ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC
BANGKOK, THAILAND

GUIDELINES FOR THE PREPARATION OF NATIONAL MASTER WATER PLANS

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FOREWORD

This publication is presented in four parts. Part One consists of guidelines for the preparation of national master water plans adopted at the expert group meeting held at Bangkok from 8 to 12 May 1989. The draft of these guidelines was prepared by the ESCAP secretariat with the assistance of an expert from the Union of Soviet Socialist Republics as well as of other experts designated by China, India, Malaysia, Pakistan, the Philippines, the Republic of Korea, Sri Lanka and Thailand.

Part Two comprises selected papers presented by country experts who participated in the Expert Group Meeting to Review and Finalize Draft Guidelines for the Preparation of National Master Water Plans. These papers highlight the experience and problems of those countries in the preparation of their national master water plans. The views expressed in the papers are those of the authors and do not necessarily reflect the views of the United Nations.

Part Three is the report of the Expert Group Meeting held at Bangkok from 8 to 12 May 1989. The report contains, *inter alia,* a brief account of the activities of United Nations agencies and other international organizations to assist countries in water resources planning, as well as the recommendations of the Expert Group which were directed at both national and regional levels.

Part Four consists of a manual for planning, design, operation and maintenance of irrigation systems prepared by the ESCAP secretariat. This manual is a supplement to the guidelines and is expected to be useful to water resources development planners who are engaged in the task of preparing a national master plan.

Manuals for planning, design and management of other sectors of water resources development, namely, "Manual and guidelines for comprehensive flood loss prevention and management", "Manual and guidelines for water quality monitoring" etc., are now under preparation by the ESCAP secretariat and when completed will be published in subsequent issues of the Water Resources Series.

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Part One

GUIDELINES FOR THE PREPARATION OF NATIONAL MASTER WATER PLANS

I. INTRODUCTION

Water is a key element in the socio-economic development of countries in the region. However, as the total amount of available water resources remains more or less constant while the demand increases with the growth of population, industry and agriculture, water is now becoming a scarce resource throughout the region. In order that this scarcity should not hamper the socio-economic progress of developing countries in the region it is very important to improve the efficiency of planning and management of water resources. In other words, a water resources plan, consistent with the overall economic, social and environmental policies of the country concerned, is an important element to ensure that water resources contribute to the country's development objectives.

The Mar del Plata Action Plan adopted by the United Nations Water Conference in Argentina recommended the formulation of master plans for countries and river basins to provide a long-term perspective for planning, including resource conservation, using such techniques as systems analysis and mathematical modelling as planning tools, wherever appropriate. It also recommended that planning should be considered as a continuous activity and that long-term plans should be revised and completed periodically, suggesting a five-year period in this regard.

Most development decisions today have multiple objectives involving economic, social and environmental dimensions and values. However, until relatively recently, this fact was not seriously taken into consideration in planning for water resources development. Instead, economic development was considered to be a desirable end in itself, often with little regard to adverse effects on social or cultural systems and the natural environment. As the pace of economic development increases these effects can no longer be ignored. The need to formulate plans for water resources development in a rational way, the multidisciplinary nature of water resources planning, development and use requiring co-ordination among various government bodies concerned with water, and the need to minimize adverse environmental impact owing to water development activities have all added to the complexity of water resources development and management.

A survey conducted by the ESCAP secretariat in 1984 to monitor the progress of implementation of the Mar del Plata Action Plan at the national level in the region indicated that many countries still did not have a comprehensive master plan for water resources development, and that those which had one were considering its revision.

In order to assist the developing countries in the preparation of a national master water plan, the secretariat prepared a paper describing the contents of such a plan, data requirements for its compilation and the methodology involved in its formulation, and submitted it to the ESCAP Committee on National Resources at its twelfth session in 1985. The Committee, after reviewing this document, suggested that a manual or set of guidelines on the preparation of national master water plans be prepared by the secretariat. One of the purposes of the guidelines would be to ensure that all the important aspects of development – economic, social, environmental – are adequately considered in the formulation and/or revision of national master water plans. The Commission considered and endorsed this proposal at its forty-second session in 1986.

Consequently, an activity concerning guidelines for the preparation of national master water plans was included for implementation in the 1988-1989 work programme of the ESCAP secretariat. The first draft of these guidelines was prepared by the secretariat with the assistance of an expert from the Union of Soviet Socialist Republics which was subsequently improved and elaborated on by experts from China, India, Pakistan, Philippines, Republic of Korea, Sri Lanka and Thailand.

The guidelines contained in this document are expected to be useful not only to those developing countries which have not yet formulated a master plan, but also to those where such plans already exist, as these plans generally require to be reviewed and updated approximately once every five years.

The secretariat acknowledges its thanks to the Government of the USSR for making the services of an expert available to ESCAP in the preparation of the draft guidelines as well as to the Governments of the People's Republic of China, India, Malaysia, Pakistan, Philippines, the Republic of Korea, Sri Lanka and Thailand for designating their experts who made valuable contributions to enhance the usefulness of these guidelines. Thanks are also due to the Governments of countries which have provided the secretariat with their national master water plans and/or information concerning their national water policies.

The secretariat also expresses its appreciation of the assistance and co-operation rendered by other specialized United Nations agencies and international institutions involved in water resources development.

II. GENERAL PROVISIONS

A. OBJECTIVES

The primary objective of a national master water plan is to establish a basic framework for the orderly and integrated planning and implementation of water resources programmes and projects, and for rational water resources management consistent with overall national socio-economic development objectives.

To meet this objective, the master water plan should:

(i) Ensure the availability of water, adequate in quantity and quality, for all necessary uses;

(ii) Develop a comprehensive and integrated approach to water and other socio-economic development, particularly with regard to interrelated water, land management and environment issues;

(iii) Encourage the preparation and implementation of comprehensive long-term plans for the sustainable development and management of water resources;

(iv) Formulate measures and/or water resources development projects which improve the efficiency of water supply and use;

(v) Identify water resources problems and set out priorities for promising water resources development projects;

(vi) Recommend implementation of financial and economic policies which distribute the costs of water supplies equitably and provide incentives for the most economic use of water resources, with due consideration for the social and environmental aspects of development;

(vii) Contribute to the successful implementation of overall national socio-economic development plans which also include the water sector;

(viii) Contribute to the formulation of long-term water policy for the country as a whole.

B. CONTENTS

A national master water plan should present the current status of development, make an assessment of the water and other related resources, look at the needs (both existing and future) for development and integrate these needs in accordance with available and potential resources. Annex 1 gives a list (not exhaustive) of some topics which can be incorporated into the national master water plan.

C. PLAN PERIOD

National master water plans should generally cover a period of at least 20 years. The United Nations Workshop on Water Resources Planning, held in Italy from 18-29 June 1979, recognized the value of producing a water resources development plan covering not less than 20 years, rolled forward periodically (if possible, annually), that would deal specifically with investment for the next five years and also provide a view on the longer term across all sectors of water use. According to the recommendations of the Mar del Plata Action Plan (1) (para 44), these plans should be revised and completed periodically. In some countries a five-year period has been used for this purpose.

Planning is a continuous process. Therefore, master water plans should be reviewed and modified as a country's ability to construct and finance projects grows, and as demands for water and land use change.

D. INITIAL DATA REQUIREMENTS

The initial data for preparation of a national master water plan are as follows:

(a) Concept of development and allocation of national economy sectors;

(b) Plans for social and economic development;

(c) Sectoral institutions (water users) data on manufacturing major types of production, their demands on water use and disposal;

(d) Reports on hydrological and hydrogeological surveys, national data systems on water resources, their regimen, quality and use;

(e) Basin (territorial) master plans of multipurpose water use and conservation;

(f) Reconnaissance and all relevant reports on major existing and proposed water resources projects and project sites.

In the process of elaboration of master plans, initial data obtained from sectoral and territorial plans may vary with time, owing to the revision of production plans for sectors of the economy. As the related water requirements may also change during the planning period, terms for the accomplishment of proposed water management and conservation measures should be revised accordingly.

E. GENERAL CONCEPTS

Master water plans should be keyed to national objectives and geared to meet changing and increasing needs.

Planning is a continuous process. Therefore, master water plans should be reviewed and modified as a country's ability to construct and finance projects grows, and as demands for water and land-use change.

Countries which have not yet had any experience in the preparation of a national master plan in any form may find it difficult to start preparing a full-fledged comprehensive master plan straight away. For such countries, the first national master water plan may be prepared in the form of a summary of the general state of water affairs in the country, with the descriptions of the means and methods of solving the country's most urgent tasks in meeting water demand. Later, a comprehensive master plan may be prepared that includes, *interalia,* a systematic assessment of the country's water resources as well as the identification of the concepts and methods of modern resource management for the water sector. Subsequent revisions and modifications of this comprehensive master plan may then be carried out, when necessary, to reflect the changes in water demand, hydrological conditions, socio-economic infrastructure affecting the quality of water, and to reflect the introduction of new technologies. This method has been used with success in some European countries (2).

F. COMMUNITY PARTICIPATION

The role of communities and other future beneficiaries of any water resources development should always be part of the planning process. The magnitude of community participation depends on the nature of the project. For example, in a rural water supply scheme beneficiaries assume a greater role, while in the case of a hydropower project their role is rather limited.

The value of community participation is not only that of utilizing local knowledge and information but also that of cost reduction and cost recovery of the project, particularly with regard to operation and maintenance. Through community participation, it is also possible to obtain accurate and reliable information on the possible future impact of the project on society and the environment.

III. WATER RESOURCES ASSESSMENT

A. GENERAL

The availability of water might be limited in relation to its many and varied needs. These needs will grow in size with the increase in population and industrialization. Agricultural output can be augmented by bringing new lands under cultivation and by improving existing agricultural and irrigation practices. Since almost every country in the region has important resources of underdeveloped hydroelectric power, this situation can also be reversed by utilizing more and more water for power generation. Good quality water in adequate quantity is required for domestic, industrial and commercial uses. Similarly, fish culture and sustenance of wildlife depends upon the development of water resources of the region.

The various important water uses are: public and domestic, rural water supply, industrial water supply, irrigation, electric power development, navigation, recreation, fish and wildlife, and maintenance of water quality.

In all the above uses, it might be necessary to build such structures as dams, reservoirs, barranges, canals, wells, etc., which in turn require appraisal and quantification of available and potential water resources. Therefore, in any comprehensive national master water plan, the occurrence, quantification and modes of exploitation of water should be adequately described.

There are usually two major sources of water, namely surface and ground waters, although there are other minor sources. In some regions, rainfall harvesting is of local importance. In assessing water resources availability, it is important to note that there are linkages between surface and ground water resources. Over-withdrawal of one could affect the availability of the other.

It should also be emphasized, however, that the basic hydrologic data available for project design should be adequate, as in the past there have been failures in some projects because the estimates of available runoff were not reliable due to the very limited data base. This also applies to the adequacy of available topographic data for the project areas. Therefore, if the deficiencies are found to be serious, it is advisable to promote the project activities only after the gaps are filled.

B. DELINEATION OF WATER MANAGEMENT AREAS

The assessment of water resources should ideally be carried out for river basins and their water management regions, delineation of which takes into account the natural and geographical factors, reflects administrative/territorial, economic and water management aspects and, therefore, completely encompasses the specific problems of water resources assessment for planning purposes.

The delineation of water management areas and subareas is implemented using topographic hydrologic maps or aerial photographs where the selection of control points and basin boundaries are made. Hydrographic characteristics of rivers and watersheds may be defined by topographic maps of scales indicated in annex 2.

Thus, the taxonomic units of upper level water *management areas may be represented by:*

(a) A whole basin of a major river flowing into a sea or a large lake;

(b) A lake basin with inflowing rivers, excluding rivers distinguished as separate areas;

(c) The part of a major river basin encompassed by control points;

(d) A whole basin of the first order tributary;

(e) A large reservoir on a major river with inflowing river sub-basins, excluding those as separate areas;

(f) A large main canal diverting water from a major river, including distributaries;

(g) Sea coast, excluding basins of major rivers as separate areas.

Generally, water management areas are used in the framework of the national water data system which represents the basic information support for a master water plan.

C. SURFACE WATER

Surface water may be considered as water flowing continuously or intermittently in surface channels and water contained in lakes, ponds and marshes. Estimates of runoff for development of water resources are carried out for each river basin and corresponding sub-basins. However, in many situations, the national boundaries cut across the river basins. Therefore, in an ideal situation, a national plan would include the sharing of water resources by all the countries lying within the river basin.

The quantity of surface runoff available for meeting present and future needs is evaluated by the following methods:

1. Analysis of available climatological and streamflow records.

2. Reconstitution of flow data by simulation.

In order to yield reliable estimates of water available for development, streamflow records of a sufficiently long period (40 to 50 years) are necessary. In cases where the length of streamflow record is not adequate, it is desirable to carry out the temporal extrapolation of the streamflow records based on rainfall records in terms of their intensities and/or pattern, as precipitation records are usually available for a much longer period than streamflow records.

A clear statement should be made in the master plan on the nature, source, reliability and adequacy of the data used in the assessment of water resources. The methods used and assumptions employed should also be stated.

In cases where long-term climatological and hydrological records are not available for estimating water resources potential, or where only brief or broken records are available, or where records are available only at locations considerably removed from the point of interest, streamflows are estimated. Of the various methods used for estimating runoff, the method of correlation with other stations is widely used. In this method, if a gauging station has been established at the control point, it is possible to establish a relationship between the record of this station and the records of other gauging stations. The relationship so established is then used for estimating the runoff for the point of study by extending the record or by filling in the missing data of the station at that point, based on the records of other stations which are relatively more complete and of greater length.

If no discharge record is available concurrently with records at other comparable stations, sufficiently reliable results can usually be obtained by applying the ratio of the drainage basins, if runoff records are available on the same stream either above or below the study points.

Some of the methods that may be used to estimate runoff are the rational formula method, hydrograph analysis method, infiltration method, regional flood analysis and flood frequency analysis.

The streamflow analysis generally includes determination of: (a) annual streamflow; (b) yearly streamflow distribution; (c) areal water resources distribution; (d) high flows or maximum discharges; (e) low flows or minimum discharges; (f) sediment runoff, including bed load and suspended load. Where applicable snowmelt contribution to the runoff should also be determined.

The quantitative assessment of water resources potential from rivers and streams should be made on a monthly basis as the month-to-month variations of water availability are the most important factors in the planning of water supply, irrigation, power and other projects.

One of the essential requirements of a national master water plan is to give recommendations in specific areas for the improvement of a data collection network. As the estimates for water resources have to be based upon hydrological, meteorological and climatological data, it is necessary to evaluate the existing hydrometeorological network and, if necessary, to recommend its upgrading.

In addition to assessing available surface water resources, there is a need to appraise and quantify the potential water resources of the river basin. This is done through preliminary studies to identify potential dam sites and assess their yields.

D. GROUND WATER

Ground water is an important source of water for socio-economic development. During recent years, the development of high-efficiency pumps and the availability of low-cost power has brought additional supplies of ground water with the result that irrigation as well as industrial and domestic water supply are now economically viable.

The main source of ground water is precipitation which percolates into the soil and is found throughout the upper strata of the earth's surface, particularly in the alluvium such as sand and gravel. Other sources are seepage, return flow, and so on. It is also found in the cracks and crevices of igneous rocks and limestone. The best aquifers are generally alluvium sand, gravel and limestones. Ground water is also found in lesser quantity in loosely cemented sandstones.

The occurrence and availability of ground water in a given area depends upon a number of factors which include the distribution of precipitation, type of soil, land topography, vegetative cover, soil/rock formation and their permeability and so on. In general, the basic data needed to assess the availability of ground water include: (a) geology of the basin, (b) precipitation on the area, (c) permeability of the aquifer, and so on.

Quite often the geology of the area is not known in sufficient detail to determine the boundaries and composition of the aquifer. In such cases, considerable hydrogeological studies have to be undertaken. These include geological and hydrogeological mapping, test drilling, seismic and resistivity surveys, electric logging, pumping tests, etc. As each area has its particular problems, the scope and depth of studies vary from place to place.

The first step in the investigation programme is to prepare an inventory of existing wells with their fluctuating water levels recorded at periodic intervals. Where such wells are non-existent, observation wells should be drilled and water-level fluctuations in these wells should be recorded. The next step is to carry out the surface geological mapping of the area, based on which a test drilling programme is prepared. This is necessary to determine the physical characteristics of the strata underlying the basin as well as the depth and the type of the aquifer – that is, confined or unconfined. Once the logs of the strata have been carefully prepared and soil samples collected for laboratory testing, the bore holes can be converted into observation wells.

The fluctuation of the water table or piezometric surface of an aquifer depends upon the properties of the aquifer, i.e., its permeability, transmissibility and storage coefficient. These properties can be determined by conducting a pumping test.

In certain areas overpumping of ground water from aquifers causes excessive lowering of the water table, resulting in undesirable adverse effects such as higher cost of pumping, decrease in available yield, brackish water intrusion, deterioration of water quality, and ground subsidence. In a national water plan, areas likely to be subjected to such conditions should be identified and appropriate remedial measures should be recommended, including the recharge of aquifers which may include water spreading and storage of the surplus surface water underground, if the geology of the area permits.

As the water level and the corresponding water availability vary with seasons of the year, ground-water availability should be estimated on a monthly basis.

The potential for ground-water development also depends on the water quality criteria as influenced by water management practices, modes of ground-water withdrawal and use. In some cases the quality of water does not remain constant but deteriorates with time. This is due to various causes such as supply of water to the field in amounts which are insufficient for irrigation and leaching of salts. This condition tends to increase the salinity of ground water in the absence of the salt export mechanism. Degradation of ground-water quality can also be brought about by employing inappropriate withdrawal techniques which may cause lateral or vertical migration of highly mineralized ground water into zones of otherwise usable ground waters.

E. QUALITY OF WATER

An important factor in planning for water resources development is the suitability of water for its intended use. The quality of water is greatly affected by the presence of minerals in soils and rocks through which surface or ground water flows. In cases where the aquifer from which water is being tapped is located near the ocean or other bodies of saline water, salt water intrusion may occur depending upon the rate of withdrawal of ground water. In addition, contamination from oil field brines, factory wastes etc., also affect the quality of water.

The usability of water for various purposes is determined by a number of criteria: physical, chemical, biological, etc. Where sufficient data on water quality is not available, a comprehensive programme may be prepared for the collection of necessary data.

The type and extent of treatment and the cost of treatment facilities should be estimated based on the results of chemical and bacteriological analyses. Since it is a specialized field of investigation, the services of well-qualified and experienced experts should be employed.

As a preparatory step for the formulation of national master water plans, the following activities concerning water quality investigation should be carried out:

(a) Compile all available data on existing water treatment plants, stream- and well-water quality and pollution levels;

(b) Classify water samples and prepare check lists of possible water uses of untreated water according to its chemical composition;

(c) Estimate probable costs of treatment;

(d) For ground water, determine salinity levels, classify areas and aquifer depths where fresh, brackish and saline water is found;

(e) For brackish water, prepare preliminary estimates of the cost of conjunctive use of brackish and fresh water;

(f) Prepare maps delineating areas suitable for a specific type of water resources development (such as domestic, industrial, and so on) on the basis of quality of water.

Water quality requirements for various uses are outlined below:

(a) Drinking water supply

Water quality for drinking purposes should generally conform to the guidelines established by the World Health Organization given in annex 3 (3). Where separate systems are available for public and domestic use, lower standards may be used for non-drinking water.

(b) Agriculture

Generally the factors which determine quality of water for irrigation uses are: (i) Total Dissolved Solids

(TDS); (ii) Sodium Absortion Ratio (SAR); (iii) Residual Sodium Carbonates (RSC).

Guidelines for the evaluation of water quality for irrigation purposes are given in annex 4 (4). Laboratory determinations and calculations needed to use the guidelines are given in annex 5. Guidelines for livestock are given in annex 6.

(c) Industry

The standards of water quality for industrial uses vary widely and should be considered on a case by case basis. The water use in any industrial process falls within one of the four basic groups: cooling water; process water; steam generation and boiler make-up; sanitary and service use. On average, 60-70 per cent of all industrial water use is for cooling.

There are two types of cooling: non-contact and contact cooling. In non-contact cooling, the action takes place via heat exchangers directly or with an intermediate cooling cycle. Often waste heat is the only result of the cooling process. However, on other occasions chemicals are added to prevent corrosion or fouling and these are sources of pollutants. In contact cooling, water may become contaminated from by-products of production processes, trace substances from the raw material or final products or other chemicals such as additives and catalysts. Therefore both waste heat and chemical pollutants will generally be present in the used contact-cooling water.

Water recycling for cooling purposes has the greatest potential for water savings within industry. However, even with recycling some "make-up" water is needed to prevent salt build-up. Small amounts of cooling water must be released as "blow-down"and fresh make-up water provided to replace the blow-down and the water evaporated during the cooling process. New technologies are being developed for using lower quality water for cooling purposes. Other process effluents may thereby be reused and higher quality water saved for other uses. However, reuse of other process water as a source of cooling water is not as widespread as recycling.

In closed (non-contact) systems, the quality of water is an important factor for the maintenance of the cooling system. In contact cooling the water quality is very important to prevent contamination of the process outputs.

(d) Fisheries

(e) Electric power

(f) Inland navigation

(g) Recreation use

Water quality standards for recreational purposes are given in table 9 of annex 3. In cases of particular interest it might be rational to organize field studies using local (biological) indicators.

F. WATER USE

The analysis of existing water resources use by sectors of the economy is to be made for the base period (10-15 years), according to the following sectors of the economy:

(a) Urban and municipal water supply;

(b) Rural water supply;

(c) Agriculture;

(d) Industry;

(e) Electric power;

(f) Fisheries;

(g) Inland navigation;

(h) Recreation.

The summary data are to be given on surface and ground water resources use in all economy sectors by river basins and water management regions based on the national water data systems. The analysis is to be conducted for the base period.

Based on the above analysis and the results of water management budgets, the assessment of available water supplies and their impact on economic development is presented for river basins, and integrated water management areas are treated according to sectors of the economy.

The analysis of water resources use by economic sectors may be made in conjunction with the estimation of water demand. This is discussed further in Chapter VIII.

IV. LAND RESOURCES ASSESSMENT

A. GENERAL

In the formulation of national master water plans, it is essential to have an appraisal of land resources and the extent of land suitable for development. An assessment of the irrigation potential should be based on the soil characteristics of available agricultural land and climatic factors. Efforts towards increased irrigation for agricultural development should become an integral part of land management.

An inventory of land development activities should include the areas suitable for irrigation as well as those requiring drainage.

The inventory classification for each water management region is carried out on the basis of the analysis of natural and economic conditions of areas within the context of crop yield potential, which depends on soil fertility and land reclamation techniques.

The planned growth of developed land areas should be outlined along with the prospects for agricultural development of improved lands: land use patterns, crop production and animal population. All possible options for rational use of agricultural land should also be considered and presented.

Suitability of land for irrigated agriculture depends upon its physical and chemical properties and on the socio-economic and environmental factors of the region. The physical and chemical properties of land which determine its suitability for irrigation are: climate, soil, topography, drainage, etc. Socio-economic factors usually determine the degree to which land can be put to agricultural use. It is desirable to determine the suitability of land for irrigation on the basis of other factors such as land classification, land use and land capability surveys. These methods are, however, costly and time-consuming.

B. LAND CLASSIFICATION SURVEYS

Land classification surveys should be carried out at three levels: reconnaissance, semi-detailed and detailed. For master planning or regional planning studies, only the first two types of surveys, namely reconnaissance and semi-detailed surveys, are required. Detailed surveys are carried out for project authorization, design and construction of projects.

Land classification at the reconnaissance level involves identification of the general outline of salient land features in the preliminary planning of irrigation development in a particular region. These surveys are normally carried out on maps having a scale of about 1:25,000 to 1:200,000 and are restricted to identification of location, extent, and quality of large areas to be used for irrigated agriculture.

Semi-detailed land classification involves careful examination of land features of potentially irrigable areas at approximately 1 km intervals. Arable and non-arable lands are also identified with considerable accuracy at this stage. This type of classification is usually delineated on maps having a scale of 1:10,000 to 1:25,000, or preferably on aerial photographs adjusted to a similar scale.

C. LAND CLASSES

In some countries land is classified on the basis of its productivity and suitability for agricultural development within a specific ecological area. In the United States of America, for example, the Bureau of Reclamation (USBR) classifies lands into six classes (7). Class 1 lands are highly suitable for irrigated farming; class 2 lands are of moderate suitability for irrigated farming; class 3 lands are of lesser suitability; class 4 lands are of marginal suitability; class 5 lands are considered to have potential for development; and class 6 lands are non-arable lands.

Where no data on land classification is available, the first step is to prepare an inventory of land use for the country. This inventory may be prepared in the form as indicated in annex 7.

D. SOIL SURVEYS

For master planning studies, reconnaissance level soil surveys are considered to be adequate. This survey is also carried out to determine the salinity and sodicity of the soil. Aerial photographs of 1:25,000 to 1:200,000 scale may be used. Land use at different locations is noted and depths of the water table to a maximum of 3 m are measured. Water samples should be collected for chemical analysis from hand-auger holes which may be drilled to 2m depth on a 1 km grid. Soil samples should also be taken from these holes at four intervals of depth, namely, 0-20 cm, 20-50 cm, 50-100 cm and 100-200 cm. Physical and chemical analysis should be carried out on the samples to determine the texture, surface and profile salinity and sodicity. The results of the soil surveys are then plotted on large-scale maps.

The reclaimability status of various soils for agriculture should be determined on the basis of soil survey data: (a) electrical conductivity of the soil saturation extracts in micro mhos per centimetre (m mhos/cm) (EC); (b) calcium plus magnesium contents of the soil solution in milliequivalents/litre (me/l); (c) sodium absortion ratio (SAR); (d) soil texture; and (e) potential acidity.

Lands are then classified for reclamation purposes into four classes using the above criteria, namely (a) reclamation not required, (b) easily reclaimable; (c) difficult to reclaim; and (d) very difficult to reclaim.

E. LAND CAPABILITY SURVEYS

Based on the land classification and soil surveys, land capability maps which indicate the suitability of land for various types of crops can be prepared. This information is of vital importance to planners in evolving future cropping patterns.

V. POPULATION – PRESENT AND FUTURE

Current data on population and population forecasting are of vital importance for the planning of any economic activity in the country. No national plan of any kind can be formulated without a knowledge of the number of people or the institutions which it is supposed to serve. Every effort should therefore be made to base the master plan on reliable current and future population figures. For this purpose it would be useful to consult the United Nations Manual of Methods for Projections of Urban and Rural Populations (8).

Among the methods used for projection of population are the mathematical method, economic method, the analogy method, the component method and so on.

Mathematical method projects total population and total population changes as a function of time.

The economic method treats population as a variable dependent on economic activity. It takes into account future needs for food, raw material, manufactured products and services in the total market area. On this basis a labour force in the market area is predicted, which in turn is used to predict population of the country.

In the case where no basic demographic data exists for estimating population growth or birth, death and migration, the analogy method is used. In this method, population is projected by transposing demographic figures for areas with comparable social and economic conditions. This method is not precise but is useful where little demographic data is available.

Where essential data is available, the component method (also called the Cohort survival method) should be used, which takes account of future changes in its parts or components (9). This method is based on a benchmark population distributed by age and sex. Mortality rates are applied to each age and sex cell and age-specific fertility rates appropriate to each age are applied to the female cells. The migration component is included either by the application of rates of migration specific to each age and sex grouping, or by the inclusion of projected numbers of migrants, i.e. negative for out-migrants and positive for in-migrants, appropriate to each age and sex grouping. In this manner, after each one-year or five-year phase in the projection period the population is calculated from the one preceding.

A separate projection of the migrant population may be desirable, where the migrant population is large and significantly different from the original population in ethnic composition or in such social characteristics as marital status, generating different demographic behaviour. In practice, future assumptions with regard to the fertility and mortality behaviour of the population are based upon prior events, which in turn reflect the inclusion of migrants in the past. Unless a radical change is anticipated, it is unlikely that such a refinement would improve the projection; and the additional data required would cast additional doubt on its advisability.

Data requirements for projection purposes fall into three broad classes: (a) benchmark or baseline population data; (b) vital statistics, and other regularly collected administrative data which can provide measures of components of population change; and (c) data on births, deaths, migration and population through sample registration and sample surveys. If such data are not available for the subject area, analogical data from other areas might be available. These should be in the degree of detail desired in the subnational projections.

Benchmark data should contain at least as much detail as the final projection is to include. Typically, the census population should be known by sex and by five-year or smaller age group. Moreover, other details which are required in the projection, or which might shed light on likely demographic changes, should be available. These may include urban and rural residence, marital status, ethnic composition or economic status.

School enrolment statistics, although lacking in complete coverage in many countries of the region, are still of potential value. Furthermore, it is highly desirable to have as a comparison, over a period of time, vital statistics and the rates of change calculated from them, to facilitate the understanding of recent changes.

In cases where adequate data is not available, other reliable methods of projection based on incomplete data should be employed. For this purpose, the United Nations manual on *Methods of Estimating Basic Demographic Measures from Incomplete Data* may be consulted (10).

VI. EXISTING WATER MANAGEMENT SYSTEM

A. GENERAL

Prior to the formulation of plans to utilize existing water resources, it is essential to conduct an appraisal of the existing water management system in all the major fields of water use including the description of physical and structural facilities available, their capacities and constraints if any, area served, population affected, water rights, water management laws, etc.

B. WATER LEGISLATION

It has always been necessary for a society to find some means of resource sharing and for resolving conflicts amongst individuals. Historically, this has been done through the local customs or traditions of particular settlements, or sometimes through a community's religious beliefs and ideals. Modern water legislation is the natural response to changes over the centuries in the functions of government and in the way water is utilized by various users.

The most significant responses of the legal system to the modern realities of water development are the replacement of custom-based rules or common law principles by written legislation of sufficient detail to cope with the complexities of modern management needs and the nomination of special government departments, not only to undertake major planning and construction activities, but also to quantify and apportion the individual entitlements of water users.

