should be put into health education and construction of sanitation structures. However it is common to observe that even rainwater programme under the ministry of health lacks sanitation and health education component.

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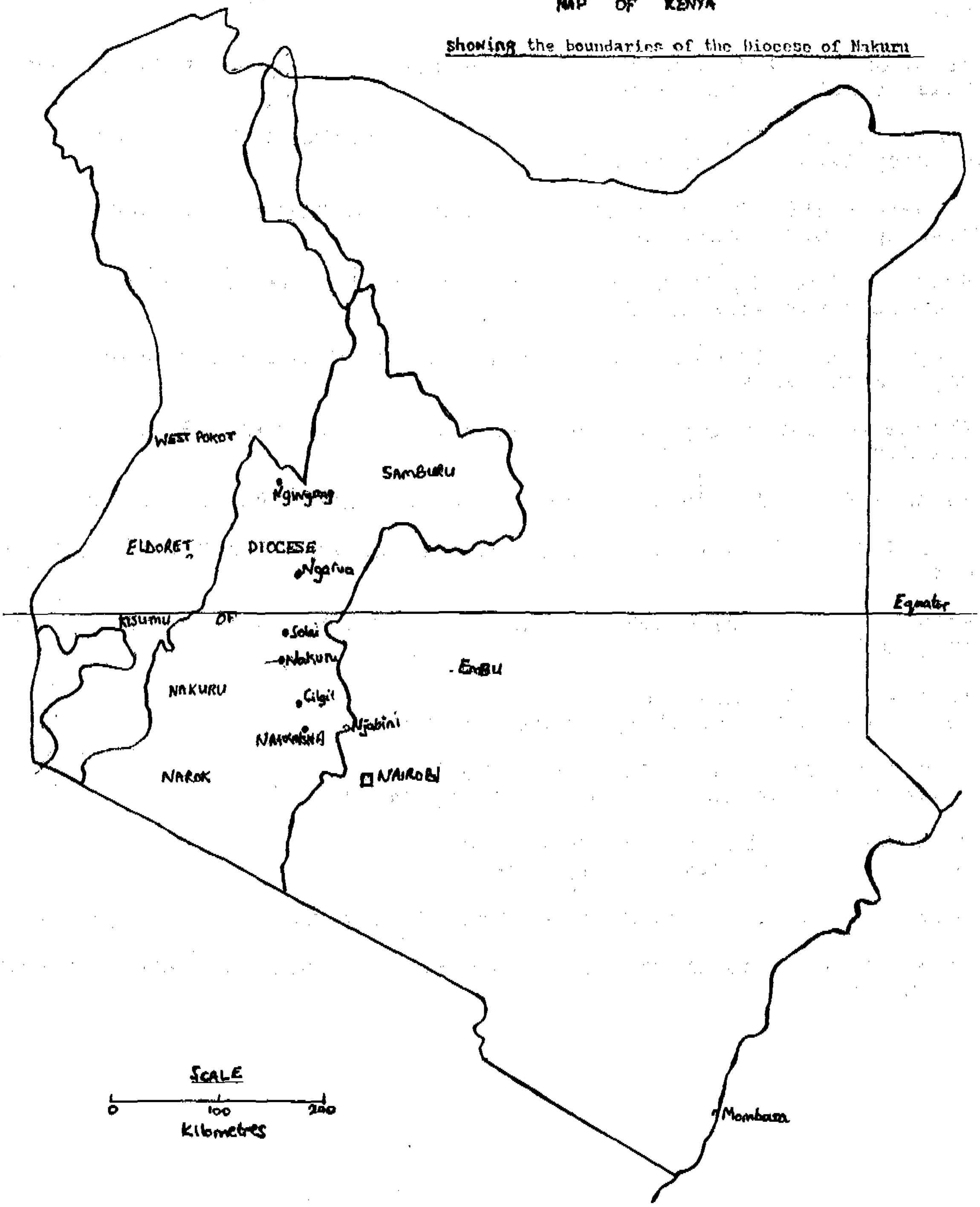
Appendix 1

MAP OF KENYA

Showing the boundaries of the Diocese of Nakuru



DIOCESE OF NAKURU

Church of the Province of Kenya (Anglican)

Telephone: Office: 41550
44832
House: 43005

CHRISTIAN COMMUNITY SERVICES
P. O. Box 56,
NAKURU, Kenya.