Historically, water resource decisions have been made independently of most other land use management decisions. However, according to recent experiences it appears that in the enactment of national water legislation the systems approach should be given its broadest possible interpretation.

Some of the reasons why this broad interpretation of the systems approach is desirable are:

(a) At the State level a systems approach is desirable institutionally, whenever State boundaries, river catchment boundaries and political boundaries do not coincide;

(b) At the farm level, land management decisions involve both soil and water resources simultaneously. Keyline and contouring systems explicitly recognise these relationships, as should all soil and water conservation concepts, which are frequently best managed on a catchment basis. Land management practices are frequently directly related to the quantity and quality (e.g. turbidity and salinity) of water runoff;

(c) Surface water management policies and practices are often directly related to ground-water systems. Consequently, there is a sound basis for their conjunctive management;

(d) Drought management policies (e.g. fodder subsidies) are often in direct conflict with soil and water conservation policies;

(e) Closer settlement policies which provide subsidies for water are, ironically, in conflict with long-term sustained production objectives in areas prone to irrigation salinity, by encouraging excess leaching applications and technically inefficient irrigation technology;

(f) Aquatic weeds management has a direct effect on water supply availability and quality;

(g) Finally, a systems approach identifies the need for a multi-disciplinary input to water resources-related issues.

(h) Flood risk/flood zoning.

C. THE ROLE OF GOVERNMENT IN WATER MANAGEMENT

In most countries of the region, customs, traditions and various types of unwritten laws have been developed mainly for the purpose of apportioning rights between private individuals. The law served the purpose of protecting one water user against the improper activities of another. If his upstream neighbour wrongfully diverted the course of the stream, proceedings might be taken against the wrongdoer to obtain compensation for damages suffered, or to have the original flow restored. It therefore provided a judicial or arbitrative framework within which water-use conflicts between individuals could be resolved.

Besides, a number of important factors such as the nature of water, fiscal and economic factors as well as social and political factors have combined to produce a situation where the Government is forced to play a more active part in managing water.

1. The nature of water

Water, in its natural state, is a unique commodity the characteristics of which seem to defy usual concepts of ownership. This, coupled with the universal dependence of life upon water, have led most legal systems to place it in a special category. With the emergence of modern political theory and ideas concerning the obligations of the State, the view that the State, as the guardian and promoter of the public good, should have the ultimate responsibility for ensuring that water is distributed, allocated and used in an efficient and equitable manner, has been widely accepted.

2. Fiscal and economic factors

Experience in most ESCAP countries has shown that the expenditure necessary for water resources development projects requires investment from the public sector. For financial reasons alone, it has thus become necessary for the government to become actively concerned with problems of water management. Further, priorities of national spending must also be established. Investment in one large-scale water development project automatically withdraws resources from other possible avenues of national development. Priorities for water development and management schemes must therefore be established in the light of the wider economic plans for the country concerned.

3. Social and political factors

The allocation or reallocation of available water to meet various economic goals involves many social and political problems. Sometimes traditional uses of water may need to be curtailed or controlled. Land may have to be acquired for headworks and distribution systems, and restrictions applied to and enforced on the character and quantity of water used. Communities may need to be resettled and demographic and production patterns changed to achieve the optimum overall benefit from a particular development investment.

Furthermore, increased competition among water users for a scarce resource leads to a wider variety of disputes. Governments, therefore, have to intervene to prevent such disputes from arising or to settle them in the most judicious way.

Factors such as those outlined above have led many countries to conclude that only the government could provide the necessary capital and human resources to plan, co-ordinate and execute major water development programmes. It was only the government which possessed the necessary constitutional and legal powers to abridge, qualify or rearrange the traditional rights of individuals to water and land, and to attend to the social, human and economic problems which accompany rapid technological and economic changes.

The government, from a position where it had merely provided the judicial or arbitrative system necessary for individuals to solve their personal disputes, thus began to take a more active administrative role in the allocation and distribution of resources. This change was paralleled by the enactment of written legislation for matters concerning water management.

Almost all countries in the region thus possess legislation which has been enacted from time to time for the purpose of qualifying the pre-existing legal regime and for conferring certain particular, if limited, powers on the government to intervene in the allocation and management of water resources. They differ only as to the extent, quality and recency of such legislation. In building up an efficient, centralized national body for the formulation and implementation of national master water plans, periodical revision and improvement of the existing water legislation and its adaptation to the practical present and future needs of the country are very important.

D. INVENTORY OF WATER MANAGEMENT SYSTEMS

An inventory of the water management systems in the river basins, water management regions (areas) and administrative/territorial units should be maintained. The information to be included in the inventory should include both designed and actual technical and economic specifications of the systems for:

(a) Existing water projects;

(b) Projects under construction;

(c) Planned water projects;

The format for the inventory is given in annex 8.

VII. WATER-RELATED ENVIRONMENTAL ISSUES AND HEALTH ASPECTS

A. GENERAL

In planning water resources development projects, environmental and health requirements as well as disaster prevention should be kept well in sight, and water quality management and environmental issues and health aspects should be included as an integral part of water resource planning.

The ultimate goal of water development projects is the sustainable socio-economic development of the nation. Precautions should thus be taken to ensure that the positive impact expected from the planned projects will outweigh the adverse impact on the water environment as well as on other development projects in the long run. One tool which has been developed and is gaining more and more acceptance is the environmental impact assessment (EIA). EIA should be incorporated in all the major water projects likely to create adverse impact. Existing guidelines for selected water projects prepared by various agencies could be consulted (ADB, UNEP, ESCAP, BRD, UNESCO, WHO, etc). Hence, the overall national master plan, regional or basin water management plan would identify the cumulative impact of each project and preventive measures could be taken.

In view of the importance of ground water as a prime source of water and as an essential part of the natural ecosystem, consideration should be given to the protection of ground water against pollution, over-exploitation and wastage.

Consideration should also be given to promotion and development of bilateral or multilateral treaties or other arrangements, where necessary, to define mutual arrangements and responsibilities among riparians regarding the sharing of water during floods and droughts, and the control of pollution.

Where absent, consideration should be given to the enactment of legislation concerning soil and water conservation as well as control and prevention of soil erosion, with major emphasis on bank protection. Legislation may take the form of a watersheds protection act, a forest act, a land authorities act, etc.

Examples of some legislative measures that contribute to the protection of the environment are:

(a) Wild life protection acts that provide for the regulation of fishing in inland waters (rivers, lakes, etc.), and also prohibit the pollution by industrial wastes of water containing fish;

(b) Flood water control acts that provide for the carrying out of flood control measures/projects by responsible bodies;

(c) Irrigation acts, water acts and underground water control acts that provide for the prevention of waste, pollution and misuse of surface and ground waters; and

(d) Public health acts that provide for the prevention of pollution to water supplies used for domestic and drinking purposes, as well as the prevention and control of water-borne and vector-borne diseases.

In irrigated agriculture as well as general agricultural development, consideration should be given to environmental management for vector control, because an excessive use of pesticides can produce adverse impacts on vector resistance, environment and human health.

One of the effective methods of environmental management for vector control in irrigation schemes is the provision of an adequate drainage system.

Attempts to increase agricultural production by using high-yield crop varieties may be incompatible with the use of ricefields for fish production. As fish act both as food protein and as predators of disease vectors, investigations should be carried out to make sure that the higher pesticide input that is required in high-yield varieties of crop does not result in lower fish yield (11).

B. SURFACE WATER QUANTITY

As the hydrologic regime of a river system will be considerably altered by planned water resources development projects, a comparison should be made of the typical hydrographs representing conditions both before and after the implementation of the projects. This comparison should also include evaluation of the adequacy of available stream gauging data for typical average, flood, and drought year conditions. The analysis should also describe the overall effect in the mass water balance for the basin above the project sites (particularly dam sites) on a monthly as well as annual basis for conditions before and after the implementation of the planned projects. Change in water regime owing to upstream development should be assessed to predict downstream environmental consequences to facilitate provision of alleviating measures.

A check should also be carried out to determine whether the possible reduction in the area of forest cover in the watershed would result in the reduction of future streamflow into the reservoir and/or reduction in the base flow of the streams, especially during the dry season. If this poses a serious problem, consideration should be given to taking reforestation measures so as to ensure continuing yield at the required minimum level (12).

C. SURFACE WATER QUALITY

A comparison of surface water quality both before and after implementation of the projects should be carried out for average as well as seasonal conditions. Water quality should be investigated both in the reservoir and the river downstream to determine the effects of storage on: (a) physical parameters (temperature, dissolved oxygen, suspended solids/turbidity); (b) dissolved mineral constituents (Ca, Mg, Na, K, Mn, Fe, etc.); (c) biological parameters (plankton, benthos); (d) applicable pollution parameters (Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), heavy metals, chlorinated hydrocarbons etc.).

A study should be carried out on the expected new ecology (resulting from each project) in the reservoir areas, in the downstream riverine zones and in the estuarine/marine zones. The study should include probable effects on fish productivity and fish food chains, considering the biological life both in the water column and benthos.

A study should also be carried out on any necessary corrective measures, including details on sampling and analyses to be used for assessing physical, chemical and biological characteristics of the affected aquatic zones, and frequency of sampling to provide statistically reliable information for all seasons of the year, and methods of evaluation for interpreting the significance of the data for each project. The required continuing monitoring programme should be planned as an integral component of the overall project operations programme (so that they will be properly funded), and should be designed so that continuing assessments may be made over the years of the effects of the projects in modifying the aquatic ecosystem. Feasible corrective measures, if required, should also be discussed.

D. GROUND WATER

A study should be carried out on the anticipated effects of each water resources development project on ground-water quantity/quality in the vicinity of the project area. The study should include possible alterations in the ground-water table, waterlogging, seepage from reservoirs and canals, alterations in infiltration due to impoundment by reservoirs, and proposed measures for correcting or offsetting adverse impacts.

The adverse impacts that should be studied include the effect of the anticipated ground-water withdrawals on: the safe yield of the aquifer (s); ground subsidence; brackish water intrusion, etc.

E. FLOODS

Floods are usually caused by excessive rainfall or snowmelt, storm surges, inadequate drainage or a combination of any these.

Many areas are periodically subjected to flood damage. In some cases, recurring floods seriously disrupt the momentum of a country's economic and social growth. The extent and frequency of flooding as well as the severity of flood damage usually determine the scale of flood mangement and protection work.

Apart from causing visible damage to urban (residential), agricultural and industrial areas, floods may also cause widespread and long-lasting damage to the soil due to possible salinization.

F. SILTATION AND EROSION

An assessment should be made of the amount of sediment (silt) expected to accumulate in the reservoirs from watershed erosion runoff and recommendations should be made for minimizing this effect. The effect of sedimentation on the useful life of the reservoir should be estimated.

Estimates should also be made with regard to the future extent of downstream erosion caused by the scour of water released by dams, including expected vertical and horizontal erosion and new water surface levels in the rivers and streams. Corrective measures to mitigate downstream erosion should also be proposed.

G. FORESTS AND WATERSHED MANAGEMENT

The possible impact of a project on forests should be studied and measures proposed to minimize adverse effects. These may include: (a) reduction or loss of forest productivity owing to inundation by a reservoir; (b) increased deforestation as a result of improved access provided by a project; (c) subsequent reduction in the effectiveness of the forests with regard to soil and water conservation.

A check should also be made to determine whether projects' expectations for future streamflows into the reservoir take into account the possible future loss of forest cover in the watershed and the resulting reductions in infiltration, which could result in the reduction of the base flow of the stream, particularly in the dry season.

H. FISHERIES

A study should be made of the expected losses in pre-project (existing) riverine fisheries owing to: (a) creation of reservoirs, particularly with regard to downstream inundation (bank overflow), downstream changes in hydrologic regime, trapping of nutrients in reservoirs; (b) interference of dams with migratory species.

A discussion should take place on the expected new situation in the reservoirs and in the altered river (and in any affected downstream estuarine and marine zones), comparing the new situation with the old, and describing plans for making up for anticipated losses (so nobody will be worse off with the developments than without) including proposed fish hatchery and artificial propagation operations, proposed fish farming etc. In other words, if a dam/reservoir will result in loss of valuable fisheries and this loss will not be offset by future reservoir fisheries, then a downstream fisheries development scheme may be required.

I. FLORA AND FAUNA

As the construction of major dam/reservoir projects almost always results in increased access to the watershed and thus serves to accelerate human activity and the related loss of forest cover/wildlife habitat, consideration should be given to the inclusion of measures for conservation of flora and fauna.

Impact on animals inhabiting the lands to be inundated by the projects should be assessed and plans for salvaging and rehabilitation should be formulated.

J. HEALTH ASPECTS

The construction of major dam/reservoir and irrigation projects almost always results in increased incidence of water-borne and vectorborne diseases. Therefore health ministries should be involved in the initial planning stage of water resources development projects, and studies should be made of the prevailing water-related diseases and the presence of intermediate hosts for helminthic diseases in the area. Data and information thus collected would be stored systematically so that they could be easily retrieved for use in a desired context.

Provisions should be made for continuous monitoring of drinking water quality covering all aspects, namely microbiological, biological, chemical and physical aspects. Remedial measures should be planned so that they can be undertaken immediately and effectively as soon as an increase in the incidence of water-related diseases is detected or the deterioration in water quality is observed.

There should be plans for an institutional strengthening of health services, training of health manpower, and adequate provision of medical supplies and equipment in those areas where major water resources development projects are contemplated.

Community education and involvement in drinking water projects and management should be promoted as an integral part of primary health care, especially in small community water supply.

K. POLLUTION CONTROL

Based on the assessment of existing characteristics of water resources quality, indicators of substances in waste-water effluents flowing into water bodies by urban runoff, pesticides/herbicides and fertilizers, and watershed sediments, should be presented. Besides, water conservation measures such as the introduction of water recycling and re-use, reuse of treated waste-water effluents and so on, undertaken by various sectors of the economy should be analysed with regard to the capacities of water treatment facilities as compared with the waste-water effluents. Comparative summary assessment of the water conservation status, including quality control by river basins should also be carried out. The disadvantages of water conservation activities should be analysed and measures for water quality improvements should be suggested.

As a result of the assessment of sectoral water demand projections, the tolerable contamination limits (TCL) of effluents in water bodies should be defined by water management regions. With the aim of establishing the TCL for economic sectors, the contents and scope of conservation measures for water and related natural resources should be outlined along with the capital costs and their economic efficiency.

The terms of setting up of water conservation projects should be defined and their estimated capital costs should be determined. The result of water conservation measures, that is, water quality improvement, should be evaluated.

L. WATER BODIES AND COASTAL AREAS

The analysis of the existing status of the stage, salt regimen, extent of pollution of coastal sea water and lakes, and environmental requirements should be outlined. Sea water balance owing to the existing off-channel withdrawals should also be presented.

Anticipated measures for reducing water losses from the water surface, stage maintaining, alleviation of excessive eutrophication of lakes, streamflow transfer, pollution control etc. should be outlined along with financial and economic specifications of projects.

Feasibility for meeting demands by required releases from reservoirs by river reaches should be presented.

The sea balance and anticipated regimen should be provided for specific planning time horizons. The subsequent changes of the sea regimen and the anticipated damages due to off-channel withdrawals, as well as alleviation measures, should be outlined.

VIII. FUTURE WATER DEMAND AND OTHER ISSUES

A. GENERAL

The various important uses of water are: domestic, municipal and industrial uses; irrigation; hydropower generation; inland navigation; fisheries and wildlife; recreation etc. In addition, flood management is usually included in water resource development projects. All the abovementioned aspects should be given due attention in any national water master plan.

The assessment of water demand projections should necessarily include the analysis of aggregate water withdrawals from surface and ground sources, the aggregate volumes of waste and the return of drainage effluents into water bodies.

The amount of downstream water releases should be determined on the basis of all downstream requirements including irrigation, water supplies, fisheries, hydropower, navigation and minimum discharges needed for sanitation and environment purposes. The estimated regime of multipurpose release during various periods (months, ten-day periods) for all users is to be established based on the combined demand of water for several purposes.

The release for environmental purposes should ensure sufficient dilution of pollutants flowing into the river and the preservation of wildlife. Apart from maintaining the minimum discharge requirements, the release for environmental purposes should ensure regular channel flushing.

The water budget should be prepared for all planning time horizons, both short-term and long-term, based on available water supply, water demands and required flow releases for each time horizon.

Shortages of supplies and remedial measures should be pointed out for each river basin and water management region in consonance with various sectors.

B. DOMESTIC AND MUNICIPAL

Forecasts of the amount of municipal water needed are usually obtained from the town or city administration. Estimates of water requirements for domestic use should be co-ordinated with economic and social studies of anticipated population growth. The estimates should show the location and type of use, the gross requirement, peak consumption rate, net consumption and amount, quality and location of return flows.

Assessment of the future demand for water supply has to be based on the growth of population in the area to be served, and its likely consumption of water per capita which again depends on the standard of living, social customs and habits, accessibility of supply, quantity of water available, climate, tariffs, and economic and educational background. Per capita residential water use in selected areas is given in annex 9 and generalized estimates of domestic water use for design purposes are given in annex 10.

For assessment of domestic water requirements (14) the following information should be collected:

(a) Urban population (area, density);

(b) Rural population (area, density);

(c) Per capita consumption rates for urban and rural areas allowing for variations due to specific needs or cultures.

(d) Rural area domestic supplies; similar information for urban areas with emphasis on adequacy of treatment, and system efficiency (untreated water supply sources should also be investigated as to available quantity and quality, to determine their suitability as standby sources).

(e) Adequacy of present supply to meet demand in terms of both quantity and quality.

In the absence of data on actual per capita water consumption rates, a minimum quantity for maintaining personal and household hygiene, as well as for adequate food preparation and preservation practices, may be taken as 40 litres per capita per day (lpcd) as a rule of thumb (15).

With house connections, water consumption may be taken as ranging between 80-250 lpcd in large cities and 50-80 lpcd in small towns and rural areas.

With public standposts, it may be taken as 15-40 lpcd.

C. INDUSTRY

Industrial requirements are based upon expected types, sizes and number of industrial plants and specific water needs of individual industries.

Water demand projection for industry should be co-ordinated with economic studies of anticipated industrial expansion, and should indicate the location and type of use as well as the amount, quality and location of return flows, waste treatment and disposal.

Industrial water use can be estimated based on the amount of water fed to the plant which could include the reuse water, the water lost due to conveyance, evaporation, seepage and leakage.

Information on industrial water requirements should be collected from the relevant departments and agencies in the country. Water-use rates for existing industries should be based on past records of such industries. For planned industries, known international standard rates should be applied. Water requirements for selected industries in the world are given in annex 12. The wide differences reported in specific water amounts reflect differences in technologies. It should be noted, however, that for many industrial plants, water withdrawals (from a source of water) per unit product and per employee have decreased as water reuse has increased.

Efforts towards achieving greater efficiency in the use of water resources in industry should consider the application of new/advanced technologies that would facilitate: the reduction of water withdrawals from natural water bodies by further development of waste-water recycling systems; the use of treated municipal waste water, treated industrial waste water, mine waste water and sea water; the reduction of consumptive losses by eliminating leakages and process losses in industry; the introduction of dry cooling techniques and eliminating non-productive water losses; and effective control over maintaining low water consumption rates.

The contamination of water resources by industrial water use can be minimized by: eliminating the discharge of untreated and undertreated waste water; the reduction of waste water discharging into natural streams; wider use of waste-water recycling systems; and improvement of techniques of waste-water treatment to meet acceptable standards.

The information concerning industrial waste-water quality, particularly regarding pre- and post-treated conditions, should also be provided.

Commercial water requirements are computed on the basis of the number of commercial establishments that serve the population and/or the individual estimated use per commercial outlet.

D. AGRICULTURE

Agriculture plays an important role in the economic development of countries in the region. In some countries, it accounts for as much as 40 per cent of the gross domestic product (GDP). In countries with predominantly agricultural economies, the majority of the population lives in rural areas which are agriculture-oriented.

The national water master plan should first prepare an overview of the agricultural sector in the country describing the present state of agriculture and the performance of the agricultural sector in the economy as well as the policy framework in general. The assessment should include the extent of land under cultivation, crops grown, cultural practices and the rural population engaged in agriculture. The pattern of growth of the agricultural sector should be studied along with its contribution to the national income, capital formation, employment, foreign trade etc. A study of agricultural policies should also be carried out to determine their impact on the performance of the agricultural sector and with a view to possible improvement. Next, a demand projection of agricultural patterns based on the nutritional needs of the population should be carried out.

Demand for agricultural products is usually projected as a range of possibilities as it is dependent on population growth, government pricing policies, personal income and the actual supply of commodities. Since it is difficult to obtain an accurate estimate of some of these variables, attempts should be made to estimate the ranges of demand for commodities.

Demand projections for agricultural products are carried out by, firstly, projecting the per capita demand of major commodities, and then applying these to the corresponding projected population levels.

Since the primary objective of planning increased agricultural production is to satisfy the nutritional needs of the population, the most important indicator of nutritional adequacy is the quantity of dietary energy, measured in calories, supplied by food consumed. Another indicator is the amount of protein supplied, measured in grammes. Therefore national demand projections should be consistent with the projected caloric and protein requirements.

Agricultural water demand should be that which is required by crops over and above the quantity of water provided by direct rainfall as effective rainfall.

Estimates of water required for irrigation development should be closely co-ordinated with the land and agricultural surveys. These surveys will furnish information regarding land suitable for irrigation and the farming practices and cropping patterns which might be developed with irrigation. Irrigation water requirements should be determined on the basis of the land to be cultivated, climate, type of soil, crop, cropping patterns and field application methods. For reconnaissance level investigations, the irrigation requirements may be estimated by comparison with the rainfall and water use of similar irrigation enterprises in the same or nearby areas. In the absence of comparable irrigation records the requirement may be estimated from the consumptive use – temperature relationship with proper allowance for water losses.

The losses from the point of diversion to the farm may be as high as 35 per cent. Minor evaporation and bank storage loss are usually negligible in comparison with total losses.

These losses (farm and conveyance losses) should be added to the crop water requirements to get the diversion requirements of water into the conveyance system.

From the above, it is clear that as much as 50 per cent of the water diverted from the rivers for irrigation of the fields could be lost in various forms, that is, farm losses, conveyance losses etc. The national master water plan should therefore fully recognize this wastage and suggest measures to reduce such losses and increase irrigation efficiency. For new irrigation works, technical advances such as the lining of canals and water courses may be considered in order to reduce conveyance losses. Alternative methods like sprinkler irrigation may also be considered.

1. Crop water requirements

Crop water requirements could be estimated on the basis of the guidelines prepared by the Food and Agricultural Organization (FAO) of the United Nations (13).

Before calculating the water requirement for a specific crop, a review should be carried out of specific studies on crop water requirements in the area and available measured climatic data. Meteorological and research stations should be visited and environment, siting, types of instruments and observation and recording practices should be appraised to evaluate accuracy of available data. If limited data from several meteorological stations are available for the project area, an improved analysis will result from preparing maps including isolines of equal values of needed climatic variables. Data relevant to crop type, crop development stages and agricultural practices should be collected.

For estimating future crop water requirements, due consideration should be given to technological advances in irrigation which will bring about increased irrigation efficiency and consequently lower crop water requirements.

The volumes of water disposal (return and drainage water) are to be defined along with those of pesticides, herbicides, chemical fertilizers and soil washed out from reclaimed lands. Water conservation activities should be identified.

The actual and possible water erosion zones are to be pointed out with qualitative and quantitative forecasts of erosion development under the impact of land reclamation and agricultural development.

2. Farm losses

Some portion of the irrigation water applied to the fields is lost either due to deep percolation or as farm waste. The extent of losses due to deep percolation usually depends on: (a) irrigation methods; (b) soil characteristics; (c) length of water run; (d) slope of the ground; (e) rate and duration of application etc. The water losses in sandy soils are greater than in (heavier and tighter) clayey soils or in soils underlain by impermeable layers at shallow depth.

Deep percolation losses usually range from 15 to 50 per cent of water applied. In the case of sprinkler irrigation these losses may be only 5 per cent whereas in flood irrigation they may be as high as 70 per cent of the water applied. Surface wastes may range between 0 and 20 per cent. For new projects, the combined deep percolation losses and surface waste may be expected to vary between 20 per cent to 60 per cent of the farm delivery.

3. Conveyance losses

Conveyance losses comprise evaporation from water surface, seepage and bank storages. The most significant conveyance loss is the seepage into the bed and banks of the canals, laterals and water courses. The losses from the point of diversion to the farm may be as high as 35 per cent. Minor evaporation and bank storage losses in comparison with total losses are usually negligible.

4. Livestock requirements

Information on water requirements for livestock should be collected from large-scale unit owners as well as from small farmers or from the authorities concerned in the country.

If no data are available, estimates based on numbers of each species of livestock and their water consumption per head would suffice as basic planning figures. Typical water requirements for livestock may be taken as indicated in annex 10 (15).

E. HYDROPOWER AND THERMAL POWER PLANTS

Hydropower generation is one of the important aspects of water use. This renewable form of energy can be generated at low cost from multipurpose projects also intended for irrigation, municipal and industrial water supply, navigation and flood control.

Compared to thermal power plants, hydropower plants are capital-intensive, while operation and maintenance costs are much lower than those of thermal plants.

Barrages with storage facilities and large canals provide excellent opportunities for hydropower generation because of relatively constant water discharge and water head. With the development of low-head generating plants, these sources have become viable alternatives for power generation.

A reliable (if not totally accurate) assessment of hydroelectric energy potential of river basins should be made prior to the preparation of detailed schemes for multipurpose water resources development. Technical, economic and environmental feasibility of development should also be carried out at the reconnaissance level based on field investigations.

The hydroelectric potential should be estimated both in terms of total annual energy output and maximum power to meet peak loads. The assessment should also be carried out for different types of potential – technical and economic. An assessment of the expansion possibilities of existing projects should also be carried out.

Assessment of hydroelectric potential should be considered as a continuous process, beginning with the most preliminary estimates using reliable methods of approximation, in areas where available data are meagre, and proceeding to the detailed assessment of economic potential in areas where the necessary data could be obtained from a number of completely investigated and designed projects.

Water requirements for hydropower production should consider the total water available for generation, the amount and characteristics of anticipated power loads and amount of regulation needed to meet load fluctuations and water demands for other purposes. Estimates may be general in character but should be co-ordinated with other studies of the potential economic and industrial growth of the power market area, including alternative or competing sources of power and energy.

In the estimation of these requirements, the following trends and patterns of power-generating capacities may be taken into consideration:

(a) Maximum involvement of economically-feasible hydropower resources into power balance;

(b) The development of power plants using alternative energy sources for heating and power generation;

(c) Upgrading equipment of thermal power plants.

Depending on the fuel/energy balance conditions, the pattern of generating capacities of various types of power plants should be determined.

For thermal power plants, estimates of water requirements should be based on plant capacities and types of cooling water arrangements.

Measures for economical and rational water use, including the recycling of water, should be considered.

Similarly, the reduction of waste-water effluent and the discharge of pollutants should be considered for nuclear and thermal heat-and-power plants. The harmful effect of waste water discharged from power plants, especially nuclear power plants, and its impact on the thermal regime of natural water as well as its use for fish breeding should be considered.

For the estimation of water use and disposal quantities from the power plant, the existing standard rates should be applied considering the possible decrease in water consumption due to implementation of water-saving techniques and water reuse systems. Water use and disposal volumes, together with water supply sources and waste-water disposal sites, need to be presented.

F. INLAND NAVIGATION

Due consideration should be given to the provision of facilities for navigation as far as possible in every multipurpose water resources development project. Although there may be some conflict and competition between river transportation and other uses of water, particularly because of the requirement for enormous quantities of water to provide a minimum river depth for navigation, it is very important to give adequate emphasis to navigation in water utilization plans.

As inland navigation is an integral part of the transport network, plans to fulfill the future demand for transport should consider the development of all modes of transport including that of waterways.

G. FISH AND WILDLIFE

Water bodies are natural habitats for aquatic life. Many fish species are migratory. To permit migratory fish to pass through man-made structures across rivers and streams, fish ladders should be installed in conjunction with the structures as far as possible. A multipurpose reservoir could often provide ideal facilities for fish and wildlife culture.

In planning water resources development projects, due consideration should be given to the development of fish and other forms of aquatic life and appropriate surveys carried out. The survey results will be useful for guidance in future plans as well as for the correction of existing defects. Fishery surveys are important because although the impoundment and regulation of flow may be beneficial to the fisheries of a river, quite often irrigation, flood control and hydroelectric power production may adversely affect fish and wildlife.

Should the surveys indicate that the planned water resources development projects would have adverse effects, the following preventive or remedial measures could be taken to offset the radical changes, among others, in the regime of river flow which affect the fisheries (16):

(a) Regulate irrigation and flood flow discharges favourable to fish culture and supply of water for hatcheries and nurseries;

(b) Minimizing the changes in (i) silting pattern and turbidity, (ii) the nutrient content of water including oxygen and carbon dioxide, (iii) temperature, and damage to the river bottom through canalization and dredging;

(c) Minimizing the harmful effects of dams acting as physical barriers to fish migrations by providing fishways, fish ladders, fish locks, fish lifts, fish screens etc., depending on the specific requirements of the particular fishery and practical financial considerations.

There are many other specific remedial measures depending upon the particular aspects of problems.

The master plan should include the evaluation of the potential of inland water bodies for fisheries development. The hydrogeochemical regime of rivers, lakes and reservoirs and their fish-catch potential should be evaluated in this regard.

The factors influencing fish reserves and fish-catch potential should be presented along with the evaluation of fish catches depending on water discharge, water level, and salinity. The optimum water releases for fish breeding should be identified to meet the requirements of fingerlings and grown fish in river delta areas.

H. INTEGRATED ASSESSMENT OF WATER DEMAND PROJECTIONS

Water demand projections determined on a sectoral basis should be aggregated for both short- and long-term time horizons.

The water demand projections determined by the various economic sectors need to be integrated into the master water plan in accordance with available water resources and priority among the sectors.

The assessment of water-demand projections for various sectors should necessarily include the analysis of aggregate water withdrawals from surface- and ground-water sources as well as the total volumes of waste return and drainage into water bodies.

Water releases for various uses should be determined. These include the requirements of fisheries, hydropower, navigation and flows needed for environment purposes. The estimated releases for various intervals (months, ten-day periods) for all users should be established depending on the maximum demand of one or several purposes.

The release for environmental purposes should ensure sufficient dilution of pollutants in the river to ensure the preservation of wildlife.

In addition to maintaining the minimum flow, the release for environmental purposes should ensure regular river channel flushing during floods.

The water management budget based on available water supply, projected water demands and required flow releases should be compiled for all planning time horizons.

Any shortages or surplus of water should be identified by river basins as well as by economic sectors.

I. FLOOD CONTROL

The hydrological analysis of floods should be carried out on the basis of available climatological and hydrological data.

The two most important aspects of a flood are its volume and its peak discharge.

The volume of flood water discharge becomes important when a part or the whole of the flood waters are temporarily stored in reservoirs for mitigation purposes, because a greater storage capacity is required for a greater flood volume. The peak discharge is important in the determination of the capacity of the flood discharge channel and the maximum levels to which the flood waters will reach. Thus, the peak discharge determines the height to which the flood protection dikes should be constructed.

Flooding of coastal areas is usually caused by a number of factors, primarily storm surges, flood plain characteristics and tidal effects. Storm surge occurs when sea level is piled up through the effect of wind. The piling up depends upon the speed, direction and the duration of wind as well as the depth of water. The effect of the wind is most serious when it concides with high tide. For the planning of flood mitigation measures, frequency curves of high-tide levels along with data on the heights and lengths of waves are required. In the absence of such data, wave characteristics can be calculated from data on wind speed, wind direction, fetch and the depth of water. The height and the orientation of the embankments are then determined based on the storm-surge water levels and height of waves.

Management and mitigation of flood damage should consider both structural and non-structural measures.

Structural measures include the contruction of various types of structures (reservoirs, dikes, barrages etc). The cost of constructing these works and the benefits derived thereby are important parameters that determine the efficiency of flood mitigation measures.

Before the adoption of structural measures, the feasibility of zoning the flood plains should be examined as it might be more economical to mitigate flood damage by allowing flood waters to overflow into the flood plains.

Non-structural measures are as important as structural measures. Non-structural measures include the efficient management of the watershed; flood plain zoning; flood forecasting and flood warning; rescue operations and relief works. Satellite or other remote sensing imagery provide useful data for the planning of flood management measures.

Brief characteristics of mudflow formation sub-areas and mud floods (mudflow types, volume and frequency), and the impact of mudflow danger for developed areas are to be outlined. A list of projects to be protected (roadways, transmission lines, arable lands, townships and settlements etc.) and their characteristics should be prepared. Damage scale and mudflow frequency, and proposed mudflow control measures are to be considered.

J. AUGMENTATION OF AVAILABLE WATER SUPPLY AND FUTURE WATER MANAGEMENT SYSTEM

Based on analysis of water management budgets carried out for specific national economy development time horizons at existing available water supplies, measures for making up any water shortages should be outlined.

These measures include: conjunctive use of surface- and ground-water resources; reuse of water; artificial ground-water recharge; desalting of saline ground water; streamflow regulation; interregional transfer of water etc.

While elaborating the measures for the augmentation of existing water resources the master plan should list projects already identified in individual river basin plans and feasibility reports. New projects proposed for the augmentation of available water resources should be included in the master plan after conducting feasibility studies. Such feasibility studies should be carried out on the basis of geological and hydrogeological investigations and studies, identifying dam sites and reservoir areas and their main features.

IX. ECONOMIC ASSESSMENT OF WATER RESOURCES DEVELOPMENT PROJECTS

A. MEASUREMENT OF BENEFITS AND COSTS

The general economic approach is to use available scarce water resources to improve resultant human welfare under sustainable environmental conditions. This means that alternative configurations of the use of water resources among types of use, over space, and through time must be compared in terms of the net benefits that the resources will generate, the benefits being interpreted in the broadest possible terms. The real costs of any particular configuration of resource use should include the benefits that could have been realized through other alternatives of resource use, and which have been foregone.

Different types of benefits and costs are generated by a given pattern of water resource use. Some visible benefits and costs are correctly reflected and some are incorrectly manifested by market prices. Some secondary benefits cannot be adequately evaluated in monetary terms. Some are not registered in the market although simulated market values can be computed, and for others it is nearly impossible to think of any kind of adequate market valuation process. Examples of the above possibilities in terms of benefits might be the market values of free market irrigated crops, the price of sugar beets, the value of recreation on publicly-provided reservoirs, and the value of a beautiful landscape or view.

An extremely important part of the economic approach concerns who gets these benefits and who pays the costs. The main reasons for the importance of these questions are:

First, the distribution of economic welfare among different economic levels of society is consident. Concern over poverty and a willingness to tax incomes at progressive rates are sufficient evidence of this point. Some water projects have been built as much to change the distribution of economic welfare as to increase aggregate economic welfare.

Second, even when a project is designed without any overt intent to affect the distribution of economic welfare among levels of society, the project and its methods of financing, nonetheless, always have some impact on this distribution, as well as on the overall magnitude of economic welfare. Since society (or the relevant subgroups affected by the decision) generally does have preferences regarding the distribution of benefits and costs, the project's distributional implications should be spelled out, although doing so will generally be a complicated task.

Third, the kinds of support and opposition that the master water plan can expect for particular projects will depend very heavily on who gets the benefits and who bears the costs. For example, navigation or hydropower projects elicit in a very predictable way the backing of some groups and the opposition of others, not only on the basis of the perceived magnitudes of overall benefits and costs but also very much on the basis of who receives the benefits and who pays the costs.

It should be noted that not all the benefits are synonomous with monetary revenues and that costs are not to be equated with cash outflows alone. For example, some of the most beneficial projects may result in no cash inflows at all (for example a village water supply programme in an underdeveloped area), and some very inexpensive projects (for example, a small diversion dam) may be very costly if they have extensive deleterious effects downstream (e.g., ecological damage or the failure of valuable crops dependent on water). Thus economic analysis is concerned with much more than inflows and outflows of money.

The objective of analysing a prospective project should be to assess just what the state of the nation (or other relevant subdivision) will be with the project (i.e., if it is built and operated) as contrasted with what the state of the nation will be without the project. Clearly such an analysis covers more than just the directly measurable economic impact. It should include an analysis of social impact (e.g., who is displaced by the project, the effect on family life, the stimulus provided for urban migration, and so on) and esthetic impacts (e.g., what the project does to enhance or degrade the environment) for which no monetary values can be assigned.

B. METHODOLOGY FOR QUANTIFICATION OF BENEFITS AND COSTS IN MONETARY TERMS

1. Benefits

The most explicit benefits from building a project are measured by the market values of the goods or services produced by the project. Thus an irrigation project produces rice, vegetables or maize which have a value in the market. Since there may be different prices in different markets at different times, questions may remain about which prices to use.

The most obvious way of assigning numerical benefits to a project is to determine the market value of the outputs it produces. Naturally, prices vary seasonally and from area to area. If prices are stable over time except for seasonal variations, a quantity-weighted average annual price would be appropriate (i.e., total sales proceeds divided by the quantity sold). Such a price should be computed for the point of production rather than for some distant market where the output will eventually be sold. That is, a deduction from the ultimate market price should be made for necessary transport costs, or the transport costs should be included as project costs. If markets are operating smoothly, the price differences among locations should generally be equal to the differences in transport costs.

If a project's output is not large relative to the total market, the project will probably not affect market prices. Projections based on current prices may then be used to value the output. However, if a project's output is large relative to total current production, the appearance of the output on the market will force prices down. This price depression must be anticipated in the analysis of benefits. The only way of calculating this effect is to establish a demand function for the commodity in question.

Market prices and demand functions indicate what people are willing to pay for commodities or services. However, markets in the usual sense do not exist for some commodities or services even though there is no inherent reason why consumers or users could not express a valuation of the commodity or service in a market setting. Prime examples are recreation using public lands and waters, flood protection, and the preservation of wilderness and other natural or historic features.

There are some instances where it becomes legitimate to use, as a measure of project benefits, the cost of the best possible way of achieving the project goals. A common example is in the evaluation of hydroelectric power. It may be difficult to determine appropriate prices for power and energy since both may be used in a complex network serving many types of customers. It has become almost traditional to evaluate the hydroelectric output in terms of the costs of the thermal plant that would be required in the system to replace the hydroelectric plant. Naturally, the thermal plant being used in the comparison would have to be designed to do the job at minimum cost.

However, alternative cost can be used as a measure of benefits only if the decision has definitely been made to achieve the objective of the project by some means, regardless of cost.

It must be noted that when alternative cost is used as a benefit measure, the lifetimes of the two alternatives being compared should be approximately the same.

The use of alternative cost as a benefit measure really results in choosing a project or design that minimizes the cost of achieving a predetermined objective, e.g., producing a quantity of electric power. This approach to project or programme optimization, in which objectives are specified in quantified non-value (e.g., physical) terms, and in which an attempt is then made to minimize the cost of achieving the specific physical objectives, is called "cost effectiveness analysis".

All cost effectiveness analysis must be extended to involve a sensitivity analysis with respect to the values of the specified objectives. That is, the analyst must compute the rates of change of the minimum achievable project cost with respect to each goal. This computation indicates the economic cost of increasing or decreasing the goals, information that is particularly valuable when the goals have been rather arbitrarily set.

2. Costs

The same situation is true for costs. The most explicit costs are those related to project inputs for which funds have to be paid out. In the case of irrigation, the costs of constructing the reservoir, the main canals and ditches, the costs of farm machinery, roads, fertilizers, labour and so on, all represent explicit monetary costs. Again, when the analysis is being made, there may be several prices applicable to each input depending on the place of acquisition, quality and so on, but market prices are available.

As in the case of benefits, the appropriateness of market prices as measures of the social value of project outputs is equally applicable to valuing project inputs and other costs imposed on society by a water project.

In some cases, the costs may also include the benefits given up in the most productive alternative use of the resources committed to the project – for example, the commitment of public lands to reservoir storage. This is justified as the land to be inundated has the potential of not only producing timber and perhaps minerals but also of providing recreational or conservation activities in the region.

C. INDICATORS FOR ECONOMIC ASSESSMENT

Cost-benefit analysis is a tool employed to give an indication of feasibility of a project; however, it should be supplemented by other analyses and not considered alone for decision making.

1. Selection of project design and size

The basic criterion for selection of the project design and size is either the present value of net benefits or incremental net profit estimated for the project. The optimum size of an individual project is also determined by maximizing the net benefits.

2. Comparison of projects

Selection of a limited number of superior projects from among several promising projects can be carried out on the basis of the following three criteria:

(a) Minimization of costs in achieving a given set of objectives;

(b) Maximization of the present value of net benefits within limited resources;

(c) Ranking of the projects as indicated by their respective cost-benefit ratios or the internal rate of return.

Details of benefit cost analysis for water system planning are given in reference (17).

Some of the indicators for economic assessment of projects are cost-benefit ratio, internal rate of return, sensitivity analysis, thermal equivalent, damage protection provided by flood control projects etc.

D. BENEFITS AND COSTS OF VARIOUS WATER DEVELOPMENT PROJECTS

1. Water supply

a. Benefits

The main benefits of domestic water supply are more social than economic. These include improved health conditions resulting from increased supply of safe drinking water, better living standards owing to the availability of water for household needs etc. It should be noted that the benefits of water for domestic purposes cannot be evaluated in monetary terms. However, for the purposes of optimum allocation of water and fixing water prices the benefits are measured typically by one or both of the following procedures:

(a) The customers' willingness to pay for delivered water when this can be deduced from market information;

(b) The cost of the next best possible source of supply for those customers (e.g., the public) who would clearly be supplied by that source in the absence of the proposed project.

b. Costs

Municipal supply costs for delivered water would include:

(a) The costs of source development including the cost of water rights;

(b) The transmission and treatment costs.

(c) The local distribution and storage costs (for new areas);

(d) The operation and maintenance of the system;

(e) The costs imposed on customers by occasional water shortage owing to extreme conditions (e.g., drought, equipment failure) that are anticipated by management but not guarded against by the system installed.

Both benefits and costs are functions of system reliability.

2. Irrigation

a. Benefits

The provision of irrigation water may lead to the provision of the following kinds of benefits:

(a) The increase in value of farm output from the irrigated land over dry farming owing to more intensive cultivation, higher-value crops and expanded acreage;

(b) The increase in net incomes after allowing a competitive return on capital of industries which either supply, transport, or process the increased agricultural production, provided that these increases would not have occurred in the absence of the irrigation. Such increased incomes would stem from greater use of an underused plant or economies of scale.

The second benefit cited above refers to what are often called secondary benefits.

b. Costs

Irrigation project costs would consist of the following:

(a) The direct project construction costs, including all canals, ditches to the farm headgates and construction overheads;

(b) The present value of all anticipated drainage costs, even if drainage will not be necessary for some time;

(c) The operating and maintenance costs of the system;

(d) The increased on-farm production costs;

(e) The loss of net incomes to agriculture and agribusiness in non-project areas when the present project displaces them through the depression of prices or the filling of production quotas;

(f) The increased costs of storage or the subsidization of shipment overseas to handle any resulting surpluses.

In carrying out the analysis, any possible increase in health problems owing irrigation waters should be taken into consideration.

3. Flood control

a. Benefits

Flood control benefits generally consist of two major components:

(a) The protection from damage to all existing and future floodplain property;

(b) The enhanced productivity of the floodplain in terms of higher net incomes from activities that displace older activities (e.g., income from higher valued agriculture that displaces pasture) or in terms of new occupancy that finds the floodplain profitable only because of the new degree of protection.

b. Costs

Flood control costs would consist of:

(a) Incremental project construction costs attributable to the flood control purpose in the case of multipurpose projects, otherwise total construction cost of the flood protection project;

(b) The value of land committed exclusively to flood control structures and storage;

(c) The values of power and water supplies foregone by virtue of reserving some of the storage capacity for flood storage and managing releases for this purpose.

4. Hydropower

In general, hydropower benefits may be defined as the improvements in conditions as a result of a certain hydroelectric project. These benefits may be divided into two categories: tangible benefits and intangible benefits.

Tangible benefits are those that can be expressed in terms of money. They can be subdivided again into direct and indirect benefits.

Direct hydropower benefits are the values placed upon supplies of energy delivered to consumers. These benefits may be taken as the revenue derived from the sale of energy to consumers (absolute benefits) or the benefits may be measured by the estimated cost of the most economical source of equivalent energy which can be generated in the absence of a hydroelectric project (relative benefits). For hydropower benefits, it is common to use the relative benefits in calculating benefit-cost ratio.

It must be noted that when alternative cost is used as a benefit measure, the lifetimes of the two alternatives being compared should be approximately the same.

The use of alternative cost as a benefit measure really results in selecting a project or design that minimizes the cost of achieving a predetermined objective – for example, producing and supplying a certain amount of electrical energy. This approach to optimization, in which objectives are specified in quantified non-value (or physical) terms and in which an attempt is made to minimize the cost of achieving the specific physical objectives, is called cost effectiveness analysis.

Indirect hydropower benefits are those which accrue subsequently, such as the stimulation of increased industrial production, conservation of exhaustible fuel resources etc.

Intangible benefits are those that cannot be measured in monetary terms. These include improvements in social and other conditions such as benefits obtained through the use of labour-saving devices, refrigeration for conservation and protection of food supplies, radio, television and similar uses.

Intangible benefits may, under some circumstances, be controlling factors in justifying the proposed undertaking. However, most project planners consider it conservative practice to judge the merits of a project on its tangible and direct benefits only. Then the indirect and intangible benefits are described separately in order that the decision makers may have full information on which to reach the decisions.

When two alternative projects perform the same functions, it will suffice to compare their costs to find the more desirable of the two. This cost comparison is made on the basis of annual costs, as the capital cost by itself is no real yardstick for comparison. For example, the capital cost of a hydropower plant may be significantly higher than that of a thermal power plant. However, its annual cost, and hence its energy cost, may be lower. The reason is that the annual depreciation on a hydropower plant is lower; operation and maintenance require less manpower; and no fuel is required to turn the turbines.

In the calculation of annual cost of a hydropower project, interest on investment is the first, and often the largest, component of the annual charges of a project. The second annual cost component is the depreciation cost which depends on the useful life of the project, and average long-term interest rates. The depreciation cost shall take the form of annual amortization payments for the gradual extinction of the debt brought about by the necessity to finance the project.

There are several methods for calculation of annual depreciation cost: the straight line method, the sinking fund method, the fixed percentage of depreciated value method etc.

It is widely accepted in most developed countries that the sinking fund method is the most suitable method in planning studies. The main advantage of using the sinking fund method is that it takes into account the interest that will accrue on the depreciation fund. In the straight line method of depreciation, the interest on the depreciation fund is not taken into consideration.

5. Inland navigation

a. Benefits

One benefit might be the amount of money and time saved by diverting present traffic to inland or coastal waterways.

By its very existence, the new, more economic waterway could generate new traffic. The value of this benefit would be measured by the willingness of the new water carrier customers to pay.

A navigable waterway could stimulate the development of businesses that would not exist in its absence. The net incomes of these businesses would constitute a project benefit. This benefit excludes incomes of all existing businesses that simply shift location to the riverside to take advantage of water navigation.

Another benefit could be the potential for recreation provided by the improved waterway. (Only the difference in recreation benefit between the improved and unimproved state of the river is to be counted.)

b. Costs

Inland navigation costs would include:

(a) The construction of all navigation features, including the channel, locks, aids to navigation, docks and other harbour facilities;

(b) The operating and maintenance costs, including lock operation and repair, traffic control, dredging and harbour facility upkeep;

(c) The construction of recreation facilities that exist only because of the navigability of the river;

(d) The value of hydroelectric power, water supply and flood control foregone by operating the system for navigation;

(c) The productivity of the land committed to the project.

6. Water quality management

The benefits and costs from this complex set of activities is difficult to evaluate. The difficulties are generally connected with the fact that sources of pollution are difficult to trace, the abatement costs of pollution are difficult to know, and the positive effects of improvements are difficult to locate and quantify.

a. Benefits

The benefits would fall into one or more of the following classes:

(a) Health improvements to parties who previously had to use the water in untreated or inadequately treated form, or who used to draw water from wells fed directly by infiltration of inferior quality surface-water supplies;

(b) Reduced intake water treatment costs by downstream municipalities;

(c) Reduced possible hazard of ground-water contamination and of the potential cost of decontamination of the aquifer;

(d) Reduced industrial intake treatment, although low-oxygen water is sometimes acceptable when it is to be used only for cooling;

(e) Increased recreational use and the upgrading of types of use from, say, non-water contact to water contact sports;

(f) Improved (even though unquantifiable) aesthetic values stemming from cleaner water free of unsightly debris;

(g) Value of useful by-products recovered from waste streams.

b. Costs

Water quality management costs would consist of all the following ordinary and unusual items:

(a) The costs of construction, operation and maintenance of structures such as dams (if constructed solely for that purpose), retaining ponds, and piping systems;

(b) The costs of municipal and industrial abatement procedures, including traditional treatment and (for industry) basic manufacturing process changes to reduce pollution;

(c) The increased costs of solid waste disposal from settling ponds or treatment plant sludge;

(d) Increased air pollution resulting from the incineration of treatment plant sludge or from odours from retention ponds and other related facilities.

All such benefits and costs should be weighed and overall costs of prevention versus subsequent treatment should be compared economically. Another frequent cost consideration is a possible loss of jobs as marginal plants are forced to close because of additional abatement costs required by additional treatment.

X. FORMULATION OF A MASTER WATER PLAN

A. WATER BUDGET ANALYSIS

In order to ensure that there is enough water to meet the various demands of the community, it is necessary to match the water demand for all purposes with the available water supply.

An inventory of the status of existing and future water resources potential and water use in terms of both quantity and quality is an important and necessary step in the establishment of an optimum master plan for the development and use of water resources. Such an inventory can be expressed in both cartographic and tabular forms.

Water budget studies for the whole country should consolidate the detailed studies for separate regions and areas. Delineation of regions may follow the drainage divides of major rivers while that of subregions may follow those of smaller streams or tributaries.

Computation of water budgets should be carried out for the existing period as well as for the immediate and long-term periods. Water budgets for the immediate future should be a forecast for a period of about five years while those for the long-term future should cover a period of about 20 years.

Water budget studies should generally include: an assessment of available water resources potential and its characteristics; assessment of existing and future water demand by various sectors of the national economy; and analyses of water supply and demand conditions in various regions/subregions, leading to the determination of surplus and deficits of water resources potential and its extent.

Water budgets should be prepared in two stages: First, water resources deficits (or surplus) for each zone/region should be identified before measures proposed in the master plan are implemented. Then, calculation should be repeated for conditions when measures proposed in the master plan are implemented; that is, additional regulating reservoirs, water transfers etc.

B. BASIN PLAN

A comprehensive national master water plan should be formulated on the basis of river basin plans. If the river basin lies fully within the national boundary, the problem is relatively simpler than when it is shared by several countries. In the latter case, an international treaty on the sharing of water should be signed before plans for the utilization of the water resources of the basin can be formulated. The same is true in the case of allocation of waters between provinces within a country where an agreement between the provinces is necessary with regard to the allocation formula.

In the preparation of a river basin plan, a basin is considered as one dynamic system from the head water to the sea. Potential water resources development projects should be identified on the basis of studies of aerial photographs, topographic and geological maps, available hydraulic and hydrological data, and earlier studies. After the preliminary identification of the projects on the basis of office studies, field trips should be undertaken to determine the feasibility of their construction. Some of the identified projects may have to be dropped if they are found to be technically unsuitable for development. Reconnaissance-level field investigations programmes of the projects should be prepared first. Then, on the basis of the results of field investigations, feasibility for development should be evaluated.

All projects so prepared are then costed to the same level of detail and an economic analysis of each project is carried out. Those projects which merit further consideration on the basis of economic analysis are listed in the portfolio of projects.

C. RANKING OF PROJECTS

Since all the projects identified in a comprehensive river basin plan cannot be constructed at the same time, it is necessary to accord priorities for thier implementation. The criteria on which such priorities or ranks are assigned are the relative urgency to meet basic human needs, the magnitude of benefits, the cost-benefit ratio, the internal rate of return, environmental considerations etc.

D. PERSPECTIVES, ACTION AND INVESTMENT PLANS

On the basis of the basin plan, programmes for short-term development (Action Plan) of about five years duration and long-term development (Perspective Plan) of about 20-25 years duration should be prepared. An investment plan is then drawn up for these development plans. This investment plan can be used by the national planning agency for the formulation of yearly national development plans. The investment plan gives the rate of investment as determined by the urgency of need in the various regions and by the availability of funds. It indicates the relationship between the water resources development expenditure and the total national expenditure.

A comprehensive river basin plan as outlined above provides a useful guide as to whether all the related programmes taken together are sufficient to achieve all the important goals of the country within the planned period.

E. FORMULATION OF A NATIONAL MASTER WATER PLAN

Various stages involved in the formulation of a national master water plan may be outlined as follows:

(a) Objective and plan period: The primary objective of a master water plan is to establish a basic framework for the orderly and integrated planning and implementation of water resources programmes and projects for rational water resources development, consistent with the overall national socio-economic development objective. The plan should cover a period of at least 20 years and be revised periodically.

(b) Screening of alternatives: The purpose of screening is to reduce the number of possibilities to a few which seem to be promising. The criteria to be used for screening may include technical, environmental and financial feasibility, institutional feasibility, cost-effectiveness etc.

(c) Design of the master plan: The above-mentional screening process provides a number of promising options for use in formulating the master plan. Different tactics would benefit different regions of the country and different groups of users. The master plan has to be designed to suit a particular scenario; for example, it should satisfy demand for water and meet the water quality standards contained in the scenario to the greatest extent possible. If a number of possible plans could fit the scenario then the one with the least net cost or the largest net benefit for the nation would be considered as the most promising one.

(d) Assessment of impact: An assessment of impact is an assessment of the consequences of alternative plans on the full range of objectives and on all interest groups – to provide safe drinking water for all, to enhance navigation, to improve the economy, to promote social equity, to preserve the environment etc.

Impact assessments should be undertaken at an early stage of project planning and should be systematically applied to the different possibilities considered in a project study. Results of impact assessment procedures should duly be taken into account in decision making. Systematic monitoring of project realization by competent authorities should ensure compliance with pre-set conditions.

Direct impact on users include changes in profit and expenditure for each user group such as agriculture, electric power generation, water-supply works, industries and shipping. Types of environmental impact include violation of water quality standards, damage to unspoilt areas, and extraction of ground water.

Types of impact affecting the entire nation include the net monetary benefits to the nation, the total economic effects in terms of government revenues, production, exports and imports, and social/distributional impact such as the creation of employment opportunities, and the redistribution of income and costs among different interest groups and localities.

Mathematical models could be used in the formulation of a national master water plan to predict the effects of different possibilities. There may be a single model or a series of models for a given problem, depending on its comlexity. A model is made up of factors relevant to a problem and the essential cause/effect relations among them. For example, a model could be prepared to assess agricultural losses caused by water shortage and salinity, and another to assess where water quality standards would be violated, and how often. Computer programmes for the models permit the examination of a large number of factors and interactions.

(a) Comparison of cases and decision making: The term "case" as used here refers to a master plan along with the system and scenario assumptions that affect its performance and impact. The cases to be compared involve the same system and scenario assumptions but different plans. The various impacts of the cases are estimated in the impact assessment stage of the analysis and then presented to the decision makers for comparison of alternative plans. The various types of impact may be displayed on a scoreboard, which is in fact a table that shows the ranking for each possibility for a particular kind of impact. Based on this factual knowledge, the policy makers can use their judgement of the relative importance of the different types of impact in order to select the preferred possibility.

(b) Revision of the analysis: Additional cases might then be designed that involve a change in plans, scenario, system assumptions or combinations of all three. Evaluation and comparison of these additional cases could yield a further set of cases for evaluation. This process continues until a decision is made on a particular master water plan to be adopted.

F. SYSTEMS ANALYSIS AS A TOOL IN WATER RESOURCES PLANNING

With increased concern for economic efficiency in water resources investment, and environmental considerations, there is increased awareness of the potential for multipurpose use of water resources as well as the need to exploit the conjunctive use of various surface- and groundwater systems.

The basic considerations for dealing with this wider view require a much more elaborate framework for the selection of projects. In this context, the United Nations Workshop (18) agreed that systems analysis provides a useful tool for aiding decision makers. The following points were indicated to show the demand for this approach:

(a) Major water projects typically involve large-scale integral, virtually permanent physical changes in the environment; large lakes and hydropower potential are created, navigable water provided, flood-plains protected.

(b) The expertise of many traditional disciplines (engineering, agronomy, economies and law, for example) can be best integrated through the systems approach.

(c) The size of investments in water projects and their capital intensive nature, especially in the face of budgetary constraints, and the fact that they often have a major effect on the economy of the region, indicate the desirability of achieving even small improvements in efficiency, which is quite possible with a systems approach.

(d) The overall project design achieved with systems analysis is likely to be better, especially in complex cases, than that designed by using conventional water resource design techniques.

(e) Systems analysis techniques lend themselves to continuous modifications and adaptation to accommodate changing needs, objectives and constraints. Hence, such studies can be carried out on a continuous, as opposed to a "stop-start" or fragmented, basis.

(f) Systems analysis has had many successful applications in the management of industrial projects, and similar techniques can be used to manage the operation of existing water resources projects.

Systems analysis techniques have the potential for significantly expediting and improving the water resources planning process. Many of the problems in this area of resource development are so complex that these techniques offer a greater degree of objectivity and flexibility. In such cases the use of systems analysis is likely to identify significant potential decreases in water resources development costs and increases in project benefits compared with conventional methods. The Workshop recognized the importance of social factors and their relationships with physical parameters. Continued improvements in the hardware and software capabilities will assist this development.

The general conclusions reached for the potentials of systems analysis argue for the recommendation that the use of systems analysis in water and related land-use planning should be promoted. For this to come about, the following factors should be taken into account:

(a) The receptivity of senior personnel to the use of systems analysis could be aided by convincingly demon-strating its effectiveness to planning agency heads.

(b) The communication and understanding of systems analysis should be aided by less mathematically-oriented discussion; increased use of well-designed short courses emphasizing the links of the systems approach to more traditional techniques; and utilization of discussions that emphasize the strength and limitations of the approach, rather than mathematics.

(c) Systems studies should integrate operational personnel into the effort. Hence agencies should ensure in-house capabilities, and not rely solely on consultants.

(d) Consultants undertaking systems studies should help train local personnel in order to provide continuing systems planning capability within the planning agencies and thus avoid the terminal nature of some systems studies.

XI. INSTITUTIONAL FRAMEWORK

A water resources plan consistent with the overall economic, social and environmental policies of the country concerned is an important element in ensuring that water resources contribute to the country's development objectives.

The organization of water resources planning and management in a nation is generally a mix of centralization and decentralization. The delegation of authority from the centre, or the power assigned to each subnational unit, varies from country to country and even within the same country according to a set of interrelated factors among which are the geographic and demographic size of the country, the social and political framework, the legal regime of water ownership, the availability of water in relation to its use, regional diversity and the traditional values and meanings of water for different societies.

The participants in the United Nations Workshop (18), representing a wide range of experiences, found that there was general agreement on the need for some degree of central planning or policy guidance to ensure efficient water resources planning within the overall framework of development. However, it was also agreed that such centralized elements in the planning process should take into account the decentralized ones, i.e., regional or local needs, desires, objectives, constraints and other related conditions. Furthermore, good overall planning must be forward-looking, anticipating that present trends in demand and in deterioration of the quality of water supplies will call for a greater stress on comprehensive centralized planning. This also means that the mixture of centralized and decentralized planning modes must be dynamic and flexible enough to meet changing conditions in the future.