Our Ref: ....

Your Ref: .... Date: ....19.......

From: The Water and Rural Engineering Department

PRICE LIST FOR WATER QUALITY TESTING

PHYSICAL - CHEMICAL TESTS

The following tests can be done at present at the given prices per test:

Ammonia	10/=
Flouride	10/=
Iron	5/=
Manganese	10/=
Nitrate	15/=
Nitrite	5/=
Phosphate	10/=
Sulphate	15/=
pH	30/=
Conductivity	10/=
Dissolved Oxygen	20/=
Turbidity	20/=

The following tests can be done but 3 months advance notice is needed and an initial deposit may be required. Their cost per test is given:

Aluminium	10/=
Boron	10/=
Bromine	5/=
Copper	12/=
Cyanuric	10/=
Hydrogen Peroxide	10/=
Molybdate	10/=
Potassium	10/=
Silica	12/=
Sulphide	15/=
Zinc	15/=

MICROBIOLOGICAL TESTS

Coliform	50/=
E.Coli	50/=
Faecal Streptococci	100/=

Advice will be freely given on which tests are required for a particular water source.

Effect of Vegetation Cover on Rain Water Harvesting

Alizadeh, A.*

Abstract

Vegetation influences the run off cycle through different processes, such as, evapotranspiration, interception, and reducing flow velocity. In an investigation, the effect of vegetation management on water yield of three small watershed was studied. Management included burning and hand removal of all vegetation cover. Rainfall and collected run off were measured for each of the precipitation. The result show that both type of management increase harvested water compare to control watershed. However the effect of burning was more significant.

INTRODUCTION

For many people living in far Southern part of Khorassan province, Iran, rain water harvesting is vitally important. This part of the country has a dry desertic climate with annual rainfall less than 150 mm (Alizadeh 1990). Tribal nomads and some peasants settle down at scattered locations of this area for several months of the year. During this period they are totally based upon rain water harvesting, both for small scale farming and drinking.

Drinking water are harvested from well specified watersheds and prevented from entering animals or people. The run off harvested from these basins are led and collected in small cistern called "Howz" (Safi Nezhad 1989). Howz is a permanent structure specially designed to minimize evaporation and percolation. Each year, at the beginning of rainfall season, Howzes are cleaned and made ready to be used again.

Harvested run off are also led to seep on sandy soils which are lately used for cultivating some kind of crops.

The purposes of this investigation was to study the effect of some easy way of vegetation management on water yield of small watersheds.

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METHOD

Three small similar adjacent watersheds were selected (watersheds A, B, and C). The area of these watersheds were 12.52, 12.85, and 13.21 hectares, respectively. Vegetation type and density, slope, and soil types of the watersheds were also similar. Rainfall at the site and run off from each of the basins were measured automatically by recording raingauge and limnographes.

At the end of the first year of the study, watershed A was left as a control. Watershed B was treated by hand removing of all vegetation cover, whenever it was needed. Watershed C was treated by burning all litter and living weeds. Rainfall and runoff were also recorded for two other consequent years.

RESULTS

Polynomial regression analysis show that there are direct relationships between runoffs from watersheds A, B, and C. These relationships are as follow;

$$RO_B = 0.2 + 1.1\ RO_A - 0.02(RO_A)2 \quad r^2 = 0.90 \qquad (1)$$

$$RO_C = 0.13 + 2.6\ RO_A - 0.16(RO_A)2 \quad r^2 = 0.89 \qquad (2)$$

In above equations, which are derived for the condition before any treatment were applied, RO_B, RO_A, and RO_C are depth of runoff from watershed B, A, and C respectively.