The decision-making process in water-related matters should be the result of the interaction of a number of organizations. The establishment of either a national or regional authority, by itself, does not guarantee the full integration, unification and harmonization of the process since it is difficult to establish a single organization that covers all facets of water management. At the regional level, water planning should be based on a national viewpoint and regional development. The national viewpoint tends to consider the long-term planning aspects while at regional level the medium- and short-term outlooks predominate. There is, therefore, a need to co-ordinate interests in order to obtain a proper balance among national, regional and sectoral aims and priorities. This is of particular importance when a river basin comprises several regions or states.

Centralized planning should be undertaken by a national organization that could be a government department, national water authority, multi-sectoral commission, or water studies institute, whose activities should ensure the existence of the necessary machinery to:

(a) Provide a view that unifies national concerns and interests in water management, with the aim of making these matters clear, and permits adjustment and improvement of the legal and institutional framework;

(b) Provide a national framework that includes evaluation and control, so that water management can be considered in relation to national economic, social and environmental aims within the context of which regional and State programmes can be fitted;

(c) Facilitate the evolution of rules and procedures, at least for all water management programmes financed by centralized funds;

(d) Provide total estimates of supply, demand and the resulting deficit or surplus of water resources, and thus define critical areas and problems that may arise in the future;

(e) Make it possible for water resources management to take place at the lowest level with the technical and financial capacity to operate efficiently and effectively;

(f) Provide the administrative and co-ordinating elements needed to deal with inter-regional and international water management problems;

(g) Carry out the institutional action necessary for the management of international waters;

(h) Co-ordinate and promote national programmes of information, research and training, and also programmes for the transfer of technology and information at the international level;

(i) Intervene, sometimes directly, in the execution of certain construction works or programmes being carried out in the regions.

Decentralized planning should generally operate within the physical limits of a river basin and be concerned with regional needs, and should be aimed at administering both water resources and water services. Such activities are carried out in accordance with the physical and administrative features of the country. Among the major functions of decentralized planning are the following:

(a) Formulating and keeping up-to-date the inventory of the supply and uses of water in the region;

(b) Operating and maintaining the regional part of the national network for measuring and recording water quantity and quality parameters, in accordance with nationally established standards, and the gathering of other local information needed for analysis of water demand for various uses and for the generation of alternative courses of action;

(c) Ensuring that all the water resources potentialities of the region are built into the framework of centralized national planning, where this exists;

(d) Preparing, and periodically revising (annually, if possible), a regional water plan that can establish, in an integrated form and with due co-ordination with national and regional development planning, whatever short- or medium-term measures are needed to ensure the desired development of water resources and their conservation;

(e) Designing, constructing, operating and maintaining the water installations necessary to regulate the quantity and quality of water in the region compatible with any national plan and co-ordinated, as necessary, with the central government departments concerned;

(f) Reviewing, and where appropriate, approving execution of public or private projects that might affect the quantity or quality of the water resources of the region;

(g) Determining the measures needed to ensure the efficient distribution and use of water in the region.

To formulate and keep up-to-date a national water plan, an iterative methodology should be adopted that allows its modification through knowledge and experience acquired from the monitoring and *ex post facto* evaluation of the programmes being implemented.

The organization created to prepare a national water plan will require creative, multidisciplinary staff, whose members should have had experience of water management but should be released from their regular responsibilities while serving as members of the planning team.

To be effective, centralized planning should be clearly related to sectoral and regional planning organizations and water users, and it must be linked to the decision-making process. It follows, therefore, that a central water organization must establish a system of two-way communication and co-ordination, both vertically and horizontally.

Recent experiences of decentralized water resources planning have shown that such planning can be executed by regional agencies, covering one or more river basins and having responsibilities for both water resources and water services.

In view of the foregoing it is recommended that:

(a) The scope of responsibility for either centralized or decentralized planning should be clearly defined by the Government;

(b) The organization responsible for centralized planning should ensure that a balance is achieved between national, regional and sectoral aims and priorities when formulating any national water policies and, where appropriate, a National Water Plan;

(c) Water plan(s) should be prepared by multidisciplinary teams whose members have practical experience of water management but who should be free from day-to-day managerial responsibilities while working for the team;

(d) Water plan(s) should be updated periodically, if possible annually, and reviewed in more detail at intervals of not less than five years, taking into account the experience gained in the intervening period;

(e) Water planning should be based on a two-day exchange of information between the higher and lower institutional levels. This should be a dynamic process leading by revision to the formulation of modifications to the overall plan for social and economic development, especially in countries with limited water resources.

XII. MANPOWER AND TRAINING IN WATER RESOURCES DEVELOPMENT

Proper assessment, planning and development of adequate manpower for water resources development projects, both in terms of quantity and quality, should be made for all necessary levels and specializations.

Planning of human resources development in the field of water resources should be carried out in the context of general human resources planning and long-term economic planning, as water resources development encompasses a large variety of socio-economic activities – for example, irrigation and drainage, water supply and sanitation, hydropower generation, navigation, fisheries, flood control, aquatic recreation, preservation of wetlands etc.

An assessment of projected manpower needs should be made based on the number, nature and scale of projects identified for implementation in the master plan. Then, on the basis of existing available manpower and the estimated total manpower requirements, the deficiency in trained manpower in various fields and levels should be worked out for training purposes.

In planning for training in water resources development, it is essential that an integrated and comprehensive approach be adopted in order to ensure self-sufficiency in training. Therefore, training programmes should be oriented not only to producing an adequate number of trained personnel but also to producing an adequate number of trainers/instructors as well as training facilities.

As regards delineation of manpower levels, the following classification used by the United Nations Administrative and Co-ordination Committee Intersecretariat Group for Water in its 1983 report on the survey of education and training in the field of water resources may be adopted: (a) professional engineer, scientist, university engineer; (b) higher-level technician, technician-engineer, middle-level engineer, engineering technician, senior technician; (c) technician, technical officer, assistant technician; (d) skilled worker, qualified worker, craftsman.

Plans for training in water resources development should include provision of adequate motivation, career incentives and an appropriate working environment to trained personnel in order to avoid brain drain and to retain them in the water resources agencies for which they are trained. The simplest way of attracting highly-trained personnel to certain disciplines is the salary structure.

For some relatively small countries, it may not be practical to establish their own training institution to train the required personnel in various fields of specialization. In such cases it may be more practical and cost-effective to train their personnel abroad. For this purpose it is necessary that the basic training provided by the national institute should be of a level that allows acceptance by foreign institutions.

As some specialized agencies of the United Nations have developed comprehensive educational and training programmes in the field of water resources planning and management, substantial benefits can be derived through these programmes at the national level (19).

ANNEXES

Annex I

CONTENTS OF A NATIONAL MASTER WATER PLAN

A. Present status of development

1. Physical features;
2. Climate;
3. Economic conditions:
   - (a) Food and agriculture;
   - (b) Industry;
   - (c) Transport;
   - (d) International trade;
   - (e) Public finance.
4. Social development:
   - (a) Population;
   - (b) Urban centres.
5. Existing water resources development:
   - (a) Multipurpose projects;
   - (b) Irrigation;
   - (c) Hydroelectric power;
   - (d) Water supply and sanitation:
     - (i) Urban;
     - (ii) Rural;
     - (iii) Industry;
   - (e) Flood management;
   - (f) Inland navigation;
   - (g) Fisheries;
   - (h) Water legislation;
   - (i) Institutional framework.

B. Assessment of water and related resources

1. Climate:
   - (a) Rainfall;
   - (b) Temperature;
   - (c) Evaporation.
2. Streamflow:
   - (a) Mean flow;
   - (b) Low flows;
   - (c) Present utilization;
   - (d) Flood flows;
   - (e) Sediment load.
3. Water quality:
   - (a) Present waste discharges;
   - (b) Water pollution regulations or quality standards.
4. Ground water:
   - (a) Location and safe yields;
   - (b) Present utilization.
5. Reservoir sites:
   - (a) Existing reservoir projects;
   - (b) Potential reservoir sites.
6. Hydroelectric power sites:
   - (a) Existing hydroelectric power projects;
   - (b) Potential hydroelectric power sites.
7. Land resources:
   - (a) Present cultivated land;
     - (i) Extent;
     - (ii) Crop pattern;
     - (iii) Agriculture inputs;
     - (iv) Crop yields.
   - (b) Classified reclaimable land;
   - (c) Unclassified reclaimable land;
   - (d) Forest land;
   - (e) Soil erosion problem.
8. Mineral resources.
9. Energy resources;
   - (a) Fossil fuel;
   - (b) Imported fuel.

Annex I *(continued)*

10. Fishery resources:
    (a) Traditional methods of fishing;
    (b) Status of fish culture.

11. Human resources:
    (a) Extent and distribution;
    (b) Calibre;
    (c) Employment opportunities.

C. Needs for development

1. National social and economic scenarios:
    (a) Population growth and distribution;
    (b) Agricultural production;
    (c) Industrial production;
    (d) Improvement of transport;
    (e) Financial sources for development;
    (f) Human resources.

2. Food and agriculture:
    (a) Foodgrain supply and demand;
    (b) Improvement of agricultural techniques;
    (c) Increase of irrigated area;
    (d) Water demand.

3. Electric power:
    (a) Demand and market;
    (b) Alternative sources;
    (c) Expansion of electric power supply systems.

4. Domestic and industrial water supply:
    (a) Urban expansion and water demand;
    (b) Industrial water demand;
    (c) Rural water demand;
    (d) Improvement of public supply systems.

5. Inland navigation:
    (a) Growth of demand;
    (b) Alternative transportation patterns;
    (c) Complementary improvement measures.

6. Flood management:
    (a) Past flood damage;
    (b) Development of flood-prone areas;
    (c) Possibilities of alternative flood prevention measures.

7. Pollution control:
    (a) Sources and quantities of waste discharge;
    (b) Waste-water treatment technologies;
    (c) Regulations and effluent charge measures.

8. Fisheries:
    (a) Demand and market;
    (b) River and reservoir environment for fish production.

D. Potential projects

1. Minor projects:
    (a) Water studies;
    (b) Engineering, geology and cost estimates;
    (c) Economic evaluation;
    (d) Financial feasibility.

2. Major projects:
    (a) Water studies;
    (b) Engineering, geology and cost estimates;
    (c) Co-ordination and functions in a basin plan;
    (d) Economic evaluation;
    (e) Financial feasibility;
    (f) Environmental impact assessment.

E. Formulation of a national master water plan

1. Establishment of long-term objectives and development targets:
    (a) Social and economic scenario;
    (b) Constraints;
    (c) Food production;
    (d) Industrial growth;
    (e) Public health improvement;
    (f) Employment.

2. Criteria for plan formulation.

3. Alternative water schemes.

4. Selection of the recommended plan.

5. Complementary programme and efforts.

Annex II

SCALE OF MAPS FOR INDICATING HYDROGRAPHIC CHARACTERISTICS OF RIVER BASINS

Watershed landscape type	*Watershed area km²*	*Map scales*			
		Layouts or aerial photographs	*1:100 000*	*1:200 000 1:300 000*	*1:500 000 1:1 000 000*
Flatland watersheds with weakly developed landscape	<100	+			
	100 . . . 1 000		+		
	1 000 . . . 10 000			+	
	>10 000				+
Flatland watersheds with developed stream and ravine network	<20	+			
	20 . . . 2 000		+		
	200 . . . 10 000			+	
	>10 000				+
Mountainous streams	<10	+			
	10 . . . 1 000		+		
	100 . . . 10 000			+	
	>10 000				+

Distances along river stem are determined by large-scale maps (1:1 000 000 and larger).

The factors for selection of control points are as follows:

(1) Conditions for streamflow formation and topology of a stream network;

(2) Locations of base stations for hydrologic and water quality observations;

(3) Administrative/territorial subdivisions;

(4) Locations of industrial plants and separate water-consuming projects;

(5) Sites of hydraulic units and reservoirs (planned, under construction and/or in operation).

Source: SNIP, 1983; Opredeleniye Osnovnykh Gidrologicheskich Charakteristik (Code of Practice. Determination of Basic Hydrological Characteristics) (In Russian), Gidrometeoizdat, Leningrad.

Annex III

GUIDELINES FOR DRINKING-WATER QUALITY

Table 1. Microbiological and biological quality

Organism	*Unit*	*Guideline value*	*Remarks*
I. Microbiological quality			
A. Piped water supplies			
A.1 Treated water entering the distribution system			
Faecal coliforms	number/100 ml	0	turbidity < 1 NTU; for disinfection with chlorine, pH preferably < 8.0; free chlorine residual 0.2-0.5 mg/litre following 30 minutes (minimum) contact
Coliform organisms	number/100 ml	0	
A.2 Untreated water entering the distribution system			
Faecal coliforms	number/100 ml	0	
Coliform organisms	number/100 ml	0	in 98% of samples examined throughout the year -- in the case of large supplies when sufficient samples are examined
Coliform organisms	number/100 ml	3	in an occasional sample, but not in consecutive samples
A.3 Water in the distribution system			
Faecal coliforms	number/100 ml	0	
Coliform organisms	number/100 ml	0	in 95% of samples examined throughout the year – in the case of large supplies when sufficient samples are examined
Coliform organisms	number/100 ml	3	in an occasional sample, but not in consecutive samples
B. Unpiped water supplies			
Faecal coliforms	number/100 ml	0	
Coliform organisms	number/100 ml	10	should not occur repeatedly; if occurrence is frequent and if sanitary protection cannot be improved, an alternative source must be found if possible
C. Bottled drinking-water			
Faecal coliforms	number/100 ml	0	source should be free from faecal contamination
Coliform organisms	number/100 ml	0	
D. Emergency water supplies			
Faecal coliforms	number/100 ml	0	advise public to boil water in case of failure to meet guideline values
Coliform organisms	number/100 ml	0	
Enteroviruses	–	no guideline value set	
II. Biological quality			
Protozoa (pathogenic)	–	no guideline value set	
Helminths (pathogenic)	–	no guideline value set	
Free-living organisms (algae, others)	–	no guideline value set	

Annex III *(continued)*

Table 2. Inorganic constituents of health significance

Constituent	*Unit*	*Guideline value*	*Remarks*
Arsenic	mg/l	0.05	
Asbestos	–	no guideline value set	
Barium	–	no guideline value set	
Beryllium	–	no guideline value set	
Cadmium	mg/l	0.005	
Chromium	mg/l	0.05	
Cyanide	mg/l	0.1	
Fluoride	mg/l	1.5	natural or deliberately added; local or climatic conditions may necessitate adaptation
Hardness	–	no health-related guideline value set	
Lead	mg/l	0.05	
Mercury	mg/l	0.001	
Nickel	–	no guideline value set	
Nitrate	mg/l (N)	10	
Nitrite	–	no guideline value set	
Selenium	mg/l	0.01	
Silver	–	no guideline value set	
Sodium	–	no guideline value set	

Annex III *(continued)*

Table 3. Organic constituents of health significance

Constituent	*Unit*	*Guideline value*	*Remarks*
Aldrin and dieldrin	μg/l	0.03	
Benzene	μg/l	10[a]	
Benzo [a] pyrene	μg/l	0.01[a]	
Carbon tetrachloride	μg/l	3[a]	tentative guideline value[b]
Chlordane	μg/l	0.3	
Chlorobenzenes	μg/l	no health-related guideline value set	odour threshold concentration between 0.1 and 3 μg/l
Chloroform	μg/l	30[a]	disinfection efficiency must not be compromised when controlling chloroform content
Chlorophenols	μg/l	no health-related guideline value set	odour threshold concentration 0.1 μg/l
2, 4-D	μg/l	100[c]	
DDT	μg/l	1	
1, 2-dichloroethane	μg/l	10[a]	
1, 1-dichloroethene[d]	μg/l	0.3[a]	
Heptachlor and heptachlor epoxide	μg/l	0.1	
Hexachlorobenzene	μg/l	0.01[a]	
Gamma-HCH (Lindane)	μg/l	3	
Methoxychlor	μg/l	30	
Pentachlorophenol	μg/l	10	
Tetrachloroethene[d]	μg/l	10[a]	tentative guideline value[b]
Trichloroethene[d]	μg/l	30[a]	tentative guideline value[b]
2, 4, 6-trichlorophenol	μg/l	10[a, c]	odour threshold concentration, 0.1 μg/l
Trihalomethanes		no guideline value set	see chloroform

[a] These guideline values were computed from a conservative hypothetical mathematical model which cannot be experimentally verified and values should therefore be interpreted differently. Uncertainties involved may amount to two orders of magnitude (i.e., from 0.1 to 10 times the number).

[b] When the available carcinogenicity data did not support a guideline value, but the compounds were judged to be of importance in drinking water and guidance was considered essential, a tentative guideline value was set on the basis of the available health-related data.

[c] May be detectable by taste and odour at lower concentrations.

[d] These compounds were previously known as 1, 1-dichloroethylene, tetrachloroethylene, and trichloroethylene, respectively.

Annex III *(continued)*

Table 4. Aesthetic quality

Constituent or characteristic	*Unit*	*Guideline value*	*Remarks*
Aluminium	mg/l	0.2	
Chloride	mg/l	250	
Chlorobenzenes and chlorophenols	–	no guideline value set	these compounds may affect taste and odour
Colour	true colour units (TCU)	15	
Copper	mg/l	1.0	
Detergents	–	no guideline value set	there should not be any foaming or taste and odour problems
Hardness	mg/l (as $CaCO_3$)	500	
Hydrogen sulfide	–	not detectable by consumers	
Iron	mg/l	0.3	
Manganese	mg/l	0.1	
Oxygen – dissolved	–	no guideline value set	
pH	–	6.5-8.5	
Sodium	mg/l	200	
Solids – total dissolved	mg/l	1 000	
Sulfate	mg/l	400	
Taste and odour		inoffensive to most consumers	
Temperature	–	no guideline value set	
Turbidity	nephelometric turbidity units (NTU)	5	preferably <1 for disinfection efficiency
Zinc	mg/l	5.0	

Table 5. Radioactive constituents

Constituent	*Unit*	*Guideline value*	*Remarks*
Gross alpha activity	Bq/l	0.1	(a) If the levels are exceeded more detailed radionuclide analysis may be necessary.
Gross beta activity	Bq/l	1	(b) Higher levels do not necessarily imply that the water is unsuitable for human consumption

Table 6. Guideline values for health-related inorganic constituents

Constituent	*Guideline value (mg/litre)*	*Constituent*	*Guideline value (mg/litre)*
Arsenic	0.05	lead	0.05
Cadmium	0.005	mercury	0.001
Chromium	0.05	nitrate (as N)	10.00
Cyanide	0.1	selenium	0.01
Fluoride	1.5[a]		

[a] Guideline value may vary depending upon climatic conditions and water consumption.

Annex III *(continued)*

Table 7. Guideline values for health-related organic contaminants

Contaminant	*Guideline value (μg/litre)*	*Contaminant*	*Guideline value (μg/litre)*
Aldrin and dieldrin	0.03	1, 1-dichloroethene[a, e]	0.3
Benzene	10	heptachlor and heptachlor epoxide	0.1
Benzo [a] pyrene[a]	0.01	hexachlorobenzene[a]	0.01[c]
Chlordane (total isomers)	0.3	gamma-HCH (lindane)	3
Chloroform[a, d]	30	methoxychlor	30
2, 4-D	100	pentachlorophenol	10
DDT (total isomers)	1	2, 4, 6-trichlorophenol[a, b]	10
1, 2-dichloroethane[a]	10		

[a] The guideline values for these substances were computed from a conservative, hypothetical, mathematical model that cannot be experimentally verified and therefore should be interpreted differently. Uncertainties involved are considerable and a variation of about two orders of magnitude (i.e., from 0.1 to 10 times the number) could exist.

[b] The threshold taste and odour value for this compound is 0.1 g/litre.

[c] Since the FAO/WHO conditional ADI of 0.0006 mg/kg body weight has been withdrawn, this value was derived from the linear multistage extrapolation model for a cancer risk of less than 1 in 100 000 for a lifetime of exposure.

[d] The microbiological quality of drinking-water should not be compromised by efforts to control the concentration of chloroform.

[e] Previously known as 1, 1-dichloroethylene.

Table 8. Organic substances for which tentative guideline values are recommended

Contaminant	*Tentative guideline value (μg/litre)*
Carbon tetrachloride	3
Tetrachloroethene[a]	10
Trichlorethene[a]	30

[a] Previously known as tetrachloroethylene and trichloroethylene, respectively.

Table 9. Water quality standards for recreation purposes

Constituent or characteristic	*Unit*	*Guideline value*	*Remarks*
Colour	true colour units (TCU)	15	
Turbidity	nephelometric turbidity units (NTU)	5	
Chlorobenzenes	ug/l	3	concentration exceeding guideline value may result in noticeable presence of odour.
Chlorophenols	ug/l	0.1	odour threshold.

Source: Guidelines for Drinking-Water Quality, Volume 1: Recommendations, Volume 2: Health Criteria and Other Supporting Information, Volume 3: Drinking-Water Quality Control in Small Community Supplies, World Health Organization (WHO), Geneva 1985.

Annex IV

GUIDELINES FOR INTERPRETATIONS OF WATER QUALITY FOR IRRIGATION[a]

Potential irrigation problem	*Units*	*Degree of restriction on use*		
		None	*Slight to moderate*	*Severe*
Salinity (affects crop water availability)[b]				
EC_w	dS/m	<0.7	0.7-3.0	>3.0
or				
TDS	mg/l	<450	450-2 000	>2 000
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)[c]				
SAR = 0-3 and EC_w =		>0.7	0.7-0.2	<0.2
= 3-6 =		>1.2	1.2-0.3	<0.3
= 6-12 =		>1.9	1.9-0.5	<0.5
= 12-20 =		>2.9	2.9-1.3	<1.3
= 20-40 =		>5.0	5.0-2.9	<2.9
Specific ion toxicity (affects sensitive crops)				
Sodium (Na)[d]				
surface irrigation	SAR	<3	3-9	>9
sprinkler irrigation	me/l	<3	>3	
Chloride (Cl)[d]				
surface irrigation	me/l	<4	4-10	>10
sprinkler irrigation	me/l	<3	>3	
Boron (B)[e]	mg/l	<0.7	0.7-3.0	>3.0
Miscellaneous effects (affects susceptible crops)				
Nitrogen (NO_3-N)[f]	mg/l	<5	5-30	>30
Bicarbonate (HCO_3) (overhead sprinkling only)	me/l	<1.5	1.5-8.5	>8.5
pH			Normal Range 6.5-8.4	

[a] Abridged version adapted from University of California Committee of Consultants 1974.

[b] EC_w means electrical conductivity, a measure of the water salinity, reported in deciSiemens per metre at 25°C (dS/m) or in units millimhos per centimetre (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per litre (mg/l).

[c] SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNa. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by EC_w. Adapted from Rhoades 1977, and Oster and Schroer 1979.

[d] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive; use the salinity tolerance tables given in reference (4). For chloride tolerance of selected fruit crops, see reference (4). With overhead sprinkler irrigation and low humidity (<30 per cent), sodium and chloride may be absorbed through the leaves of sensitive crops.

[e] For boron tolerances, see reference (4).

[f] NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen (NH_4-N and Organic-N should be included when waste water is being tested).

Annex IV *(continued)*

Assumptions in the guidelines

The water quality guidelines are intended to cover the wide range of conditions encountered in irrigated agriculture. Several basic assumptions have been used to define their range of usability. If the water is used under greatly different conditions, the guidelines may need to be adjusted. Wide deviations from the assumptions might result in wrong judgements on the usability of a particular water supply, especially if it is a borderline case. Where sufficient experience, field trials, research or observations are available, the guidelines may be modified to fit local conditions more closely.

The basic assumptions in the guidelines are:

Yield potential: Full production capability of all crops, without the use of special practices, is assumed when the guidelines indicate no restrictions on use. A "restriction on use" indicates that there may be a limitation in choice of crop, or special management may be needed to maintain full production capability. A "restriction on use" does *not* indicate that the water is unsuitable for use.

Site conditions: Soil texture ranges from sandy-loam to clay-loam with good internal drainage. The climate is semi-arid to arid and rainfall is low. Rainfall does not play a significant role in meeting crop water demand or leaching requirement. (In a monsoon climate or areas where precipitation is high for part or all of the year, the guideline restrictions are too severe. Under the higher rainfall situations, infiltrated water from rainfall is effective in meeting all or part of the leaching requirement.) Drainage is assumed to be good, with no uncontrolled shallow water table present within two metres of the surface.

Methods and timing of irrigation: Normal surface or sprinkler irrigation methods are used. Water is applied infrequently, as needed, and the crop utilizes a considerable portion of the available stored soil-water (50 per cent or more) before the next irrigation. At least 15 per cent of the applied water percolates below the root zone (leaching fraction [LF] $\geqslant$15 per cent). The guidelines are too retrictive for specialized irrigation methods, such as localized drip irrigation, which results in near daily or frequent irrigation, but are applicable for subsurface irrigation if surface applied leaching satisfies the leaching requirements.

Water uptake by crops: Different crops have different water uptake patterns, but all take water from wherever it is most readily available within the rooting depth. On average about 40 per cent is assumed to be taken from the upper quarter of the rooting depth, 30 per cent from the second quarter, 20 per cent from the third quarter, and 10 per cent from the lowest quarter. Each irrigation leaches the upper root zone and maintains it at a relatively low salinity. Salinity increases with depth and is greatest in the lower part of the root zone. The average salinity of the soil-water is three times that of the applied water and is representative of the average root zone salinity to which the crop responds. These conditions result from a leaching fraction of 15-20 per cent and irrigation that is timed to keep the crop adequately watered at all times.

Salts leached from the upper root zone accumulate to some extent in the lower part but a salt balance is achieved as salts are moved below the root zone by sufficient leaching. The higher salinity in the lower root zone becomes less important if adequate moisture is maintained in the upper, "more active" part of the root zone and long-term leaching is accomplished.

Restriction on use: The "Restriction on use" shown in the water quality guidelines table is divided into three degrees of severity: none, slight to moderate, and severe. The divisions are somewhat arbitrary since change occurs gradually and there is no clearcut breaking point. A change of 10 to 20 per cent above or below a guideline value has little significance if considered in proper perspective with other factors affecting yield. Field studies, research trials and observations have led to these divisions, but management skill of the water user can alter them. Values shown are applicable under normal field conditions prevailing in most irrigated areas in the arid and semi-arid regions of the world.

Source: Water quality for agriculture, FAO Irrigation and Drainage Paper 29 Rev. 1, FAO, Rome, 1985, pp. 8-11.

Annex V

LABORATORY DETERMINATIONS NEEDED TO EVALUATE COMMON IRRIGATION WATER QUALITY PROBLEMS

Water parameter	*Symbol*	*Unit*[a]	*Usual range in irrigation water*	
Salinity				
Salt content				
Electrical Conductivity	EC_w	dS/m	0-3	dS/m
(or)				
Total Dissolved Solids	TDS	mg/l	0-2 000	mg/l
Cations and anions				
Calcium	Ca^{++}	me/l	0-20	me/l
Magnesium	Mg^{++}	me/l	0-5	me/l
Sodium	Na^{+}	me/l	0-40	me/l
Carbonate	CO_3^{--}	me/l	0-.1	me/l
Bicarbonate	HCO_3^{-}	me/l	0-10	me/l
Chloride	Cl^{-}	me/l	0-30	me/l
Sulphate	SO_4^{--}	me/l	0-20	me/l
Nutrients[b]				
Nitrate-Nitrogen	NO_3-N	mg/l	0-10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0-5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0-2	mg/l
Potassium	K^{+}	mg/l	0-2	mg/l
Miscellaneous				
Boron	B	mg/l	0-2	mg/l
Acid/Basicity	pH	1-14	6.0-8.5	
Sodium Absorption Ratio[c]	SAR	(me/l)[a, b]	0-15	

[a] dS/m = deciSiemen/metre in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/centimetre)

mg/l = milligram per litre $\simeq$ parts per million (ppm).

me/l = milliequivalent per litre (mg/l ÷ equivalent weight = me/l); in SI units, 1 me/l = 1 millimol/litre adjusted for electron charge.

[b] NO_3-N means the laboratory will analyse for NO_3 but will report the NO_3 in terms of chemically equivalent nitrogen. Similarly, for NH_4-N, *the laboratory will analyse for* NH_4 *but report in terms of chemically equivalent elemental nitrogen. The total nitrogen available to the plant will be the sum of the equivalent elemental nitrogen. The same reporting method is used for phosphorus.*

[c] SAR is calculated from the Na, Ca and Mg reported in me/l:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

Where Na, Ca and Mg are sodium, calcium and magnesium in me/l from the water analysis.

Source: Water quality for agriculture, FAO Irrigation and Drainage Paper 29 Rev. 1, FAO, Rome, 1985, pp. 8-11.

Annex VI

GUIDELINES FOR LIVESTOCK DRINKING WATER QUALITY

Table 1. Water quality guide for livestock and poultry uses[a]

Water Salinity (EC_w) (dS/m)	*Rating*	*Remarks*
<1.5	Excellent	Usable for all classes of livestock and poultry.
1.5-5.0	Very satisfactory	Usable for all classes of livestock and poultry. May cause temporary diarrhoea in livestock not accustomed to such water; watery droppings in poultry.
5.0-8.0	Satisfactory for livestock	May cause temporary diarrhoea or be refused at first by animals not accustomed to such water.
	Unfit for poultry	Often causes watery faeces, increased mortality and decreased growth, especially in turkeys.
8.0-11.0	Limited use for livestock	Usable with reasonable safety for dairy and beef cattle, sheep, swine and horses. Avoid use for pregnant or lactating animals.
	Unfit for poultry	Not acceptable for poultry.
11.0-16.0	Very limited use	Unfit for poultry and probably unfit for swine. Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry and swine may subsist on waters such as these under certain conditions.
>16.0	Not recommended	Risks with such highly saline water are so great that it cannot be recommended for use under any conditions.

[a] Adapted from National Academy of Sciences (1972; 1974).