In watershed B, after removing vegetation cover, equation (1) changed as follow;

$$RO_B = 0.41 + 2.5\ RO_A - 0.09\ (RO_A)^2 \quad r^2 = 0.95 \qquad (3)$$

Also similar equation (equation 2) changed to be as;

$$RO_C = 0.69 + 4.2\ RO_A - 0.31\ (RO_A)^2 \quad r^2 = 0.94 \qquad (4)$$

Comparing equations (1) and (3) the effect of vegetation management, due to removal, will be equal to the difference of them. subtracting equation (3) from equation 1 will result;

$$\Delta RO_B = .21 + 1.4\ RO_A - 0.07\ (RO_A)^2 \qquad (5)$$

Also, by subtracting equation (2) from equation (4), the effect of burning the vegetation will be;

$$\Delta RO_C = 0.56 + 1.6\ RO_A - 0.15\ (RO_A)^2 \qquad (6)$$

Since equations (5) and (6) are positive for all the time, the two kind of vegetation management have direct and positive effect on increasing water yield.

DISCUSSION

Vegetation influences the run off cycle through different processes (Starosolszky 1987). Among these processes, evapotranspiration, interception, and flow velocity are more important (Alizadeh 1978). From the result of this study, any management which can reduce vegetation cover can result an increase in water yield However, comparing equations (5) and (6) it shows that the effect of burning is more significant.

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RAIN WATER HARVESTING - THE CONSTRAINTS

S.H.C. DE SILVA*

Abstract

Water resource exploitation for human needs has grown by leaps and bounds in the last two decades. Nearly all the suitable sites for storage dams and river diversions have been utilized and ground water extracted regardless of consequences as in Bangkok.

Water for all by the year 2000 still remains an ideal, Rivers that were once perennial now become raging torrents that convey their runoffs in the form of flash flooding. As forests are reduced by deforestation and catchments urbanised the need to harvest rain before it reaches the dry streams beds or fall into polluted rivers, becomes of paramount importance.

Runoff areas in catchments continue to diminish and are replaced by concrete paving or bitumen covered roads or asbestos or tiled roofs. Rainfall runoff from such artificial catchments can be collected in cisterns above ground or in tanks below. Preserving the rain close to where it fell avoids contamination that occurs with surface runoff. Percolation and evaporation loss is reduced. But rainfall in urban areas has its drawbacks when atmospheric pollution, sulfur dioxide and carbon dioxide from vehiclular traffic, coal fired power stations or industrial flue gases can convert the composition of rain to acid rain is very real.

Collection of rain in cisterns also could attract growth of organisms and larvae that could promote diseases like malaria, filaria, dengu and Japanese encephalitis, if such water is consumed without boiling. Water stored in underground cistern could be contaminated by leakage from septic tanks in the proximity adding nitrates and phosphorous. Cisterns take up space in high value urban areas.

Population growth the world over has mushroomed to such extents that efforts made by countries to supply their basic requirements of water for drinking, for irrigation and for power production can hardly copy with.

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River diversions have virtually been complete. Damming rivers for water storage is also at its end, at least economically. Only the difficult and found devouring, once rejected dam sites now remain. They may be on fault zones, earthquake prone areas, or underlain by fissures or limestone caverns, as at Ataturk dam on the Euphrates in Turkey, The Khao Laem dam in Thailand or Samanala in Sri Lanka.

If rainfall is scarce and intermittent and ground water is difficult to get, storage of rainwater has been practised for ages. With population pressures leading to the desecration of catchment by settlement, the only catchment remaining unexploited will be those of roofs housing, paved areas or asphalted roads.

Runoff from such impervious surfaces which are generally steep will be rapid compared to a sloping natural topography. The higher velocities will promote erosion of surface and lifting of all deposited dust and any loose material on the surface.

In tropical countries birds as crow, pigeon, house sparrow, rodent and pole cat normally make their habitat on roofs or over trees overhanging same. Their faeces and droppings will invariably collect on roofs and valley gutters and rainwater in collection system is bound to be polluted. Rainwater catchment can also be from specially prepared and protected surfaces on ground.

The protection needed is to minimise infiltration losses either by cementing or use of impervious linings as plastic sheet, rainwater harvested thus should be protected from evaporation or pollution. In Mediteranean countries, rainwater catchments have been used for thousands of years. In other parts of the world attempts are presently being made to adapt indigenous architecture to provide rain water catchment and storage installations. e.g Famousvillages of Dogon in dry Bandiagera plateau, in central Mali, where the inner walls of their tall granaries are lined with cement or plastic sheet and store rainwater from roofs.