Annex VI (continued)

Table 2. Guidelines for levels of toxic substances in livestock drinking water[a]

Constituent (Symbol)	*Upper Limit (mg/l)*
Aluminium (Al)	5.0
Arsenic (As)	0.2
Beryllium (Be)[b]	0.1
Boron (B)	5.0
Cadmium (Cd)	0.05
Chromium (Cr)	1.0
Cobalt (Co)	1.0
Copper (Cu)	0.5
Fluoride (F)	2.0
Iron (Fe)	not needed
Lead (Pb)[c]	0.1
Manganese (Mn)[d]	0.05
Mercury (Hg)	0.01
Nitrate + Nitrite (NO_3-N + NO_2-N)	100.0
Nitrite (NO_2-N)	10.0
Selenium (Se)	0.05
Vanadium (V)	0.10
Zinc (Zn)	24.0

[a] Adapted from National Academy of Sciences (1972).

[b] Insufficient data for livestock. Value for marine aquatic life is used here.

[c] Lead is accumulative and problems may begin at a threshold value of 0.05 mg/l.

[d] Insufficient data for livestock. Value for human drinking water used.

Table 3. Suggested limits for magnesium in drinking water for livestock[a]

Livestock	*Magnesium Concentration (mg/l)*	*(me/l)*
Poultry[b]	<250	<21
Swine[b]	<250	<21
Horses	250	<21
Cows (lactating)	250	<21
Ewes with lambs	250	<21
Beef cattle	400	33
Adult sheep on dry feed	500	41

[a] Adapted from Australian Water Resources Council (1969).

[b] The tolerance of swine and poultry for magnesium is unknown but could well be less than 250 mg/l.

Source: Water quality for agriculture, FAO Irrigation and Drainage Paper 29 Rev. 1, FAO, Rome, 1985, pp. 112-114.

Annex VII

INVENTORY OF LAND USE

Culturable irrigated areas

(a) Perennial

(b) Non-perennial

(c) Culturable waste (inside culturable irrigated areas)

(d) Areas under irrigation by miscellaneous sources

Wells

Streams

Rainfed

Riverine

Torrents

Total cultivated areas

Range land (culturable waste outside culturable irrigated areas)

Forests

Total area (suitable for agriculture and forestry)

Remaining areas (unsuitable for agriculture and forestry)

Total area of the nation.

Annex VIII

FORMAT FOR INVENTORY OF WATER MANAGEMENT SYSTEM

The summary data presented should include both designed and actual technical and economic specifications of projects:

(1) Reservoirs

- total storage capacity;
- active storage capacity;
- dead storage capacity;
- surcharge storage;
- reservoir yield;
- dam type and height;
- spillway capacity;
- appurtenant works (intakes, tunnels, diversions);
- hydropower plant (instanced capacity, power generation; number of units);
- navigation locks (type and capacity);
- volume of work (concrete, embankment etc.);
- capital, operation and maintenance costs.

(2) Diversion structures

- dam type and height;
- intake structure capacity;
- capital, operation and maintenance costs.

(3) Canals

- capacity;
- length;
- purpose;
- capital, operation and maintenance costs.

(4) Pumping plants/pumped-storage power plants

- type and capacity;
- total lift/head;
- number of units, installed capacity, power generation;
- purpose;
- capital, operation and maintenance costs.

(5) Irrigation projects

- irrigated data (full service);
- headgate capacity;
- crop value;
- capital, operation and maintenance costs.

(6) Water treatment plants

- type of treatment;
- capital, operation and maintenance costs.

(7) Others (flood control structural measures, river training, artificial groundwater recharge rates etc.

Information on all existing water projects should be also supplemented with data on the construction period and terms of completion. Additionally, the modes of operation of existing water management systems and major problems should be identified (reservoir inadequate operations, sedimentation, evaporation losses, water shortages, irrigation efficiency, flooding and waterlogging, pollution hazards, spills etc.)

Annex IX

PER CAPITA RESIDENTIAL WATER USE IN SELECTED AREAS[a]

Country	*Place*	*Estimated daily use per capita in litres*	*Source*	*Year*
Urban: Multiple taps or mixed use				
Developing nations	Several hundred	11-930	Dieterich and Henderson 1963, p. 26	
Costa Rica	2 metered cities	264-388	Wieters, Zobel, and Henderson 1959	1956
	7 unmetered cities	216		1959
	34 flat rate cities	444		
Ghana[b]	Accra: High-grade housing	675	Tahal 1965	1965
	Medium-grade housing	166		
	Low-grade housing	34		
	Substandard housing	27		
	Tema: High grade	342		
	Medium grade	265		
	Low grade	108		
Greece		144	Papanastasiou 1967	1965
India	Kalyani	113	Lee 1968	
	New Delhi	136		
Japan[c]	Osaka	520	Japan 1967	1966
	Yokohama	395		
	Tokyo	348		1966
	Kobe	328		1966
	Kyoto	317		1966
Kenya	Nairobi	90	City council report	1966
South Africa	Cape Town	144-53	Cluver, n.d., p. 29	c. 1953
	Johannesburg	158	Morris 1965	1965
	Queenstown	225		
	Pretoria	239		
	Durban	243		
Tanzania	Dar es Salaam (all supplies)	81	Tanganyika Ministry of Communications, Power and Works 1964	1962
	Dodoma	86		
	Moshi	202		
Turkey	Greater Istanbul	105	Noyan and Senogullari 1967	1965
Uganda	Kampala	72-338	Scaff 1964, p. 180	
	All municipal supplies	202	Uganda Protectorate 1960/61	
U.K.	Bradford	144	Skeat 1961, p. 56	1958
	Tees Valley	126	*ibid.*	1958
	Birmingham	99	*ibid., p. 69*	1958
	Glasgow	212	*ibid.*	1959
	Liverpool	126	*ibid.*	1958
	London	162	*ibid.*	1959
U.S.	All cities	227	U.S. Senate 1961, 7	1960
	Towson, Md.: rental	190	Johns Hopkins' Report 1:2-16	1959-62
	Residence value, $14 000	194		
	Residence value, $19 000	214		
	Residence value, $37 000	247		
Uruguay	Montevideo	176	Castagnino 1966	1964
	Punta del Este	447		
	All other towns	130-270		
Zambia	Mazabuka	27	G. Marais 1966: personal communication	
	Lusaka, Suburban African	13-50		

Annex IX *(continued)*

Country	*Place*	*Estimated daily use per capita in litres*	*Source*	*Year*
Single taps				
Guatemala	Single automatic tap systems	60	Aris 1967	1966
Paraguay	Asuncion pilot area: single taps	28-49	Borjesson and Bobeda 1964, p. 858	1964
Pakistan	Comilla pilot area: single automatic taps	16	Est Pakistan Water and Sewer Authority 1968	1968
Urban standpipes				
India	Calcutta: standpipe or pump	30	Lee 1968	1964
Turkey	Greater Istanbul	15	Noyan and Senogullari 1967	1965
Uganda	Kampala	14	Scaff 1964, p. 32	
Venezuela		15	Dieterich and Henderson 1963, p. 28	
Rural Connected				
West Germany	Rural systems	83	Schickhardt 1967	
Not connected				
Bolivia	Seven villages	10	Teller 1969	
Kenya	Zaina	7	Fenwick	
Nigeria	Anchau District	23-27	Nash 1948	1948
Sudan	Kordofan	9-16	FAO Land and Water Survey 1967, p. 238	1967
Tanzania	26 villages in 10 districts	5-26	Warner 1969	1969

[a] Abridged version.

[b] Estimates of household use for Accra were based on metered observations at six standpipes and five households for two months; at Tema 282 housing units were studied for two weeks.

[c] Includes industrial uses.

Source: Water for Human Consumption, Selected papers prepared for the IVth World Congress of the International Water Resources Association (IWRA); Tycooly International Publishing Ltd., Dublin, 1982, pp. 144-145.

Annex X

GENERALIZED ESTIMATES OF DOMESTIC WATER USE FOR DESIGN PURPOSES

Country	*Place*	*Estimated daily use per capita (litres)*	*Reference*
Urban, multiple taps			
Developing countries	Multiple taps	120-240[a]	Dieterich and Henderson, 1963, p. 28
	Private connections	250	Wagner and Lanoix 1959, p. 209
Guatemala	Guatemala City	243	Toppe and Willemsen, 1967
India	Calcutta	225	Lee and Burton, 1965
	Urban places of less than 10 000 without waterborne sewage	56	Longland 1952, p. 102
	Same with waterborne sewage	90-113	
	Urban places	45-225	
Iran	Greater Tehran	250	Dilmaghani 1967
Kenya	Nairobi	159	City Engineer 1968: personal communication
Peru	National water programme	190	Escobar 1969
Rhodesia	Urban places: European	90-113	Longland 1952, p. 102
	African	9-45	
South Africa	Urban places, sewered	135[b]	Cluver, n.d., p. 29
	Urban places, not sewered	45	
Tanzania	Urban places: European	180	Tanzania,
	Asian	90	Ministry of Works: personal communication,
	African	45	1965
Uganda	Urban places, institutions	180-203	Ministry of Public Works 1965
U.S.	Urban	380	Johns Hopkins, Report II, p. 5
Venezuela	Urban places less than 20 000	200-400[c]	Dieterich and Henderson 1963, p. 30
	Urban places 20 000-50 000	250-500	
	Urban places more than 50 000	300-600	
Single tap			
Developing countries		40-60	Dieterich and Henderson 1963, pp. 23, 28
India	Calcutta	90	Lee and Burton 1965
Standpipe			
Developing countries		15	Wagner and Lanoix 1959, p. 209
Developing countries		20-40[a]	Dieterich and Henderson 1963, p. 28
Turkey	Greater Istanbul – public spigots, by year 2000	40	Noyan and Senogullari 1967
Rural, piped connections			
Guatemala	Rural communities	60	Aris 1967
Latin America	Rural places	100-125	M. Hollis: personal communication, 1965
U.K.	England and Wales (rural)	135	Skeat 1961, p. 49
	Scotland (rural)	180	Skeat 1961, p. 49
U.S.	Rural farmsteads with piped dwelling and barn	207	U.S. North Atlantic Regional Water Study 1968
	Indian or Alaskan native communities	50	U.S. Public Health Survey, Div. of Indian
	(with single tap only)	30	Health 1967, p. 3

Annex X *(continued)*

Country	*Place*	*Estimated daily use per capita (litres)*	*Reference*
USSR	Urban and rural standard houses without bath facilities	125-160	USSR 1963, p. 95
	Houses with bath facilities	150-400	
Venezuela	Villages and towns	100-125	Hollis 1965
Standpipe			
Kenya	Rural places	20-40[d/]	Water Development Dept. 1965
Latin America	Rural places	40	Hollis 1965
Tanzania	Rural areas	10	Gilman 1940
Tanzania	Rural areas	45	Holloway 1969

[a/] Upper figure includes waste.

[b/] Includes industrial use.

[c/] Range is for metered and unmetered.

[d/] Includes livestock use. Taken from estimates for households, assuming five members each.

Source: Water for Human Consumption, Selected papers prepared for the IVth World Congress of the International Water Resources Association (IWRA); Tycooly International Publishing Ltd., Dublin, 1982, pp. 147-148. Reprinted by permission of IWRA. Copyright 1982 by IWRA.

Annex XI

PLANNING GUIDE FOR WATER USE

Types of establishments	*Gallons (U.S.) per day*	*Litres per day*
Airports (per passenger)	3-5	11-19
Apartments, multiple family (per resident)	60	227
Bath houses (per bather)	10	38
Camps:		
Construction, semi-permanent (per worker)	50	189
Day with no meals served (per camper)	15	57
Luxury (per camper)	100-150	379-568
Resorts, day and night, with limited plumbing (per camper)	50	189
Tourist with central bath and toilet facilities	35	132
Cottages with seasonal occupation (per resident)	50	189
Courts, tourist with individual bath units (per person)	50	189
Clubs:		
Country (per resident member)	100	379
Country (per non-resident member present)	25	95
Dwellings:		
Boardinghouses (per boarder)	50	189
Additional kitchen requirements for non-resident boarders	10	38
Luxury (per person)	100-150	379-568
Multiple-family apartments (per resident)	40	151
Rooming houses (per resident)	60	227
Single family (per resident)	50-75	189-284
Estates (per resident)	100-150	379-568
Factories (gallons per person per shift)	15-35	57-132
Highway rest area (per person)	5	19
Hotels with private baths (two persons per room)	60	227
Hotels without private baths (per person)	50	189
Institutions other than hospitals (per person)	75-125	284-473
Hospitals (per bed)	250-400	946-1 510
Laundries, self-service (gallons per washing, i.e., per customer)	50	189
Livestock (per animal):		
Cattle (drinking)	12	45
Dairy (drinking and servicing)	35	132
Goat (drinking)	2	8
Hog (drinking)	4	15
Horse (drinking)	12	45
Mule (drinking)	12	45
Sheep (drinking)	2	8
Steer (drinking)	12	45
Motels with bath, toilet and kitchen facilities (per bed space)	50	189
With bed and toilet (per bed space)	40	151
Parks:		
Overnight with flush toilets (per camper)	25	95
Trailers with individual bath units, no sewer connection (per trailer)	25	95
Trailers with individual baths, connected to sewer (per person)	50	189
Picnic:		
With bath houses, showers and flush toilets (per picnicker)	20	76
With toilet facilities only (gallon per picnicker)	10	38
Poultry:		
Chickens (per 100)	5-10	19-38
Turkeys (per 100)	10-18	38-68
Restaurants with toilet facilities (per person)	7-10	26-38
Without toilet facilities (per person)	2½-3	9-11
With bars and cocktail lounge (additional quantity per patron)	2	8
Schools:		
Boarding (per pupil)	75-100	284-379
Day with cafeteria, gymnasiums and showers (per pupil)	25	95
Day with cafeteria but no gymnasiums or showers (per pupil)	20	76
Day without cafeteria, gymnasiums or showers (per pupil)	15	57
Service stations (per vehicle)	10	38
Stores (per toilet room)	400	1 510
Swimming pools (per swimmer)	10	38
Theatres:		
Drive-in (per car space)	5	19
Movie (per auditorium seat)	5	19
Workers:		
Contruction (per person per shift)	50	189
Day (school or offices per person per shift)	15	57

Source: Water for Human Consumption, Selected papers prepared for the IVth World Congress of the International Water Resources Association (IWRA); Tycooly International Publishing Ltd., Dublin, 1982, pp. 153-154. Reprinted by permission of IWRA.

Annex XII

WATER REQUIREMENTS FOR SELECTED INDUSTRIES IN THE WORLD[a/]

(Water requirements for unit of product produced)

Industry, product and country	*Unit of product (ton, except as specified)*	*Water required per unit (litres)*
Food products		
Bread		1 100
Bread or pastry, Belgium		2 100 to 4 200
Bread, United States		600
*Bread, Cyprus		
Canned food		
Belgium:		
Fish, canned		400
Fish, preserved		1 500
Fruit		15 000
Vegetables		8 000 to 80 000
Canada:		
*Fruits and Vegetables		10 000 to 50 000
Cyprus:		
*Citrus/tomato juice		2 800
*Grapefruit sections		16 000
*Peaches/pears		10 000 to 15 000
*Grapes		30 000
*Tomatoes, whole		2 000
*Tomato paste		21 000
*Peas		10 000
*Carrots		16 000
*Spinach		30 000
Israel:		
*Citrus fruits	ton of raw citrus	4 000
*Vegetables		10 000 to 15 000
United States:		
Apricots		21 200
Asparagus		20 500
Beans, green		9 300
Beans, lima		69 800
Beets, corn and peas		7 000
Grapefruit juice		2 800
Grapefruit sections		15 600
Peaches and pears		18 100
Pork and beans		9 300
Pumpkin and squash		7 000
Sauerkraut		950
Spinach		49 400
Succotash		34 800
Tomato products		20 500
Tomatoes, whole		2 200
*Industry average, fruit, vegetables and juices (1965)		24 000
Meat		
*Meat freezing, Cyprus	ton of carcass	500
Meat freezing, New Zealand		3 000 to 8 600
*Meat packing, United States	ton of prepared meat	23 000
*Meat packing, Canada	ton of carcass	8 800 to 34 000
Meat products, Belgium	ton of prepared meat	200
Sausage factory, Finland		20 000 to 35 000
*Sausage factory, Cyprus		25 000
Slaughtering, Finland	ton, live weight	4 000 to 9 000
*Slaughtering, Cyprus	ton of carcass	10 000
*Meat preserving, Israel	ton of prepared meat	10 000

Annex XII *(continued)*

(Water requirements for unit of product produced)

Industry, product and country	*Unit of product (ton, except as specified)*	*Water required per unit (litres)*		
Fish				
*Fresh and frozen fish, Canada		30 000	to	300 000
*Canned fish, Canada		58 000		
*Canning and preserving fish, Israel	ton of raw fish	16 000	to	20 000
Poultry				
*Poultry, Canada	ton	6 000	to	43 000
*Chickens, Israel	ton of dressed chicken	33 000		
*Chickens, United States	per bird	25		
*Turkeys, United States	per bird	75		
Milk and milk products				
Butter:				
*New Zealand		20 000		
Cheese:				
*Cyprus		10 000		
*New Zealand		2 000		
*United States		27 500		
Milk:				
Belgium	1 000 litres	7 000		
Finland		2 000	to	5 000
*Israel		2 700		
Sweden		2 000	to	4 000
*United States		3 000		
Milk powder:				
*New Zealand		45 000		
South Africa		200 000		
*Whey, United States		10 000		
*Dairy products, general, Canada		12 200		
*Ice cream, United States		10 000		
*Yogurt, Cyprus		20 000		
Sugar				
*Denmark	ton of sugar beets	4 800	to	15 800
Finland	ton of sugar beets	10 000	to	20 000
*France	ton of sugar beets	10 900		
*Germany, Federal, Republic of	ton of sugar beets	10 400	to	14 000
*Great Britain	ton of sugar beets	14 900		
*Israel	ton of sugar beets	1 800		
*Italy	ton of sugar beets	10 500	to	12 500
*United States	ton of sugar beets (range)	3 200	to	8 300
*United States	ton of sugar beets (average)	6 000		
Beverages				
Beer:				
Belgium	kilolitre	7 000	to	20 000
Canada	kilolitre	10 000	to	20 000
*Cyprus	kilolitre (incl. cleaning bottles)	22 000	to	30 000
Finland	kilolitre	10 000	to	20 000
*France	kilolitre	14 500		
*Israel	kilolitre	13 500		
*United Kingdom	kilolitre	6 000	to	10 000
United States	kilolitre	15 200		
*Whiskey, United States	kilolitre proof spirit	2 600	to	76 000
*Distilled spirits, Israel	kilolitre	30 000		
*Wine, France	kilolitre	2 900		
*Wine, Israel	kilolitre	500		

Annex XII *(continued)*

(Water requirements for unit of product produced)

Industry, product and country	*Unit of product (ton, except as specified)*	*Water required per unit (litres)*		
Miscellaneous food products				
Chocolate, confectionery, Belgium		15 000	to	17 000
Gelatin (edible), United States		55 100	to	83 500
Maize (wet milling), United States	litre of maize	15.0	to	25.5
Maize syrup, United States	litre of maize	3.8	to	4.3
*Wheat milling, Cyprus		2 000		
*Wheat milling, Israel		700	to	1 300
Potato flour, Finland	ton of potatoes	10 000	to	20 000
*Potato starch, Canada	ton of starch	80 000	to	150 000
*Macaroni, Cyprus		1 200		
Molasses, Belgium	hectolitre of raw material	1 000	to	12 000
Molasses, United States	hectolitre of 100 proof	840		
Pulp and paper				
Groundwood pulp				
Finland	ton of wood pulp	30 000	to	40 000
Sulphate pulp				
Finland	ton of pulp	250 000	to	350 000
*Sweden	ton of unbleached pulp	75 000	to	300 000
*Sweden	ton of bleached pulp	170 000	to	500 000
Sulphite pulp				
Finland	ton of bleached pulp	450 000	to	500 000
Finland	ton of unbleached pulp	250 000	to	300 000
*Sweden	ton of bleached pulp	300 000	to	700 000
*Sweden	ton of unbleached pulp	140 000	to	500 000
Wood pulp				
*Sweden	ton of dry pulp	50 000	to	100 000
South Africa		150 000		
Blotting paper, Sweden		350 000	to	400 000
Kraft, printing and fine paper, Finland		375 000		
*Newsprint, Canada		165 000	to	200 000
Fine paper, Sweden		900 000	to	1 000 000
Newsprint paper, Sweden		200 000		
Packing and cartridge paper, Sweden		125 000		
Press paper, Finland		200 000		
Printing paper, Sweden		500 000		
Cardboard, Finland		125 000		
Paperboard, United States		62 000	to	376 000
Paper and cardboard, Belgium		180 000		
Strawboard, United States		109 000		
Wallboard, Finland		125 000		
*Wallboard, Sweden		50 000		
*Industry average, United States	ton of pulp and paper	236 000		
*Industry average, United Kingdom	ton of paper board	90 000 2/		
*Industry average, France	ton of pulp and paper	150 000		
Petroleum and synthetic fuels				
Aviation gasoline, United States	kilolitre	25 000		
Gasoline, United States	kilolitre	7 000	to	10 000
Gasoline, polymerization, United States	kilolitre	34 000		
Kerosene, Belgium	ton	40 000		
Synthetic gasoline, United States	kilolitre	377 000		
Oilfields, United States	kilolitre of crude petroleum	4 000		

Annex XII *(continued)*

(Water requirements for unit of product produced)

Industry, product and country	*Unit of product (ton, except as specified)*	*Water required per unit (litres)*		
Oil refineries				
Sweden	ton of crude petroleum	10 000		
Synthetic fuel				
From coal:				
South Africa		50 100		
United States	kilolitre	265 500		
From natural gas, United States	kilolitre	88 900		
From shale, United States	kilolitre	20 800		
Chemicals				
Acetic acid, United States		417 000	to	1 000 000
Alcohol, 100 proof, United States	litres	138		
Alcohol, 190 proof, United States	litres	52	to	100
Alumina (Bayer process), United States		26 300		
Ammonia, synthetic, United States	ton of liquid NH_3	129 000		
*Ammonia (naphtha, reforming), Japan		255 000		
Ammonium nitrate, Belgium		52 000		
Ammonium sulphate, United States		835 000		
Calcium carbide, United States		125 000		
Calcium metaphosphate, United States		16 700		
Carbon dioxide, United States		83 500		
*Caustic soda and chlorine, Canada		125 000		
*Caustic soda (Solvay process), United States		60 500		
*Caustic soda (Dual process), Federal Republic of Germany		160 000		
Cellulose nitrate, United States		41 700		
Charcoal and wood chemicals	ton of crude $CaAc_2$	271 000		
*Chroline, Federal Republic of Germany		12 600		
*Ethylene, Israel		16 000		
Gases, compressed and liquified, Canada	cubic metre	60	to	70
Glycerine, United States		4 600		
Gunpowder, United States		401 000	to	835 000
Hydrochloric acid (salt process), United States	ton of 20 Be HCl	12 100		
Hydrochloric acid (synthetic process), United States	ton of 20 Be HCl	2 000	to	4 200
Hydrogen, United States		2 750 000		
Lactose, United States		835 000	to	918 000
Magnesium carbonate, basic, United States	ton of basic $MgCO_3$	18 000		
	ton of $MgCO_3$	163 000		
Oxygen, United States	cubic metre of O_2	243		
*Polyethylene, Federal Republic of Germany		231 000	(incl. 225 000 cooling water)	
*Polyethylene, Israel		8 400		
Potassium chloride (sylvinite), United States		167 000	to	209 000
Smokeless powder, United States		209 000		
Soap, Belgium		37 000		
*Soap, Cyprus		4 500		
Soap (laundry), United States		960	to	2 100
Soda ash (ammonia soda process), 58 per cent, United States		62 600	to	75 100
Sodium chlorate, United States		250 000		
Sodium silicate, United States	ton of 40 Be water-glass	670		
Stearine, soap and washing agents, Sweden	ton of fat	70 000	to	200 000
Sulphuric acid, Belgium		20 000	to	25 000
Sulphuric acid (chamber process), United States	ton of 100 per cent H_2SO_4	10 400		
Sulphuric acid (contact process), United States	ton of 100 per cent H_2SO_4	2 700	to	20 300
*Sulphuric acid, Federal Republic of Germany	ton of SO_3	83 500		
Textiles				
Steeping, dressing, scouring and bleaching				
Steeping flax, Belgium		30 000	to	40 000
Dressing flax, Sweden		30 000	to	40 000
Scouring wool, Belgium		240 000	to	250 000

Annex XII *(continued)*

(Water requirements for unit of product produced)

Industry, product and country	*Unit of product (ton, except as specified)*	*Water required per unit (litres)*		
Washing wool, Sweden		10 000		
Bleaching textile, Belgium		180 000		
Dyeing				
Textiles, Belgium		200 000		
*Textiles, France (range)		52 000	to	560 000
*Textiles, France (average)		180 000		
Finishing				
Wet finishing of textiles, Belgium		100 000	to	150 000
Dyeing and finishing				
*Cotton yarn, Israel		60 000	to	180 000
*Synthetic yarn, Israel		90 000	to	180 000
*Wool yarn, Israel		70 000	to	140 000
*Fabrics, Israel		60 000	to	100 000
Mills				
Cotton:				
Finland		50 000	to	150 000
Sweden		10 000	to	250 000
*Canada	square yard	1.0		
Wool:				
Finland	ton of cloth or yarn	150 000	to	350 000
Sweden	ton of wool	400 000		
Synthetic fibres:				
Artificial silk, Sweden		2 000 000		
Rayon:				
Belgium		2 000 000		
Finland		1 000 000	to	2 000 000
Rayon staple, Belgium		550 000		
*Industrial duck products, Canada		22 000		
*Carpets, Canada	square yard	20		
Mining and quarrying				
Gold, South Africa	ton of ore	1 000		
Iron ore (brown), United States		4 200		
*Bauxite, United States	ton of ore	300		
Sulfur, United States		12 500		
Copper, Finland		3 750		
*Copper, Israel		3 100		
*Gravel, Israel		400		
Limestone and by-products, Belgium		200	to	6 500
Iron and steel products				
Belgium:				
Blast furnace, no recycling		58 000	to	73 000
Blast furnace, with recycling		50 000		
*Finished and semi-finished steel, no recycling		61 000		
Finished and semi-finished steel, with recycling		27 000		
Canada:				
*Pig iron		130 000		
*Open hearth steel		22 000		
France:				
*Smelting		46 000		
*Martin process (open hearth)		15 000		
*Thomas process (Bessemer converter)		10 000		
*Electric furnace steel		40 000		
*Rolling mills		30 000		
Germany, Federal Republic of:				
*Steel works		8 000	to	12 000

Annex XII *(continued)*

(Water requirements for unit of product produced)

Industry, product and country	*Unit of product (ton, except as specified)*	*Water required per unit (litres)*		
South Africa:				
Steel		12 500		
Sweden:				
Iron and steel works		10 000	to	30 000
United States (average):				
*Fully integrated mills		86 000		
*Rolling and drawing mills		14 700		
*Blast furnace smelting		103 000		
*Electrometallurgical ferroalloys		72 000		
*Industry, consumptive use (est.)		3 800		
Miscellaneous products				
*Automobiles, United States	vehicle	38 000		
Boilers, steam, United States	horsepower-hour	15		
*Casein, New Zealand		55 000		
Cement, Portland				
*Belgium		1 900		
*Cyprus (dry process)		550		
Finland		2 500		
*United States (wet process)		900		
Ceramics and tiles, Belgium		1 800	to	2 000
***Coal*				
*Ruhr (Fed. Rep. of Germany)		1 000 (min.)		1 750 (avg.)
*Great Britain			less than 3 000	
*Netherlands		2 650		
Coal, Belgium		5 000	to	6 000
Coal, coke and by-product coke, United States		6 300	to	15 000
Coal washing, United States		840		
Condensers, surface, United States	pound of condensed steam	9.1	to	27.3
(**Includes generation of electricity. If this is not included, the quantities above are reduced by about one-half)				
Distilling, grain				
Belgium	hectolitre of grain treated	6 000	to	7 000
United States	hectolitre of grain treated	6 450		
Distilling, Sweden	kilolitre of 100 per cent alcohol	15 000		100 000
Electric power (conventional thermal):				
Sweden	ton of coal	200 000	to	400 000
South Africa	kilowatt-hour (consumptive use)	5		
*United States	kilowatt-hour	200		
Explosives				
Sweden		800 000		
United States		835 000		
Fertilizer plant, Finland	ton of saltpetre (25 per cent nitrogen)	270 000		
Glass, Belgium		68 000		
Laundry				
*Cyprus	ton of washed goods	45 000		
Finland	ton of washed goods	20 000		
Sweden	ton of washed goods	30 000	to	50 000
Leather				
Leather, South Africa		50 100		
Leather factory, Finland	ton of hides	50 000	to	125 000
*Leather tanning, United States	sq. metre of hide	20	to	2 550 (range)
*Leather tanning, United States	sq. metre of hide	440		(average)
*Leather tanning, Cyprus	sq. metre of small animal skins	110		
Non-ferrous metals, raw and semi-finished, Belgium		80 000		
Rock wool, United States		16 700	to	20 900

Annex XII *(continued)*

(Water requirements for unit of product produced)

Industry, product and country	*Unit of product (ton, except as specified)*	*Water required per unit (litres)*
Rubber, synthetic, United States		
Butadiene		83 500 to 2 750 000
Buna S		125 000 to 2 630 000
Grade GR-S		117 000 to 2 800 000
Starch		
Belgium	ton of maize	13 000 to 18 000
Sweden	ton of potatoes	10 000

a/ Abridged version.

b/ Does not include cooling water for power generation plants.

* Figures based on newer data (post-1960).

Other figures based on older data (pre-1960).

Annex XIII

METHODS FOR ESTIMATING CROP WATER REQUIREMENTS

The FAO manual recommends a three-stage procedure to calculate crop water requirements: (a) the effect of climate on water requirements; (b) the effect of the crop characteristics on crop water requirements; and (c) the effect of local conditions and agricultural practices on crop water requirements.