Other simple constructions for storage of rainwater have been developed in Botswana, Senegal and Sudan to provide water at a low per capita cost. A further development in utilizing large catchments is the use of sand and gravel filled dams from which water is extracted through a shallow well dug in the deepest part of the dam. This extraction has the added advantage of providing good filtration.

Storage of rainwater in cisterns either above ground or below ground and covered under tropical conditions can suffer from anaerobic conditions, due to traces of organic matter.

If cisterns are exposed they will be subject to evaporation loss and become a nursing place for mosquito larvae. Such mosquito can be the harbinger for deadly diseases as filaria, malaria, Japanes encephalitis or dengue.

Since the Gulf conflict and the continued oil well infernos the prospects for rain water harvesting has come across an insuperable problem. Already oil and soot from the Gulf fires have been detected in the Himalayas, half a continent away.

The global pollution is increasing daily with over 600 oil wells burning out of control. Human efforts to collect water from the heavens is in a grave jeopardy. The irony of the gulf war fought to safeguard oil for the richer nations has created an impasse to all countries.

It is the lesser developed countries in the third world that will bear the brunt of this catastrophe which is acid rain and particulate matter mostly toxic in the form of lead and sulfur. Small countries without major rivers will have to collect rainwater for survival. Boiling can reduce germs but what of the acids and heavy metals!

The scenario, post Gulf crisis is a scenario that humanity never dreamt of. The atmospheric pollution from automobiles, industries coal fired power stations, etc., pales into insignificance with the deadly gases and soot emanating from the burning oil wells which the experts say will last for two years!

The present man made disaster on the environment is so vast that our efforts to exploit small catchments for harvesting rain, and acid rain at that , surpasses all understanding. If man is to survive, the efforts to overcome the new environmental hazards will be stupendous. Howmany will succumb before the pre Gulf scenario could be established?

The motto drinking water for all by the year. 1990 was revised to the year 2000, but the present crisis will ensure that will be a very distant "dawn" provided the ozone depletion is frozen and sea levels will not change.

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Rainwater Harvesting in Semi-arid and Arid Eastern Africa

Erik Nissen-Petersen*

In semi-arid and aird Africa there are several methods of harvesting rainwater as water supply for people, livestock, crops and forestry. The method depends mainly on the features of the landscape and on the amount of labour and founds awailable.

The type of rainwater harvesting systems for water supply for people and livestock can be classified per type of landscape as follows:

SLIDE NO.1

In sandy riverbeds with only a seasonal flow of water for a couple of weeks in a year, it is possible to built subsurface dams with draw-off piping to a cattle through for livestock and a shallow well for domestic water.

SLIDE NO.2

On flat land without any riverbeds one can build large earth dams by using heavy machinery or smaller earth dams by using oxen, donkeys and manual labour.

Such an earth dam can provide water for livestock from the reservoir and domestic water from a shallow well sunk downstream of the earth dam.

SLIDE NO.3

On land with hills it is also viable to build earth dams but it might possible to locate a site for a shallow well in a water-bearing pocket at the foot of the hills or perhaps it might be possible to find a spring on the hill-side.

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SLIDE NO.4

In landscapes with rock outcrops or rock-slopes it is very viable to build rock catchment dams which can supply water for domestic use.

SLIDE NO.5

Various types of water tanks can be build in every type of landscape as long as one can find a roof or a rock from where rainwater run-off can be collected.

Rainwater harvesting systems in Eastern Africa are popular by the communities living there because of the following reasons:

1). Rainwater harvesting for water supply is cost-effective because other methods of supplying water cost more in terms of design, construction and maintenance.

    For example; the groundwater table is usually found at some 80 metres depth, that is about 250 feet, and it can only be reached by means of an expensive borehole with a motor-pump.

    Furthermore, in many areas the groundwater is saline and cannot be used for anything except for watering livestock.

2). Another good reason for using rainwater harvesting in semi-arid Africa, is that there are very few perennial rivers.

    Since it is very expensive to pipe water from these few rivers to the populated parts in the dry areas of the country, the only feasible method of water supply is rainwater harvesting.