For the first procedure, a reference crop evapotranspiration is calculated, using one of the four methods presented – the Blaney-Criddle, Radiation, Penman, or Pan Evapotranspiration method – modified to enable use of mean daily climate data for 30- or 10-day periods. The reference crop evapotranspiration is defined as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". The choice of method should be based primarily on the type of climatic data available and on the accuracy required in determining water needs.

For the second procedure, the effect of the crop characteristics on crop water requirements is taken into account by applying the respective crop coefficients (kc) to the reference crop evapotranspiration (ETo) obtained by the first procedure. Hence, the crop evapotranspiration (ETcrop) is determined as a product of kc and ETo. In selecting the appropriate kc value for each period or month in the growing season for a given crop, the rate of crop development must be considered. General climatic conditions such as wind and humidity should also be considered.

The crop growing season can be divided into four stages:

(a) *Initial stage:* germination and early growth when the soil surface is not or is hardly covered by the crop (groundcover < 10%).

(b) *Crop development stage:* from end of initial stage to attainment of effective full groundcover (groundcover ≅ 70-80%)[1].

(c) *Mid-season stage:* from attainment of effective full groundcover to time of start of maturing as indicated by discolouring of leaves (beans) or leaves falling off (cotton). For some crops this may extend to very near harvest (sugarbeets) unless irrigation is not applied at late season and reduction in ET crop is induced to increase yield and/or quality (sugarcane, cotton, some grains); normally well past the flowering stage of annual crops.

(d) *Late-season stage:* from end of mid-season stage until full maturity of harvest.

To determine kc values for these four different stages, for each crop type kc values for various growth stages should be plotted against each month of the growing season as shown in figure II.

Next:

(a) Establish planting or sowing date from local information or from practices in similar climatic zones;

(b) Determine total growing season and length of crop development stages from local information;

(c) Initial stage: predict irrigation and/or rainfall frequency; for predetermined ETo value, obtain kc from figure I and plot kc value as shown in figure II;

(d) Mid-season stage: for given climate (humidity and wind), select kc value from table 1 and plot as straight line;

(e) Late-season stage: for time of full maturity (or harvest within a few days), select kc value from table 1 for given climate (humidity and wind) and plot value at end of growing season or full maturity. Assume straight line between kc values at end of mid-season period and at end of growing season;

(f) Development stage: assume straight line between kc value at end of initial to start of mid-season stage.

For each 10- or 30-day period the kc values can be obtained from the prepared graph.

Crop coefficient values for different kinds of crops are given in FAO Irrigation and Drainage Paper 24(13). For example, kc values for rice are given in table 2.

[1] Start of mid-season stage can be recognized in the field when crop has attained 70 to 80% groundcover which, however, does not mean that the crop has reached its mature height. Effective full groundcover refers to cover when kc is approaching a maximum.

Annex XIII *(continued)*

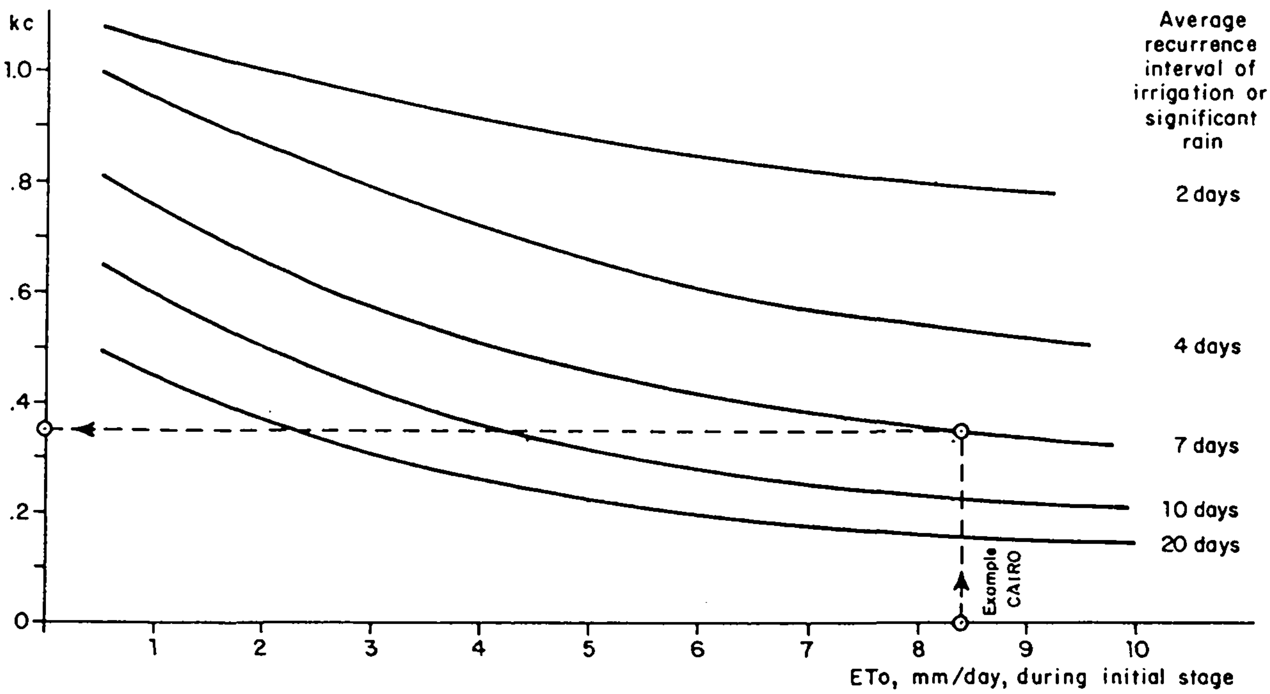

Figure I. Average kc value for initial crop development stage as related to level of ETo and frequency of irrigation and/or significant rain

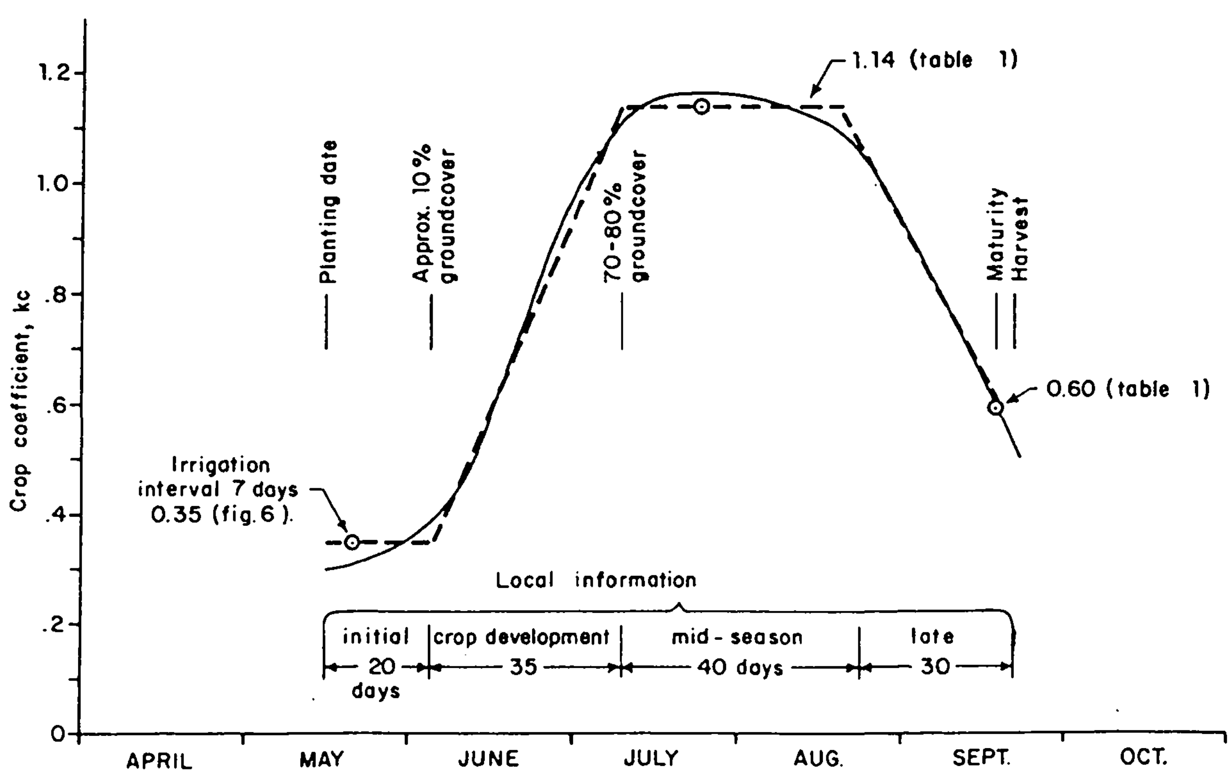

Figure II. Example of crop coefficient curve

Annex XIII *(continued)*

Table 1. Crop coefficient (kc) for field and vegetable crops for different stages of crop growth and prevailing climatic conditions

Crop	*Humidity*		*RHmin*	*>70%*	*RHmin*	*<20%*
	Wind m/sec		*0-5*	*5-8*	*0-5*	*5-8*
	Crop stage					
All field crops	initial crop dev.	1 2	Use Fig. 2 by interpolation			
Artichokes (perennial-clean cultivated)	mid-season at harvest or maturity	3 4	.95 .9	.95 .9	1.0 .95	1.05 1.0
Barley		3 4	1.05 .25	1.1 .25	1.15 .2	1.2 .2
Beans (green)		3 4	.95 .85	.95 .85	1.0 .9	1.05 .9
Beans (dry) Pulses		3 4	1.05 .3	1.1 .3	1.15 .25	1.2 .25
Beets (table)		3 4	1.0 .9	1.0 .9	1.05 .95	1.1 1.0
Carrots		3 4	1.0 .7	1.05 .75	1.1 .8	1.15 .85
Castorbeans		3 4	1.05 .5	1.1 .5	1.15 .5	1.2 .5
Celery		3 4	1.0 .9	1.05 .95	1.1 1.0	1.15 1.05
Corn (sweet) (maize)		3 4	1.05 .95	1.1 1.0	1.15 1.05	1.2 1.1
Corn (grain) (maize)		3 4	1.05 .55	1.1 .55	1.15 .6	1.2 .6
Cotton		3 4	1.05 .65	1.15 .65	1.2 .65	1.25 .7
Crucifers (cabbage, cauliflower, broccoli, Brussel sprouts)		3 4	.95 .80	1.0 .85	1.05 .9	1.1 .95
Cucumbers Fresh market Machine harvest		3 4 4	.9 .7 .85	.9 .7 .85	.95 .75 .95	1.0 .8 1.0
Egg plant (aubergine)		3 4	.95 .8	1.0 .85	1.05 .85	1.1 .9
Flax		3 4	1.0 .25	1.05 .25	1.1 .2	1.15 .2
Grain		3 4	1.05 .3	1.1 .3	1.15 .25	1.2 .25
Lentil		3 4	1.05 .3	1.1 .3	1.15 .25	1.2 .25
Lettuce		3 4	.95 .9	.95 .9	1.0 .9	1.05 1.0
Melons		3 4	.95 .65	.95 .65	1.0 .75	1.05 .75
Millet		3 4	1.0 .3	1.05 .3	1.1 .25	1.15 .25
Oats	mid-season harvest/maturity	3 4	1.05 .25	1.1 .25	1.15 .2	1.2 .2
Onion (dry)		3 4	.95 .75	.95 .75	1.05 .8	1.1 .85
(green)		3 4	.95 .95	.95 .95	1.0 1.0	1.05 1.05

Annex XIII *(continued)*

Crop	Humidity / Wind m/sec		RHmin >70% 0-5	RHmin >70% 5-8	RHmin <20% 0-5	RHmin <20% 5-8
Peanuts (Groundnuts)		3	.95	1.0	1.05	1.1
		4	.55	.55	.6	.6
Peas		3	1.05	1.1	1.15	1.2
		4	.95	1.0	1.05	1.1
Peppers (fresh)		3	.95	1.0	1.05	1.1
		4	.8	.85	.85	.9
Potatoes		3	1.05	1.1	1.15	1.2
		4	.7	.7	.75	.75
Radishes		3	.8	.8	.85	.9
		4	.75	.75	.8	.85
Safflower		3	1.05	1.1	1.15	1.2
		4	.25	.25	.2	.2
Sorghum		3	1.0	1.05	1.1	1.15
		4	.5	.5	.55	.55
Soybeans		3	1.0	1.05	1.1	1.15
		4	.45	.45	.45	.45
Spinach		3	.95	.95	1.0	1.05
		4	.9	.9	.95	1.0
Squash		3	.9	.9	.95	1.0
		4	.7	.7	.75	.8
Sugarbeet		3	1.05	1.1	1.15	1.2
		4	.9	.95	1.0	1.0
	no irrigation last month	4	.6	.6	.6	.6
Sunflowers		3	1.05	1.1	1.15	1.2
		4	.4	.4	.35	.35
Tomatoes		3	1.05	1.1	1.2	1.25
		4	.6	.6	.65	.65
Wheat		3	1.05	1.1	1.15	1.2
		4	.25	.25	.2	.2

NB: Many cool season crops cannot grow in dry, hot climates. Values of kc are given for latter conditions since they may occur occasionally, and result in the need for higher kc values, especially for tall rough crops.

Source: FAO Irrigation and Drainage Paper 24, revised 1977, FAO, Rome.

Annex XIII *(continued)*

Table 2. Kc values for rice

	Planting	*Harvest*	*First and second month*	*Mid-season*	*Last 4 weeks*
Humid Asia					
wet season (monsoon)	June-July	November-December			
light to mod. wind			1.1	1.05	.95
strong wind			1.15	1.1	1.0
dry season[a]	December-January	mid-May			
light to mod. wind			1.1	1.25	1.0
strong wind			1.15	1.35	1.05
North Australia					
wet season	December-January	April-May			
light to mod. wind			1.1	1.05	.95
strong wind			1.15	1.1	1.0
South Australia					
dry summer	October	March			
light to mod. wind			1.1	1.25	1.0
strong wind			1.15	1.35	1.05
Humid S. America					
wet season	November-December	April-May			
light to mod. wind			1.1	1.05	.95
strong wind			1.15	1.1	1.0
Europe					
(Spain, S. France and Italy)					
dry season	May-June	September-October			
light to mod. wind			1.1	1.2	.95
strong wind			1.15	1.3	1.0
U.S.A.					
wet summer (south)	May	September-October			
light to mod. wind			1.1	1.1	.95
strong wind			1.15	1.15	1.0
dry summer (Calif.)	early May	early October			
light to mod. wind			1.1	1.25	1.0
strong wind			1.15	1.35	1.05

[a] Only when RHmin $>70\%$, kc values for wet season are to be used.

Source: Guidelines for predicting crop water requirements, FAO Irrigation and Drainage Paper 24 (revised), FAO, Rome, 1977.

Annex XIII *(continued)*

These requirements are defined as the depth of water needed to meet the water loss through evapotranspiration of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility, and achieving full production potential under the given growing environment. Crop-water requirements may be expressed in cubic metres per year per hectare.

The FAO manual recommends a three-stage procedure to calculate crop water requirements: (a) The effect of climate on water requirements; (b) the effect of the crop characteristics on crop water requirements; and (c) the effect of local conditions and agricultural practices on crop water requirements.

For the first procedure, a reference crop evapotranspiration is calculated, using one of the four methods presented – the Blaney-Criddle, Radiation, Penman, or Pan evapotranspiration method – modified to enable use of mean daily climate data for 30- or 10-day periods. The reference crop evapotranspiration is defined as "the rate of evapotranspiration from an extensive surface of 8 to 10 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". The choice of method should be based primarily on the type of climatic data available and on the accuracy required in determining water needs. The climatic data required for each of the four different methods are given in table 3.

For the second procedure; the effect of the crop characteristics on crop water requirements is taken into account by applying the respective crop coefficients (kc) to the reference crop evapotranspiration (ETo) obtained by the first procedure. Hence, the crop evapotranspiration (ETcrop) is determined as a product of kc and ETo.

Factors affecting the value of crop coefficient (kc) are mainly the crop characteristics, crop planting or sowing data, rate of crop development, length of growing season and climatic conditions. Crop coefficient values for rice as well as methodology for estimating crop water requirements are given in annex 8. Approximate ranges of seasonal crop evapotranspiration (ETcrop) for different crops are given in annex 9. The values indicated will change depending on the climate, crop characteristics, length of growing season and time of planting.

For the third procedure, the effect of local conditions and agricultural practices on crop water requirements is taken into consideration by making necessary adjustments or corrections for: variation of climate over time, space, altitude and size of an irrigation development; variation in the level and salinity of available soil water; variation in the method of irrigation; and variation in cultural practices.

An estimate should also be made of return flows from irrigation showing amount, quality, location and time of occurrence.

Table 3. Approximate range of seasonal ETcrop in mm

Seasonal ETcrop	*mm*	*Seasonal ETcrop*	*mm*
Alfalfa	600 - 1 500	Onions	350 - 600
Avocado	650 - 1 000	Oranges	600 - 950
Bananas	700 - 1 700	Potatoes	350 - 625
Beans	250 - 500	Rice	500 - 950
Cocoa	800 - 1 200	Sisal	550 - 800
Coffee	800 - 1 200	Sorghum	300 - 650
Cotton	550 - 950	Soybeans	450 - 825
Dates	900 - 1 300	Sugarbeet	450 - 850
Deciduous trees	700 - 1 050	Sugarcane	1 000 - 1 500
Flax	450 - 900	Sweet potatoes	400 - 675
Grains (small)	300 - 450	Tobacco	300 - 500
Grapefruit	650 - 1 000	Tomatoes	300 - 600
Maize	400 - 750	Vegetables	250 - 500
Oil seeds	300 - 600	Vineyards	450 - 900
		Walnuts	700 - 1 000

Source: Guidelines for predicting crop water requirements, FAO Irrigation and Drainage Paper 24 (revised), FAO, Rome 1977, p. 36.

Note: The effect of the crop characteristics on crop water requirements is taken into account by applying the respective crop coefficients (kc) to the reference crop evapotranspiration (ETo). Hence, the crop evapotranspiration (ETcrop) is determined as a product of kc and ETo.

Factors affecting the value of crop coefficient (kc) are mainly the crop characteristics, crop planting or sowing data, rate of crop development, length of growing season and climatic conditions. Crop coefficient values for different kinds of crops are given in annex 6. Approximate ranges of seasonal crop evapotranspiration (ETcrop) for different crops are given above. The values indicated will change depending on the climate, crop characteristics, length of growing season and time of planting.

Annex XIII *(continued)*

Table 4. Reference crop evapotranspiration methods

Method	*Blaney-Criddle*	*Radiation*	*Penman*	*Pan evaporation*
Temperature	*	*	*	*
Humidity	0	0	*	0
Wind	0	0	*	0
Sunshine	0	*	*	
Radiation			(*)	(*)
Evaporation				*
Environment	0	0	*	

Note: * Measured data
0 Estimated data
(*) If available, but not essential

Annex XIV

WATER REQUIREMENTS FOR LIVESTOCK

Cattle	25-35 litres per head per day (lhd)
Horses and mules	20-25 lhd
Sheep	15-25 lhd
Pigs	10-15 lhd
Poultry (Chicken)	15-25 litres per 100 head per day (l/100/d)

Source: H. Ricarte, "Population/Water demand projections", training course on masterplanning for rural water management conducted jointly by the International Training Centre for Water Resources Management (CEFIGRE) and Asian Institute of Technology (AIT), Bangkok, Thailand, 12-31 May 1986.

REFERENCES

1. Mar del Plata Action Plan United Nations Water Conference, Mar del Plata, Argentina, 14-25 March 1977. Department of International Economic and Social Affairs, (May 1983).

2. *The Hungarian Water Master Plan* ECE Committee on Water Problems Seminar on Water Management Systems, Bratislava, Czechoslovakia, 15-19 September 1986, (10 March 1986).

3. *Guidelines for Drinking-Water Quality,* vol. 1, *Recommendations,* vol. 2 *Health Criteria and Other Supporting Information,* vol. 3, *Drinking-Water Quality Control in Small Community Supplies,* Geneva, World Health Organization 1985.

4. R.S. Ayers and D.W. Westcot, *Water quality for agriculture,* FAO Irrigation and Drainage Paper 29, Rev. 1.

5. *Water for Human Consumption: Selected papers prepared for the IVth World Congress of the International Water Resources Association,* (IWRA) (Tycooly International Publishing Ltd., Dublin, 1982), pp. 161-168.

6. *Revised Action Programme for Irrigated Agriculture: Main Report* vol. I, *Water and Power Development Authority* (Pakistan, May 1979), p. V-28, para 5.66.

7. *Planning of Projects for Development of Water Resources,* Seminar papers, Rio de Janeiro, Brazil 1958, Revised 1971, (Denver, Colorado United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Division of Planning Co-ordination, p. H-35).

8. *Manual VII: Methods for Projections of Urban and Rural Population,* (United Nations publication, Sales No. 74, XIII. 3).

9. *Guidelines for Preparing Subnational Population Projections,* Asian Population Studies No. 32, Bangkok, ESCAP, 1975, p. 4.

10. *Manual IV, Methods of Estimating Basic Demographic Measures from Incomplete Data,* (United Nations publication, Sales No. 67, XIII. 2).

11. Joint WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control, *Report of the Seventh Meeting, Rome, 7-11 September 1987,* Geneva, World Health Organization, 1987, pp. 43-45.

12. "Environmental impact assessment guidelines for water resources development," paper presented at the Expert Group Meeting on Environmental Impact Assessment of Development Projects, 15-19 August 1988, Bangkok.

13. "Guidelines for predicting crop water requirements," FAO Irrigation and Drainage Paper 24 (revised), Rome (Food and Agriculture Organization of the United Nations 1977).

14. *Detailed Work Plan for the National Master Water Plan, Stage I,* Ministry of Water Development, The Republic of Kenya, New York-Nairobi, Tippetts-Abbett-Mc-Carthy-Stratton, October-1976.

15. H. Ricarte, "Population/water demand projections", training course on masterplanning for rural water management conducted jointly by the International Training Centre for Water Resources Management (CEFIGRE) and Asian Institute of Technology (AIT), Bangkok, Thailand, 12-31 May 1986.

16. *Multiple-purpose River Basin Development,* Part 1, *Manual for River Basin Planning,* Flood Control Series No. 7 (United Nations Publication, Sales No: 1955. II.F.1), pp. 11-70.

17. Charles W. Howe, "Benefit-cost analysis for water system planning", Water Resources Monograph 2, (Washington D.C., American Geophysical Union, 1971).

18. *Water Resources Planning Experiences in a National and Regional Context,* Report of a United Nations Workshop convened in co-operation with the Government of Italy, Castelgandolfo and Stresa, Italy, 18-29 June 1979 (TCD/SEM. 80/1).

19. *UNESCO International Hydrological Programme.*

Part Two

SELECTED COUNTRY PAPERS

(Presented at the Expert Group Meeting to Review and Finalize Draft Guidelines for the Preparation of National Master Water Plans)

I. CHINA: ON THE CHINESE MASTER WATER PLAN AND A WATER RESOURCES DEVELOPMENT PROJECT – THE SOUTH-TO-NORTH WATER TRANSFER

A. ISSUES AND TASKS OF THE MASTER WATER PLAN IN CHINA

Water conservancy has been an important issue for the Chinese nation from time immemorial. In the several thousand years of civilized history, it has played a great role in the social and economic development of the country. Water conservancy activities stagnated in the first half of this century owing to wars.

Since 1949, with the founding of the People's Republic of China, an enormous development of water conservancy undertaking has been made to meet the urgent requirements of socialist construction. From 1949 to 1987, water facilities were constructed or improved, including 200,000 km of levees, thousands of water sources, 82,800 reservoirs of various scale with a total capacity of 447.5 km^3 and 640 million ponds, 5,343 irrigation districts of a large scale (irrigated land of over 667 ha in a district), 2.43 million wells, pumping facilities for irrigation and drainage with a total capacity of 62.42 million kW and 30,190 MW of hydropower generating capacity. The following results have been attained:

- Flood control capability of the major rivers has been raised; flooding is basically under control. The measures on the Yellow, Huaihe, Haihe, as well as some reaches of the Yangtze River provide protection from 40 or 60 year floods.
- Irrigated area has increased to 48 million ha (47 per cent of the total area of cultivated land) and 18.7 million ha of the area liable to waterlogging (78 per cent of the total) has been preliminarily harnessed. Land with irrigation and drainage facilities contributes to two-thirds of the country's grain production. Irrigation and drainage have resulted in the development of agriculture, a contributing factor in the provision of adequate food and other farm produce for the 1.1 billion population.
- Annual water supply for municipal, industrial and mining amounts to 57 km^3. The provision of drinking water for 105.7 million people and 62.13 million head of domestic animals in agriculture and livestock farming areas has been preliminarily arranged.
- Hydroelectric stations generate 100.2 billion kWh of power annually, making up 20 per cent of the total power output of the whole country.
- The total length of inland navigation is 110,000 km.
- 500,000 km^2 of soil erosion area (one-third of the total) has been brought under control initially.

With modernization, construction and population growth, however, water conservancy in China is facing a serious challenge. Major problems facing the country at present are:

- The water resources management system, including laws, regulations, policies, organizations and facilities concerned, is incomplete.
- Flood calamity is still a serious threat to the development of the national economy and social stability.
- Water demands severely exceed supply so that irrigation facilities are extremely unsuitable for the development of agriculture, and serious water shortages appear in north China as well as many cities in the country.
- Soil erosion and water pollution become increasingly grave by the day.
- Water utilization for hydropower, navigation and the aquatic products industry is at a low level.
- The quality of many existing projects has become poor; many facilities are aging and in need of repair to the extent that benefit derived from them has decreased. Renewal or improvement is required.

To solve these problems, China has carried out several activities for the master water plan in recent years;

(a) The outline of water development in China has been drafted. This outline is to discuss, prove and comprehensively analyse some of the significant issues, which will exert a long-term impact on water resources development on a macro scale. It will also identify the strategic

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objectives, plans and measures as well as the major principles and policies of the techniques and economy for achieving the objectives.

The outline has analysed the current problems and their solutions, set the development goal and task for the near future (by the year 2000) and the mid-future (by the year 2020), and forecasted the direction of development in the further future (by the year 2050). It has also determined the guiding ideology and major principles of water development, and identified the basic tasks relating to water resources development such as flood control, water resources development (including water conservation and new sources reclamation), water resources protection, irrigation and drainage, hydropower generation, soil conservation, water body and water project management, co-ordination of the development with navigation, aquatic products industry and recreation, activities of hydrology, planning and scientific research, personnel training, reform of the organization system, legislation and so on.

The major function of the outline is to lay out a guideline; it cannot replace water planning of each river basin or region. The preparation of the outline is based on scientific forecasts. The outline will require continuous modification to reflect changes in practise.

(b) The study on the rational use and balancing supply and requirement of water resources in China has been carried out.

The study took four years from 1982 to 1986, and more than 3,000 scientific and technological personnel took part in the research activities. The general report of the study is "The Utilization of Water Resources in China". In addition, 38 sub-reports were compiled on every major river basin area, every province, autonomous regions and metropolises respectively. The contents of the general report are as follows:

- Centring on the utilization of water resources, the physical, social and general economic situations as well as water utilization in the study areas have been expounded. For the study, the territory of whole country was divided into nine regions, 82 secondary regions, 302 third-class regions and more than 2000 calculating units.
- The amount, characteristics, present development and utilization of water resources in China have been explained and existing problems have been analysed.
- The situation of water supply and requirement by the year 2000 has been forecast; the amount of water shortage by that time has been predicted and the present condition of water shortage in various regions has been studied. According to the analysis and based on the parameters of cultivated land, irrigation, population, industry and utilization ratio of water resources, the level of water shortage in every study region has been evaluated comprehensively. "Water-short" regions and "water-shortest" regions have been identified.
- The situation of water supply and requirement in seven major regions has been thoroughly studied, and measures to solve their water supply problems have been proposed.
- Lastly, the principal way to solve the water supply and requirement issues in the whole country and the policy concerned has been suggested.

The report shows a clear picture of the situation and trend of water resources development and utilization in China. It provides an important basis for strategic study and planning by regions or sectors in the country. It is also an important preparation for, and component of the national master water plan.

(c) Comprehensive water plans on every major river have been revised. The Yangtze, Yellow, Huaihe, Haihe, Pearl, Songhuajiang and Liaohe are the seven major rivers in China. Riverbasin water plans for each of them were prepared in the 1950's. The plans made strategic studies of the general direction, the steps and the key measures for development. To meet current requirements, the plans of every river basin have been revised based against the original plans and practice of construction. The revision of the plans will be completed next year and will become an important base of the nation's master water plan.

Moreover, plans for interbasin water transfer, such as south-to-north water transfers (including the east route project, middle route project and west route project) and north-to-south water transfer project (diverts water from the Songhuajiang River to the Liaohe River), the national irrigation and drainage plans, the national long-term water supply and demand plans, and the planning of water resources development for the major agricultural areas, are also being formulated.

In the light of specific conditions in China, the following characteristics should be considered in preparation of a national master water plan:

1. The master water plan should be combined with the establishment and perfecting of the water resources management system. The economic and political structures in the country are being reformed. In adapting water resources development to the demands of modernization and construction, the manner of water resources manage-

ment under the new conditions will affect the preparation of the master water plan.

2. Flood control is still an important issue in the master plan of water resources development. The threat of flood is still a prominent problem in many areas of China. The original capacity of flood control measures in some areas is very low. They can protect the areas from a five-year flood or a 10-year flood only. On some reaches of rivers, the capability of flood control has decreased, because of various reasons such as soil erosion, siltation of river courses, poor management, lack of strict enforcement of laws and of artificial barriers on the flood channels. Loss from flood damage will be more serious than ever because of population increases and the development of the economy. Therefore, flood water must not be treated lightly in China.

3. To solve water-shortage problems in China, long-term arrangements including water conservation, new water sources reclamation and resources protection should be made. Because of the very large population, very small quantity of water resources per capita, and uneven distribution of bodies of water, the greater part of China's territory is considered as a "water-shortest" region. By world standards, China is generally a water-short country. With the development of the economy and society, water-shortage problems become increasingly serious while the affected area has widened. To prepare for the further future, essential measures have to be adopted at a favourable time, based on good planning. To reach a macro scale solution, a strategic disposition should be made by taking a broad and long-term view. It means that prospects for social and economic development and the rational exploitation of resources in the whole country should be taken into account.

4. The selection of measures in the near future should constitute the major demonstration activities of the master water plan. As it is difficult to accurately estimate future development, plans should allow for unforeseen circumstances in the further future. Measures in the near future, however, have to be determined with great care, because they need considerable input of capital and manpower. Moreover, the economic capability which is low in the initial stages of development, has to be spread to meet not only the present needs but also future requirements as well. China, with its vast territory and obvious differences between regions, has very limited capital for water resources development in the near future. Decision making on the subject is a very complex issue, which must be studied seriously. For this reason a thorough investigation and study should be carried out on the initial projects, to be constructed in the next five or 10 years which are included in the 20- or 30-year scheme of the master plan.

China lacks the experience for preparation of a master water plan. An integrated master plan has not been submitted yet. We must learn from all countries throughout the world. The ESCAP guidelines for the preparation of national master water plans will be very helpful to water resources development activities in China. Chinese water planners are very pleased to exchange experience and knowledge with colleagues from the same rector in all countries.

B. SOUTH-TO-NORTH WATER TRANSFER PROJECT – A STRATEGIC PROJECT OF THE WATER RESOURCES DEVELOPMENT IN CHINA

The core issue of water resources development in China is how to meet the requirements of the continuously developing national economy, taking into account the characteristics of water resources in the country.

The most important characteristic of water resources in China is that the amount of water resources per capita is low (equal to 1/4 of the mean value of the world, 1/5 of that in the United States or 1/6.5 of that in USSR); aerial distribution is considerably uneven, and does not coincide with the distribution of population and cultivated land (the amount of water resources per capita in the north of China, except for internal drainage area, is equal to 23 per cent of that in the south and the amount of water resources per ha of cultivated land in the north is equal to only 11 per cent of that in the south); and the water volume varies significantly from month to month and year to year.

According to the comprehensive study on balancing water supply and requirements, the water deficient areas in China are concentrated in the middle and lower basins of the Yellow River, the Huang-Huai-Hai Plain, the Shandong Peninsula, the Liaohe River Plain and Eastern-Liao Peninsula. The northern part of the Huang-Huai-Hai Plain is the most severely affected. The utilization rates of local water resources in these areas are relatively high (50 per cent of the runoff has been developed and used). To solve the water shortage problems of these areas, the productive structure of agriculture and the distribution of industry must be reasonably regulated. The choice of agricultural and industrial development as well as urban and rural construction in the north should be suited to the actual condition of water scarcity and the difficult question of water supply in the area. At the same time, further development of water resources must be carried out, including tapping potential local water resources, making adjustments to the resources within the area, and transferring water from other basins with transferring water from the Yangtze River as a basic measure. While the Yangtze River provides water for its basins' economic development, domestic supply and the water needed to protect the river's ecological environment, it has enough water to be transferred to the north. The proposal for the south-to-north water transfer project was raised at the beginning of the 1950's. This project would be considered as one of the strategic measures for water resources development to be put into practice in the near future.

South-to-north water transfers in China includes three projects, the west route, middle route and east route projects. The west route project diverts water from the upper reaches of the Yangtze River and its tributaries to the upper reaches of the Yellow River. Its main role is to supplement water for the upper and middle reaches of the Yellow River as well as the north-west region and to improve the condition of silt discharge. The middle route project taps water from the middle reaches of the Yangtze River and its main tributary, the Hanjiang River. It can supply water to most parts of the Huang-Huai-Hai Plain by gravity. The east route project transfers water from the lower reaches of the Yangtze River where water sources are sufficient, northward along the Grand Canal to supplement water on the eastern part of the Huang-Huai-Hai Plain. At the same time, the capability of navigation on the Beijing-Hangzhou Canal will be recovered and enlarged. The three water transfer routes have their own rational water-supply scope. They can co-operate with each other but cannot be replaced.

The first stage of the east route project of the south-to-north water transfer will be put into practice in the near future, owing to serious shortage of water in a large area of the eastern part of north China. It has been projected that unless the south-to-north water transfer project is put into practice and water from the Yangtze River is transferred to the north of the Yellow River by the end of this century, the water resources crisis will not be alleviated. It would affect not only the growth of the economy, but could worsen the serious environmental problems caused by continuous water scarcity.

The east route project of south-to-north water transfers will divert water from the lower reaches of the main stream of the Yangtze River which is to the southeast of Hangzhou City in Jiangsu Province. Water will be conveyed northward by means of pumping step by step mainly on the Beijing-Hangzhou Canal, and flows across the Gaoyou, Hongze, Luoma, Nansi and Dongping lakes, and across the Yellow River by a tunnel dug under its river bed at Weishan in Shandong Province, and then to Tianjin by gravity. The conveyance trunk route from the Yangtze River to the Beidagang Reservoir in Tianjin will be 1,180 km long, and the entire route including all the subsidiary routes will total 2,370 km. The difference in elevation between the Yangtze River and the Dongping Lake, the highest point on the route, is 40 metres. The total lift of pumping stations in 13 steps is 64 metres. The capacity of pumping water from the Yangtze River will be probably enlarged to 1,400 m^3/s in the further future. The existing capacity of the first step pumping station (the Jiangdu Pumping Station) is 400 m^3/s, and will be enlarged to 600 m^3/s in the first stage project. The designed capacity of the project to cross under the Yellow River will probably be 700 m^3/s in the further future, and its capacity will be 100 m^3/s in the first stage project if the project extends northward. The capacity of sending water to Tianjin will be 180 m^3/s in the further future, and 100 m^3/s in the first stage project.

In the proposal for the further future, the average water amount pumped from the Yangtze River may be some 23 km^3 annually. During especially dry years in the water receiving area, the maximum water pumped from the Yangtze River may be 38 km^3. Municipal, industrial and navigation water use along the transfer route may be provided with 13.6 km^3 of water annually. At the same time, the water requirements of 4.2 million ha of irrigated land would be met by co-operating with the local water utilities.

The first state project will, on the average, pump 8.5 km^3 of water annually to a maximum of 16.9 km^3 from the Yangtze River by extending the capacity of the existing project in Jiangsu Province to 600 m^3/s. The original plan of the first stage project was only to convey water to the Dongping Lake south of the Yellow River. According to a further study, if the scale of the lower reach of the conveyance channel is appropriately enlarged and the operation is adjusted, the first stage project can transfer water at an estimated average amount of 1.7 km^3 annually to the north. The entire first stage project will increase water-supply by 5.4 km^3 annually. The project can basically meet the municipal and industrial water demand of some cities, including Tianjin, in common drought years by the end of this century, and also improve the condition of water supply for 1.5 million ha of irrigated land along the conveyance route. If the extension to the north is considered in the first stage project, the total earthwork volume is 168 million m^3, the total installed capacity of pumping stations is 320 MW, the estimated capital investment is 3.5 billion yuan (about US$ 1 billion).

A solution to the technical problems of the project has been worked out. A water conveyance tunnel crossing the Yellow River and a series of large pumping stations are the key projects. To make a thorough investigation of geological conditions and examine the construction methods for digging a tunnel in karst stratum under water, a prospect tunnel with a cross section of 2.6 metres by 2.9 metres was dug at the site of the proposed water conveyance tunnel, which will have a circular cross section of 9 metres in diameter, and will convey 200 m^3 of water per second. The east route water transfer project needs low head and large flow pumps. The pumps have to work throughout the year. As their utilization hours are high, the facilities to be installed must be of high efficiency and reliability in operation. The whole project requires 500 to 600 pump units (estimated at 25 m^3/m per unit). In the last ten years, pumps of this kind have been developed. With advanced techniques introduced from abroad China possesses the capability of producing high efficiency pumps of this kind.

The environmental impact of the project is a major concern of the public. Research work on the impact on the Yangtze River of the entire projects of south-to-north water transfer is being carried out continuously. The environmental impact of the first stage project was studied widely and thoroughly with emphasis on the impact on the estuary of the Yangtze River, soil salinization on irrigated land in north China and both sides of the conveyance trunk canal, the probability of a northward movement of the schistosomiases epidemic, and the aquatic environment etc. The study also stressed the improvement of the environment arising from water transfer, and the measures to protect transferred water from pollution. The conclusion of the evaluation has been approved by the agency environment protection and by environmentalists. Generally, owing to the low ratio of the amount of water transferred by the first stage project to the quantity of water downstream of the Yangtze, the impact from the water transfer is relatively insignificant and compensatory measures to counter any probable adverse impacts are being planned.

The economic assessment on and benefits to be derived from this project have been made in detail. In the near future, the capacity for water transfer is small, and would mainly meet the need for industrial and municipal water use in the north and increase the appropriate agricultural water use in the south where the water cost is relatively low. Based on economic benefit assessment, the principle share in the cost and repayment will be studied and will comply with the national policy of bringing every positive factor to promote development.

The operation and management of the project have a legislative foundation in the "Water Law of the People's Republic of China", which was put into force in July 1988. The water administration of the State Council, Ministry of Water Resources, will enact a complete set of regulations, improve the water management regulation system progressively and set up essential organizations, in order to practise water management arbitration by legislation. System engineering is being used as a tool by scientific research personnel to study the operational scheme of this complicated system.

While making preparations for the construction of the east route project of the south-to-north water transfer planning and study activities both for the middle route project and west route project are also being undertaken.

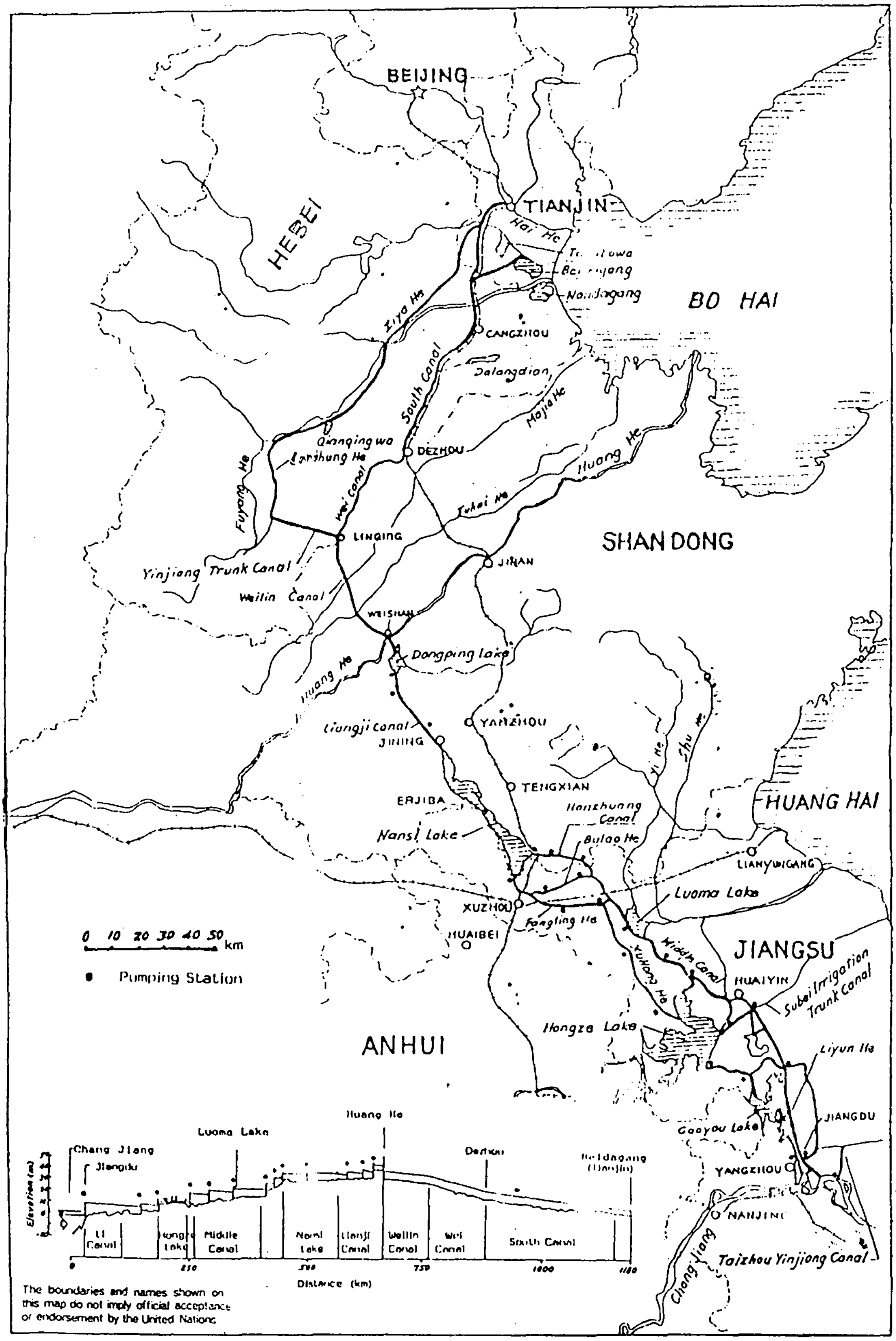

Figure 1. A sketch of the east route scheme of the south-to-north water transfer

II. MALAYSIA: PROBLEMS ENCOUNTERED IN THE PREPARATION OF A NATIONAL MASTER WATER PLAN

A. BACKGROUND

Malaysia is located between latitude 1° and 7° north, and longitude 100° and 119° east. The country comprises two regions, peninsular Malaysia and the States of Sabah and Sarawak, separated by 640 km of the South China Sea. Together the two cover an area of 330,400 sq km.

Peninsular Malaysia, made up of 11 States, adjoins Thailand in the north and stretches down to the Straits of Johore in the south, which separates the peninsula from Singapore. Sabah and Sarawak are situated respectively in the north and northwest of the Borneo Island.

The population of Malaysia in 1988 was estimated to be 16.9 million, 83 per cent of whom live in peninsular Malaysia, 10 per cent in Sarawak and 7 per cent in Sabah. Until the 1980s it was official policy to encourage a slow growth rate in the population. This policy has now been reversed, and based on a projected growth rate of 3.2 per cent per annum, the aim now is to achieve a target population of 70 million by the year 2095.

About 22 per cent of the land in Malaysia is utilized for agriculture. Townships, mining activities and other uses take up another 10 per cent, leaving 68 per cent under forest cover. Approximately half the agricultural land is cultivated with perennial crops. The other half is taken up by annual crops, mixed horticulture, shifting cultivation and to a much lesser extent by fish ponds.

The gross domestic product (GDP) in 1988 was estimated at $M 65,338 million (at constant 1978 prices) with the major exports being electrical and electronic products, crude oil, rubber, palm oil, timber, liquid natural gas (LNG) and some manufactured goods.

B. CLIMATE

Malaysia enjoys a tropical climate influenced by the northeast and southwest monsoons. The former, prevailing between November and January, brings heavy rainfall predominantly to the east coast of peninsular Malaysia. The latter prevails during April and May of peninsular Malaysia and between May and July for Sabah and Sarawak. Rainfall during these periods is generally less than during the northeast monsoon.

The annual average rainfall is 2,420 mm for peninsular Malaysia, 2,630 mm for Sabah and 3,830 mm for Sarawak, the heavier precipitation being in the east coast of peninsular Malaysia and the coastal regions of Sabah and Sarawak.

Temperature and humidity are consistently high being of the order of 26°C and 80 per cent respectively. Daily temperature variations are about 5°C and monthly variations even less, of the order of 2°C. The mean annual open water evaporation varies from 1,800 mm in the north to 1,600 mm in the south, with the maximum evaporation occuring in March and April and the minimum in November and December.

C. OVERVIEW OF WATER RESOURCES AND DEMANDS

On the whole, Malaysia has abundant water resources. The annual rainfall over the land mass amounts to 990 billion m^3, of which some 57 per cent (566 billion m^3) appears as surface runoff and 7 per cent (64 billion m^3) goes to recharge ground water. The balance of about 360 billion m^3 returns to the atmosphere as a result of evaporation and transpiration. Groundwater storage potential has been estimated to be 99 billion m^3 and the safe yield is about 11.8 billion m^3/year.

The main water user sectors are irrigated agriculture, domestic and industrial water supply and hydro-power. Minor users include mining, fisheries and livestock.

In 1980, domestic and industrial water demand was 1.3 billion m^3 while irrigation demand was 7.4 billion m^3. It is projected that by the year 2000, the annual domestic and industrial water demand will grow to 4.8 billion m^3 and the irrigation demand to 10.4 billion m^3. Demand for power has been increasing rapidly over the past years with an annual growth of between 10 per cent and 16 per cent. At present, hydropower supplies 1,245 MW or about 26.5 per cent of the total installed generating capacity.

Comparing water demands with resources, there appears to be abundant water for use. The total annual water demand in 1980 was 1.4 per cent of the available water resources and even by the year 2000 this will only be about 3 per cent. However in regions of major demands,

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water shortage has often occurred in recent years. The reason for this is the wide variation in rainfall distribution in time and space, resulting in very low river flows during the dry season and high flood flows running to waste during the wet season. Further, some regions of high water demand do not coincide with regions of abundant water resources.

D. NATIONAL WATER RESOURCES STUDY

In the late 1970s, the rapid economic growth in Malaysia brought the problems of water imbalance into sharper focus resulting primarily from water-use conflicts. With water resources development and management activities gaining more and more importance in the context of the country's socio-economic development, it became necessary to view the management of water resources as a national undertaking. Consequently, from 1979 to 1982, the Government of Malaysia carried out a National Water Resources Study with the objective of establishing a basic framework for the orderly planning and implementation of water resources development programmes and projects.

The study covered the following major aspects:

- Assessment of water resources and water demands by all water-use sectors and how these demands could be met;
- Assessment of hydropower potential;
- A study of water pollution and flood problems and the measures to mitigate them;
- A study of existing legal and institutional arrangements and the changes necessary to ensure effective and efficient execution of water resources development and management plans.

The study was thus organised to address the principal water issues and to prepare a long-term water resources development plan based on an overview of water resources, present and future needs, and water problems. The plan would include both structural and non-structural measures. The structural works include source development, multi-purpose dams, inter-basin transfers, river improvement and other engineering works, while the non-structural portion includes institutional and legal measures.

E. NATIONAL MASTER WATER PLAN

The outcome of the National Water Resources Study was a master water plan which contains recommendations on actions to be taken by the Government for water resources development and management in the future. The master plan dealt with:

- The formulation of a national water policy;
- The preparation of an implementation programme;
- Criteria for formulating pricing policy;
- The setting up of administrative and institutional frameworks;
- Legal provisions.

On the basis of certain targets to the year 2000, an implementation programme was prepared for the national master water plan. The programme comprises:

- The development of water supply and irrigation projects to include source development of 43 storage dams, to achieve the target of providing water supply to the entire population by the year 2000 except for the rural areas of Sabah and Sarawak, where for reasons of remoteness and non-availability of water sources a 90 per cent coverage has been taken; and to achieve the target of self-sufficiency in rice;
- The development of 13 hydropower projects estimated to have a total installed capacity of 1026 MW in peninsular Malaysia, five projects in Sabah and three projects in Sarawak with installed capacities of 374 MW and 204 MW respectively, in order to reduce dependence on fossil fuel for power generation;
- The construction of flood mitigation projects involving the improvement of 850 kilometres of river channels, the construction of 12 dams, 82 kilometres of floodway, 12 embankment projects and the resettlement of about 10,000 people, to provide protection to 50 per cent of the population in flood prone areas by the year 2000;
- The construction of 21 sewage projects in towns and population centres and the improvement of the effluent purification systems of palm oil, rubber and sugar mills in order to attain a standard of BOD of 5 mg/litre in rivers by the year 2000 and to maintain the desired environmental quality.

F. PROBLEMS FACED IN PREPARATION OF A MASTER WATER PLAN

Among the problems faced in preparing the master water plan were:

- Setting up of a database;
- Obtaining long term plans;

- Lack of co-ordination among water-related sectors;
- Federal/State responsibilities;
- Rapid changes in situation;
- Uneven distribution of supply and demand;
- Increased awareness of the environment.

1. Setting up of a database

One of the prerequisites for preparing a master water plan is the setting up of a database containing information on the existing situation with respect to hydrology, water use, population, economy etc. In Malaysia, and this is probably true for most developing countries, such information is not readily available, and where available, is sometimes incomplete, inadequate or unreliable. Occasionally, even where information is available, it is not readily accessible or is known only to some.

2. Obtaining long-term plans

Master water plans have both short- and long-term objectives, and these must tie in with the socio-economic objectives of the country. In Malaysia, while projections for the short term are readily available, the same is not true for long-term plans. Most long-term plans, where available, are national in nature and projections of growth are often "guesstimates". This problem is perhaps inherent in that long-term records are not readily available to permit meaningful extrapolations to be made.

3. Lack of co-ordination among water-related sectors

Traditionally, water resources development and management in Malaysia has been fragmented among various Federal and State departments and agencies in accordance with their respective functions and activities related to water. In the absence of a comprehensive system to co-ordinate the multifarious activities, each sector tends to focus on its problems in isolation. This has led to some duplication of activities and functions, and conflicts and competition have occurred, leading to wastage in the use of resources.

4. Federal/State responsibilities

Malaysia is a federation of 13 States and the federal territories of Kuala Lumpur and Labuan. Under the Malaysian Constitution, jurisdiction and legislative powers in all aspects of water are distributed between the Federal Government and the State Governments. There are three Lists, namely, a Federal List, a State List and a Concurrent List which distributes areas of jurisdiction.

Among the items enumerated in the Federal List are hydropower, navigation and maritime fisheries while those in the State List include rivers, riverine fisheries and water (including water supplies, rivers and canals if they are wholly within one State or regulated by an agreement among all the States concerned). The Concurrent List, i.e. within the jurisdiction of both the Federal and State Governments, include irrigation and drainage, town and country planning, public health and the rehabilitation of land which has suffered soil erosion. Further, all matters pertaining to land fall under the jurisdiction of the States.

Resulting from this diverse situation, the existing water-related laws have been formulated mainly for the purpose of regulating and managing sectoral water use and no established concepts of water resources development and management are found in these laws. In the preparation of the national master water plan, it was found that there was a need to have an infrastructural co-ordinating mechanism as well as a comprehensive national water code if rational planning, financing and implementation of projects were to be achieved.

Consequently, the final water master plan included recommendations for the setting up of administrative and institutional frameworks as well as the need for more comprehensive legal provisions.

5. Rapid changes in situation

With the advent of independence, there was a natural inclination among the decision makers to accelerate development of the country and increase the standard of living in as short a time as possible. Large tracts of forests were cleared for development and this resulted in a change in the hydrological regime, creating water shortages and flooding. In the preparation of the national master water plan, events sometimes overtook the planning process, e.g. proposals for source development had to be curtailed due to rapid development or colonisation of the catchment areas.

During this period, Malaysia experienced a rapid growth in its urban population due to rural-urban migration and urbanisation. This concentration of population and industries in selected areas aggravated the water supply-demand situation, such that low flows were insufficient to meet all demands while high flows caused flooding (increased run-off due to urbanization) which ran to waste.

6. Uneven distribution of supply and demand

Although Malaysia appears to have abundant water for use, water shortage has already occurred in regions of major demand where the available water resources have not been able to meet rapidly increasing demands, particularly in the dry season. In some of these regions, the practicable limit of water resources development have been reached and it has become necessary to consider inter-basin and inter-State transfers of water.

In the preparation of the master water plan, efforts to meet the demands of industrialised regions had to be tempered with the need to achieve a more equitable distribution of the resource. While economically industry provides a higher return for the use of the water, socio-political considerations necessitate a proportioning of the supply to the rural agricultural areas. The fact that water is under the jurisdiction of the States can further compound the problem, particularly in regions where the upstream agricultural areas lie in one State and the down-stream industrial areas lie in another State.

7. Increased awareness of the environment

Water resources development projects have resulted in a number of environmental problems, including deforestation, soil erosion and sedimentation of rivers. In addition, large water resources projects, such as the building of dams for hydroelectric power generation or irrigation, inundates large tracts of land and necessitates the resettlement of large numbers of people.

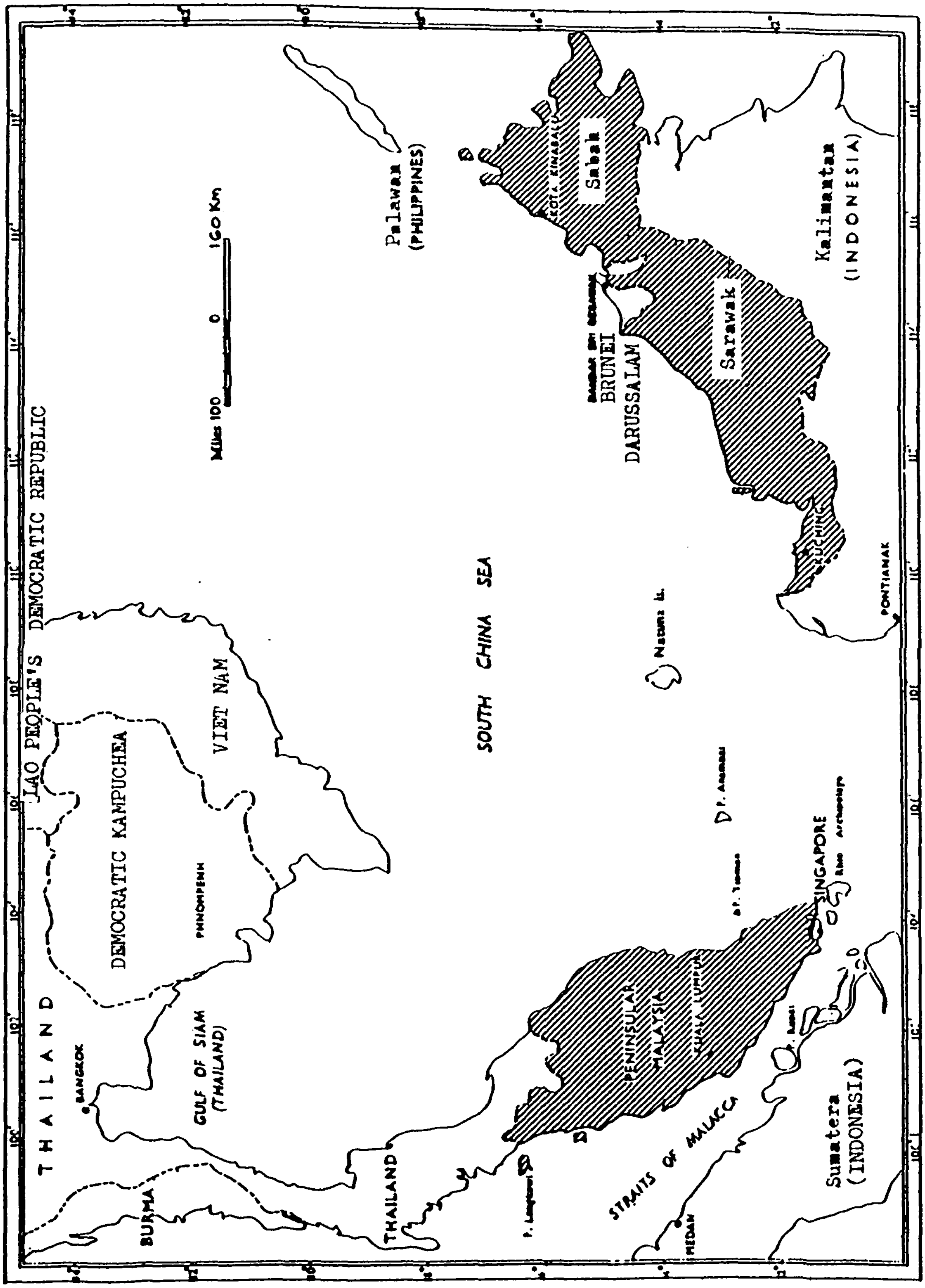
Of late, awareness of environmental issues has emerged in Malaysia and people have begun to realise that environmental degradation threatens human health and well-being. Recently, a proposal to construct a dam in the National Park aroused concern and opposition from large segments of the population and consequently, the proposal was deferred. Dirty rivers are no longer tolerable and a 10-year programme to clean up the Klang River which flows through the capital city of Kuala Lumpur is under serious consideration.

In the preparation of the master water plan, it became necessary not only to provide water to meet the needs of people, agriculture and industry, but also to provide for a minimum river maintenance flow equal to the 97 per cent probability exceedence of the daily natural discharge.

G. CONCLUSION

Malaysia's water resources are abundant. Nevertheless there is a need for proper management, if the country is to be free of water resources constraints. As it is, much of the water runs to waste during the wet season and the quality of the remaining water is threatened by pollution. The national master water plan which has been prepared sets out proposals to overcome these problems utilising both structural and non-structural measures. The structural measures include source development, multipurpose dams, inter-State and inter-basin water transfers, river improvement and other engineering works while the non-structural portion includes institutional and legal measures.

The completed master water plan will, however, have to be reviewed and updated at regular intervals to meet changing conditions. In this respect, the lessons learnt from the past will prove invaluable. In addition, the guidelines prepared by ESCAP will fill a gap in enhancing the knowledge and expertise of engineers and planners who will undertake this review.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 2. Malaysia and its neighbouring countries

III. PHILIPPINES: EXPERIENCE IN THE PREPARATION OF WATER PLANS

A. INIRODUCTION

The Philippines, by nature, is endowed with abundant water resources. With an average annual rainfall of 2,500 mm, the country has promising water resources to supply all the requirements for irrigation, municipal and industrial water needs and the generation of hydroelectric power (Figure 3). It has about 421 principal river basins with drainage areas ranging from 40 to 25,500 km^2 and 59 natural lakes, aside from numerous individual streams (figure 4). There are four major groundwater reservoirs with areas ranging from 6,000 to 10,200 km^2 which when combined with other smaller reservoirs identified would aggregate to an area of about 50,000 km^2.