3). Since rainwater harvesting is the most viable method of getting water in the dry regions of Africa, it has been practised for many years by settled people and their animals.

Rainwater harvesting is therefore a known and accepted way of supplying water.

But unfortunately, many rainwater harvesting systems in semi-arid Africa have failed to provide a perennial water source throughout the years.

Some of the reasons for these failures can be described as follows:

1). Some designs are based on an average annual rainfall for estimating the run-off volume of run-off. Since the average annual rainfall in a semi-arid region can vary from, say 300 millimetres to 2000 millimetres in a year, calculations based on an annual average rainfalls will produce less half of the expected volume of water in some years.

    Such a rainwater harvesting system might therefore be considered a failure by the users or the donor because

2). Other designs overlook the fact that evaporation in tropical regions can be as high as 250 millimetres annually.

    If therefore a water reservoir, say a water tank, is not roofed, then most of the stored water will evaporate and the user will be short of water before the next rainy season. Such a project might also be considered to a failure.

3). In tropical semi-arid regions it is normal with an dry season of some 5 to 7 months in a year without any rainfall at all.

    That means that the storage capacity must be sufficient for those months without rain, otherwise the system cannot supply sufficient water.

    Since storage capacity is usually the most expensive part of a rainwater harvesting system, it is a rather common practise to build a storage reservoir too small, and that will also give a dry reservoir before the next rainy season.

4). The user of a household rainwater system has to realize that he or she can only consume a certain volume of water per day. If she uses more water than that then the system will run dry too early.

These examples of partly failed rainwater harvesting systems could be rectified if:

a). The designers will take more into considerations the local conditions of rainfall, evaporation and consumption.

b). the consumers have built enough storage capacity to be self-sufficient.

c). when they learn how conserve water by controlling the daily consumption.

d). and when the consumers learn to reduce wastage by maintaining their rainwater harvesting system properly.

With these few points on the advantages and disadvantages of rain-water harvesting in Eastern Africa, I thank you for your attention.

If you have any questions concerning these points, please do not hesitate to see me.

Water Harvecting Practices in North-east Iran

(an overview)

A. Koocheki*

INTRODUCTION

Water harvesting is a process of collecting and storing water from an area that has been treated or covered to increase precipitation runoff. The collected water is stored in a suitable container for domestic use or it is used for agricultural purposes. The latter in normally referred to as runoff farming and is used to provide water for the growing crops (Frasien 1985).

Much of the early history of rainwater harvesting has its origin in Europe. The Romans achieved considerable control of runoff by building structures to modify the outflow of lakes. Runoff was collected for the primary purpose of running watermills, forming fish ponds or for recreational purposes. Rain water harvesting techniques for agriculture were extensively practised throughout a vast region of North America, South America, North Africa, Middle East, China and India. This technique was flourished in Negev desert during the days of Roman Empine, when the Roman trade mute to the East passed through the area (United Nations Environment Programme, water resources series vol.5, 1983).

WATER HARVESTING IN IRAN

Water harvesting in this context referes to any activity related to water expolitation for domestic or agricultural purposes. There are different ways of water collection in Iran, the most espectacular of which is qanat. In general ground water resources are expolited by using wells, springs and qanats. Rainwater is collected directly from roofs or from or by constructions such as ponds, bandsars, abanbar, etc.

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Iran

In this paper an attempt has been made to evalute these techniques with particular reference to those employed in North-east Iran.

1. Water collection for Domestic Use. For this purpose water is expolited by abanbars springs, wells and ponds. Although qanat to built mainly for agricultural purposes, in some cases where water is drinkable, it is also used for domestic purposes.

a. Abanbars. Since the climatic conditions of this part of the country is dominated by arid and desert type of climate, drinking water is vital. The most important way of water collection and storage, particularly in southern parts of the region, adjacent to the desert is by the use of abanbar which is an underground cistern (Figs 1,2,3). Although this is not is use extensively these days but still is the main source of drinking water in some areas. The remains of abanbars are still present in old trade routes such as silk road. At that time water was collected from roof and courtyard of Karvansaras (what could be similar to motels) and stored in abanbars. For destruction of insects larva some kind of fish were introduced or different salts were used.

Abanbar is normally built by local materials and bricks and the capacity depends on the requirement of the people involved. Water is first collected from ground catchments to small plots (Band) for further siltation and then released in abanbar. For filteration the gutter is filled with crop residues and plant materials. This is believed to enhance cooling of water in summer.

Water in abanbar is not hygenic and disinfection in needed. This is normally practiced where the sole source of water for domestic use is provided by adanbar.

b. Springs. This type of water use is mainly in mountainous areas. Water from springs is collected in unlined pits or ponds. Unlined pits and ponds are usually poor water storage facilities. Springs are one of the important water sources for nomads in mountainous rangelands.

c. Wells. Wells are blow ground structures. In many villages and plain rangelands this is still the main water storage facilities. Wells are normally cylindrical in shape and their depths ranges from few meters up to 50 or even more meters. Wells are usually situated near farm yards, roads, barren slopes or houses. Water is brought up by primative methods with human or animal power.

d. Water from roofs. This is practiced in far North of the region mainly in forkaman area near the border with Russia. Water is normally collected from roofs with corrugated galvanized steel and kept in concrete or steel storages in courtyards. This is used in places where other sources of available water is not suitable for domestic use.

2. Water collection for agricultural use

a. Qanat. Water tables slope generally from higher terrain down in the direction of plains. A continuous horizontal ground flow develops along the slope, which transports the water infilterated within the intake area to the lower-leying plains. Horizontal gulleries were constructed thousands of years ago to collect this excess infilteration water. The ancient structure were usually composed of vertical dug wells which collected the water and gently sloping tunnels which channel the water from the head wells to lower points of the terrain. These complex structures are called qanat in Iran, Kariz in Afghanistan and Pakistan (fig 4). The first shaft is usually sunk in a hill slope to a level below the water table, and is called the motion well. Shafts are sunk at intervals of 20 to 30 m in a line along the direction of ground water flow. The dimensions of interconecting tunnel are 1 to 1.5 m height and 0.4 to 0.8 m width. The maximum discharge from qanat is of the order of 30 liters per second.

Qanal building is a skill in which some families specialize and which provides their livelihood. Water from qanat is normally used for irrigation but when it is intended for consumption, an encloseure is erected to cover a ground level cistern into which the qanat discharged, to the pollution is avoided. Water is then taken by pots from the cistern. It is said that qanats excavated from Alborz mountain (United Nations Environment Programme water resources series vol.5, 1983).

b. Bandsar. Bandsar are plots of land formed by constructing small earthen walls around them. The rainwater running off the neighbouring region is diverted to these plots. The main purpose of this system is to store water in the soil and to bring silt and organic matter contained in the water on the soil for dryland crop production. Height of a band does not exceed 3 m and the plot area is mainly dependent upon the topography of the land. Crops grown in Bandsars are normally melon watermelon cumin and safron.

In some cases hillsides are cleaned of rooks and gravel to increase runoff and ditches are constructed to carry water to fields below. Recently attemps have been made to utilize storm flows, normally running to waste for augumentation of soil moisture storage in rangelands and croplands (Kowsar 1981).

c. Terracing and pitting. Terracing is another application of water harvesting. Low walls are built along the contours of slope from stones and rock fragments. Their uphill sides are filled with soil collected from the slope between terraces. The surface thus becomes bare and ensures the complete runoff of rainwater. Soil surface application of asphalt of these terraces for tree plantation has been demonestrated successfully (Kowsar 1985).

Pitting is another type of rainwater collection mainly in flat Rangelands. This is done by special equipments made for this purpose (e.g. Pitter)

d. Microcatchments. In this system water is provided for single plants on steep and generally rocky slopes. The unprepard soil surface is generally uneven and thicker soil layers accumulate in depressions. Trees and vines are planted in these depression. A small dyke is formed from rock fragments, stones and soil below and beside the plant to retain the water running down.

e. Pot irrigation. In some parts of desert area on a very small scale narrow-necked clay pots are burried in the soil and filled with water when required. Vine and trees are planted adjacent to the pots where water peneterates to the root zone. This practice is not economically feasible.

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