Unfortunately, the distribution of water resources varies widely with time and location due to the archipelagic nature of the country's geography and the local orographic arrangement which influence climatic conditions (figure 5). Also, there is a tendency for it to become scarce if not properly managed in order to optimize its development in meeting the changing patterns of consumption and increased use among the rapidly expanding population.

The development and utilization of the country's water resources has evolved over a long period in a setting of abundant natural resources, and practically without the benefit of a broad planning framework which considers available resource supply and existing regional needs. With the growing demands of the population and expanding agricultural and industrial development, concerted efforts in the sector become imperative in order to meet the increasing scarcity of water and the changing patterns of water use.

B. INSTITUTIONAL FRAMEWORK

The planning and implementation of water resources development projects and related land resources of the Philippines is the concern of many agencies, government as well as private. Among these are some 42 regional national and regional agencies. For purposes of administrative supervision, these agencies are placed under 12 of the more than 20 executive departments of the national Government. In accordance with tradition, each of these agencies has been organized so as to be responsible for a certain aspect of water resources development. This interplay of specialized government functions can best be illustrated in the areas of water supply, irrigation, hydropower, flood control, navig ation, pollution, watershed management etc.

Each of the agencies undertakes programmes and projects exclusively within its own sectoral field of responsibility. For instance, irrigation activities are the concern of the National Irrigation Administration (NIA), hydropower is the concern of the National Power Corporation (NPC) and the National Electrification Administration (NEA), water supply projects are the concern of the Metropolitan Waterworks and Sewerage System (MWSS), Local Water Utilities Administration (LWUA), the Department of Public Works and Highways (DPWH), the Department of Local Government (DLG), while flood control and drainage projects are undertaken by the Department of Public Works and Highways (DPWH), including the development of small water impounding projects which are also the concern of several other agencies other than the above.

Project identification and planning are often performed to meet the targets of the agency with little or no regard to the needs of others. Frequently, this has resulted in the overlapping of activities and competition for the right to develop the same water resources.

It is under this institutional setting that the Government felt a need for an authoritative national organization to co-ordinate and integrate all activities in water resources development and management to carry out the policy of the Government in encouraging the conservation, development and optimum utilization of water and related land resources on a comprehensive and co-ordinated basis, in order to meet the present and future water needs of the country.

Hence in 1974 the National Water Resources Council (NWRC), a high-level, ex-officio body with sufficient authority to achieve the basic objectives, was established by virtue of Presidential decree 424. The NWRC which is now the National Water Resources Board (NWRB) pursuant to Executive Order No. 124-A is responsible for co-ordinating and integrating all activities related to water resources development and management and in addition exercises regulatory and adjudicatory functions relative to water rights and other provisions of the Philippine Water Code, as

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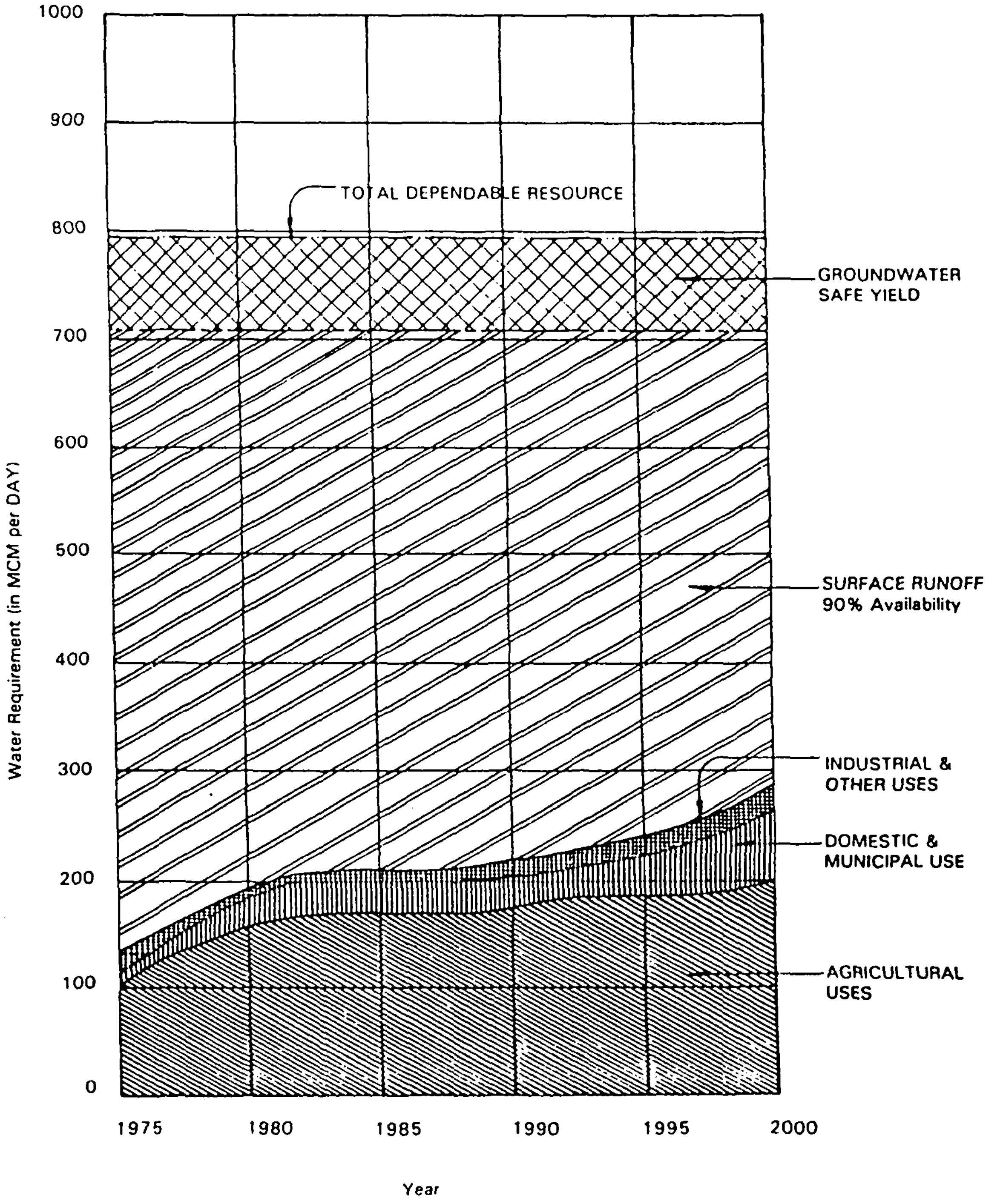

Figure 3. National water picture of the Philippines, 1975-2000

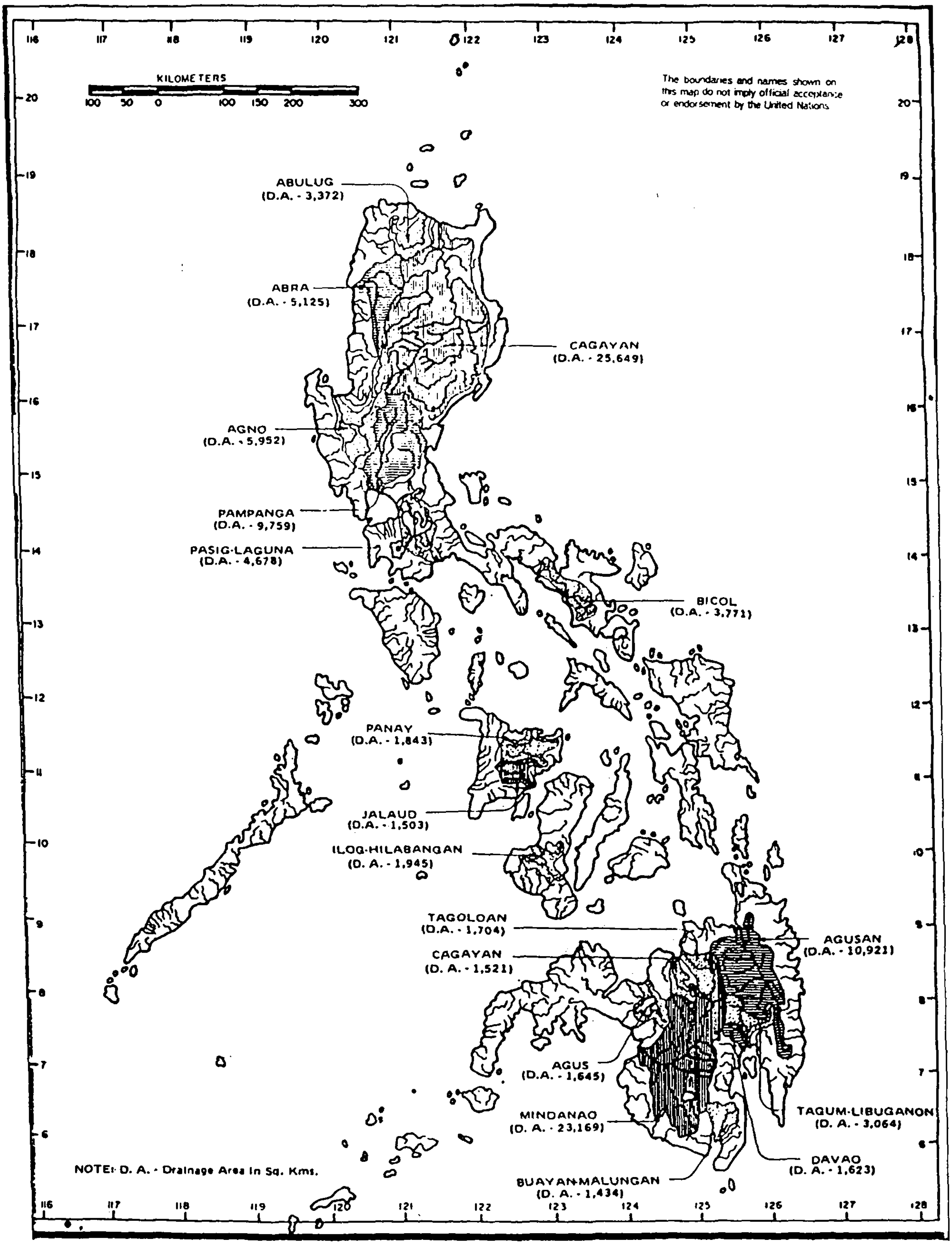

Figure 4. Major river basins in the Philippines

well as in the regulation of water utilities outside the jurisdiction of MWSS and LWUA. The principal objective of the Board is to achieve a scientific and orderly development and management of all water resources of the Philippines, consistent with the principles of optimum utilization, conservation and protection to meet present and future needs.

In line with its regulatory and executory functions, the NWRB is vested with the task of reviewing and approving the water resources development plans and programmes of any agency to determine: if such plans and programmes are within the context of the overall national plans and programmes; if due consideration was given to all water resources problems in the project area; if the planning of the project was co-ordinated with other agencies involved in water resources; and if it is compatible with the basin plan and with basin needs and resources in the event that no basin plan has been evolved.

One of the other significant function of the Board is to advise and apprise the National Economic and Development Authority (NEDA) on matters pertaining to water resources development plans and programmes. The NEDA Board, which is chaired by the President of the Philippines, is responsible for co-ordinating the formulation of continuing and integrated socio-economic development plans, policies, programmes and projects of all sectors of society. This includes the formulation of annual and medium-term public investment programmes, programming of official development assistance in the forms of grants, concessional loans from foreign governments and multilateral agencies and organizations, and the monitoring and evaluation of plan implementation.

C. EXPERIENCES IN THE PREPARATION OF WATER PLANS

The Philippines has had quite a number of experiences in the preparation of water resources development plans dating back to the early 1960's. These are usually in the form of water resources surveys, comprehensive basin feasibility studies, basin framework planning studies, basin master plan studies as well as sectoral master plans. Some of the significant studies worth mentioning and already completed are: The Water Resources Survey, Investigation and Studies for the seven major river basins in the Philippines by the United States Bureau of Reclamation for the Philippine Government and the United States Agency for International Development (USAID); the water resources development studies for the Laguna Lake basin of the Laguna Lake Development Authority (LLDA); the framework planning studies of the NWRB; the master plan study for the Cagayan River Basin done by the Japanese International Co-operation Agency (JICA) for DPWH; and the Water Supply, Sewerage and Sanitation Master Plan of the Philippines 1988-2000.

Aside from these, there are other master planning studies, some of which have either just started or are being proposed.

1. Water resources survey of seven major river basins

Due to the serious flood losses in Central Luzon in 1960 the Philippine Government's attention was focused on the urgent need of the country for flood control, water supply for irrigation and domestic use, hydroelectric power generation and other related functions of water resources development. With the assistance of USAID, a pilot survey of the basic action programme was conducted in 1961; it concluded that if the fullest utilization is to be achieved by the Philippine Government, a comprehensive study of the water resources of each of the seven major river basins – which include Pampanga, Agno, Bicol, Cagayan, Cotabato-Agus, Jalaur and Ilog-Hilabangan river basins – should be made by the Philippine Government and that it should have the benefit of outside guidance in the technical aspects of overall planning for development of water resources of the basins.

A water resources survey team from the Bureau of Reclamation was sent to the country from 1963 to 1966 to assist the Philippine Government to undertake surveys, investigations and studies with the end view of formulating a comprehensive programme for multipurpose river basin development. The objective is the creation of unified river basin plans to serve as a co-ordinating guide for Philippine government agencies charged with the planning and execution of various categories of water resources projects.

The output of the study consisted of various reports which set out in detail the land and water resources of the river basin and described the physical characteristics of the basin in terms of resources development potential.

The plan of development is essentially one of regulation of the basin streams and rivers found to be physically and economically favorable to development. Based on the investigation and analyses it was concluded that the elements of the basin plan had merit and that detailed studies should be undertaken to prove their engineering and economic feasibility.

Not long after, as a follow-up to these studies, feasibility investigations were conducted on the various dams identified and to date some of the recommendations are now operational like the Pantabangan Dam.

2. Comprehensive water resources development studies for Laguna Lake

Laguna Lake or Laguna de Bay, is the largest lake in the Philippines and perhaps one of the largest in Southeast Asia with a surface area of 900 km² and drainage area of about 4,000 km² (figure 6). It is quite shallow, having an average depth of 2.8 meters. It is also a critical area for development in the Philippines, being located very near the capital city and it is probably the most studied lake basin in the Philippines.

The Laguna Lake Development Authority (LLDA), which has exclusive jurisdiction over the development of the lake region, together with international consultants provided by agencies such as the United Nations Development Programme (UNDP), USAID, the World Health Organization (WHO) and the Asian Development Bank (ADB), have undertaken or collaborated in studies focusing on identification of the major potential uses of the resources of the Laguna Lake Region and the definition of the constraints and means of their development. Such studies include:

(a) **Feasibility survey for the control of Laguna de Bay hydraulic complex and related development (1967-1970) – T. Ingledow & Assoc. Ltd**

The recommendations/findings were:

(i) The Marikina dam is not economically feasible as there are unresolved doubts about the dam foundation and tightness of reservoir.

(ii) The Mangahan floodway will free all parts of Manila and suburban area downstream of it from flooding and is recommended.

(iii) A hydraulic control structure and navigation lock across the Napindan River should be constructed to prevent the influx of salt water and to control outflows from the lake.

(iv) Laguna Lake should be used as a source of water supply for Metro Manila following the year 1979.

(v) The Paranaque spillway is not economically feasible and is not recommended.

(b) **Irrigated agricultural development for lands surrounding Laguna Lake (1971-74) – Hydrotechnic Corp., New York**

The consultant recommended a programme of irrigated agricultural development of about 18,315 hectares of available agricultural land which would increase crop production from 1.6 to 2.6 crops per year.

The study reiterated the recommendation of previous studies on the urgent need for the construction of the

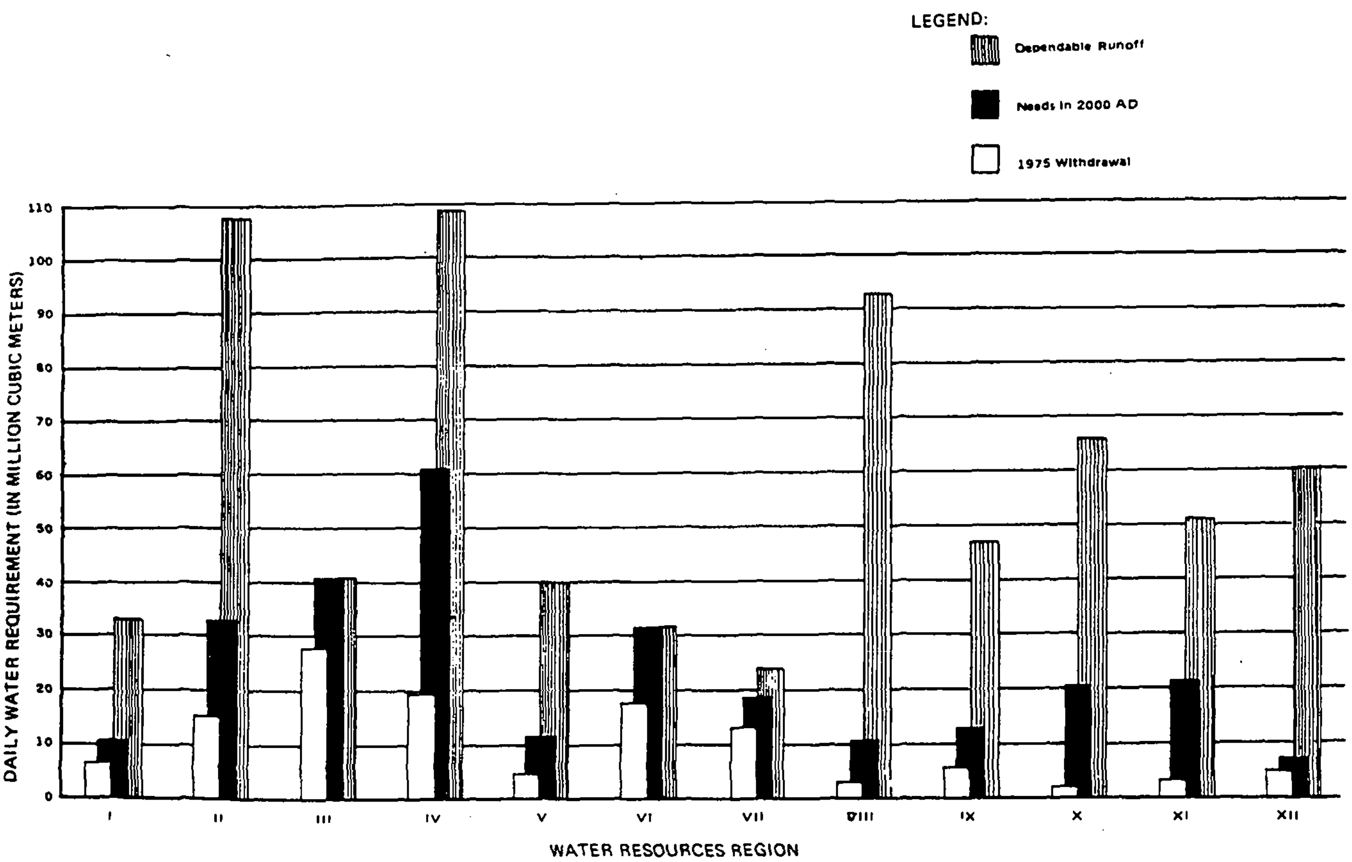

Figure 5. Regional water picture of the Philippines

hydraulic control structure as the first major step towards halting the progressive deterioration of the environmental quality of the lake and its surroundings. The construction and operation of the hydraulic control structure are essential to the success of the irrigation programme as it would permit availability of fresh water year round.

(c) Laguna de Bay water resources study (1972-74) – Sogreah, France

This is a follow-up study to the T. Ingledow studies to ascertain more accurately the feasibility of the various developments recommended by the previous study which are dependent on fresh water. The water quality aspects were given emphasis because of the possibility of using the lake for water supply for Metro Manila, irrigation and fishing. The consultants came up with the following recommendations:

(i) The hydraulic control structure is the key to the development of Laguna de Bay water resources and immediate construction is recommended.

(ii) The Mangahan floodway permits complete protection of Greater Manila area against Pasig and Marikina River overflows and immediate construction is strongly recommended.

(iii) The Paranaque spillway is not economically feasible and is not recommended.

(iv) An alternative to the Paranaque spillway is a sluiceway in the Mangahan flooding diversion weir.

(v) A study of regional interceptors for the west shore of the lake and east Marikina area and their construction if found feasible.

(d) Comprehensive water quality management, Laguna de Bay (1975-1978)

Two of the key elements of the project were:

(i) Monitoring of the water quality of the lake and its tributaries and the waste discharges from various sources;

(ii) Limnological investigations of the process of entroplication including the delineation of the algal growth limiting factors.

The consultant's recommendations include:

(a) Continuation of water quality monitoring to provide a basis for water quality management operations.

(b) Continuation of pollution assessment as the basis to evaluate the adequacy of the various pollution-reduction measures.

(c) Implementation of pollution reduction measures with emphasis on the construction of regional interceptor sewers which are considered to be the key factor in the water quality management of the lake.

It should be noted that up to now the common recommendations such as a hydraulic control structure, the Mangahan floodway including a sluiceway to allow back-flow to the Marikina River and as alternative to the Paranaque, as well as irrigation programmes around the lake have been implemented. The regional interceptor sewers have also been pursued up to feasibility studies.

The proposed Marikina dam was also re-studied and found feasible but was not pursued further for one reason or another. Due to the flooding in the Marikina River and Laguna Lake coastal areas in October 1988, there were suggestions to re-study the feasibility of the Paranaque spillway. The Government has also initiated the preparation of a proposal to prepare a master plan for the Laguna Lake basin in view of the pressure brought about by competing uses of its resources.

3. Framework planning studies

These studies formed part of the UNDP country programme for 1978-1981 subsumed under the UNDP assistance in general and regional development. It has for its basic objectives the promotion of planned and co-ordinated development of the water resources sector by strengthening the capabilities of NWRB in the discharge of its regulatory, advisory, planning and co-ordinating functions.

To enhance the co-ordinated development as well as to have manageable units for planning in the sector, the then NWRC divided the country into 12 water resources regions. Based on this regionalization, the council initiated the formulation of the regional water resources framework plans using the river basin concept of development.

Regional framework studies were undertaken by the NWRB from 1976 to provide an in-depth analysis of existing water and related land resources problems in the country's 12 water resources regions, and to guide future and equitable development among regions by identifying major water and related problems and suggesting appropriate solutions as well as showing all resource potential of each region. The study was completed in 1982 with the completion of the 54 regional and basin framework studies covering the 12 water resources regions of the country.

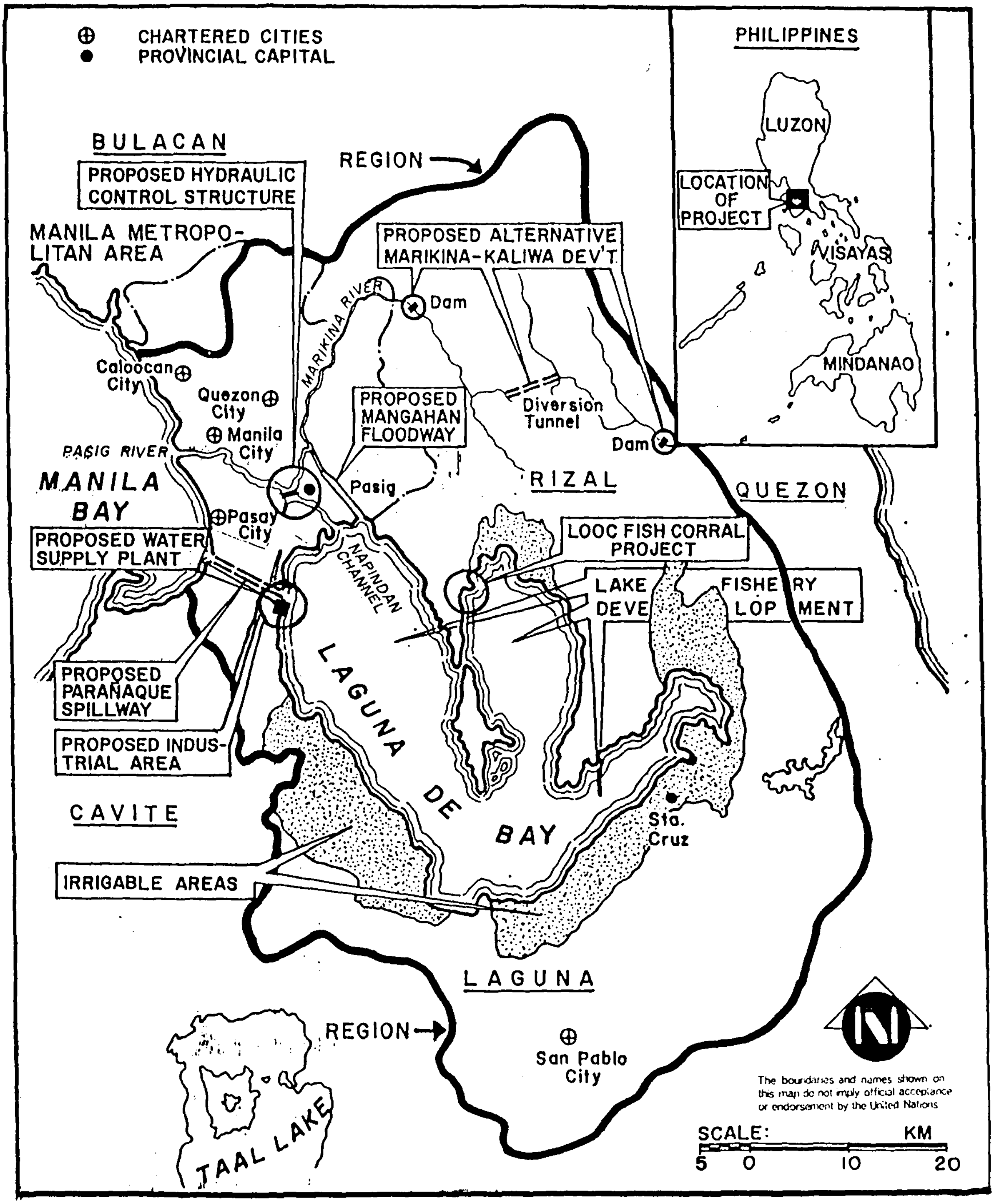

Figure 6. Laguna Lake Development Authority: region and main locations

Some major aspects of the study in terms of its over-all specific value are:

(a) The framework studies provide a rather indicative plan of development for land and water resources. They do not examine the feasibility of the development required but rather they identify demand requirement subject to pre-defined objectives and over-all potentials of development, mainly with respect to water and land. Hence they do not propose a specific development plan selected from the family of feasible alternatives. Their value is in their comparative analysis and the preferential ranking and subregions and of issues to be solved without a subregion. No project identification has been attempted and no benefit-cost analysis has been done. This is in line with the task of NWRB as a co-ordinating agency rather than an implementing one.

(b) The socio-economic, physical and engineering data have been compiled from secondary data sources. There are data deficiencies in terms of availability and/or quality but the objectives of the framework planning effort was to identify these deficiencies and to try and compile the relevant available data in a most consistent manner. The data in aggregate form are of value for reference for further detailed analysis.

(c) The framework plans, while not resulting in a definite single optimal development plan, provide a most valuable assessment of the needs and potentials in the field of water and related land resources.

It is worthwhile mentioning that the framework plans of the NWRB are in great demand by consultants and government agencies involved in water resources development of the country as a reference guide.

4. Master plan study on the Cagayan River basin water resources development (1985-1987) – JICA

In response to the request of the Philippine Government, the Japanese Government decided to conduct a master plan study of the Cagayan River basin through the Japanese International Co-operation Agency (JICA). This master plan is intended as a guide for the Government in the implementation of water resources development in the region, in line with the nation's socio-economic development objectives.

The Cagayan River basin covers an area of 27,300 km^2 and is located in northern Luzon, Philippines. In the course of the study, the NWRB framework plans were utilized as one of the references by the consultants.

The recommended master plan, with a target period of 20 years, consists of the various proposed schemes for flood control, agricultural development and hydropower development. Several multipurpose dams and single purpose dams are also proposed to meet anticipated water demands that will be brought about by the proposed development.

Costings of the various schemes and the schedule of implementation were included. Also, a short-term plan consisting of schemes proposed for implementation within 10 years was also included.

5. Water supply, sewerage and sanitation master plan of the Philippines, 1988-2000

The master plan is the result of an extensive interagency undertaking involving among others the various water agencies such as the Department of Public Works and Highways, the Department of Health, the Department of Local Government, the National Economic and Development Authority, the Metropolitan Waterworks and Sewerage System, the Local Waterworks and Utilities Administration and the National Water Resources Board.

It was conducted as a positive response to the United Nations declaration of the 1980s as the International Drinking Water Supply and Sanitation Decade for which the world body called on all nations of the world to give more attention and effort to the provision of adequate drinking water supply and sanitation services to the people.

The plan seeks to set the framework and agenda for concerted action by government policy makers and programme implementors, at all levels, in the execution of management of water supply, sewerage and sanitation projects nationwide. It is also intended to serve as a guiding reference for the private sector and non-governmental organizations, both local and foreign, which might be involved in the development of the sector.

D. PROBLEMS ENCOUNTERED IN THE PREPARATION OF WATER PLANS

The major problem encountered in such a planning exercise is on the availability of data and even if these are available, problems arise as to the accuracy, reliability, timing and coverage. There is also the need for disaggregation from the national or regional level to the provincial or basin level.

Another problem is the lack of consultation during the planning process with the people to be affected by proposed development in the basin. Problems will most likely arise during project implementation and operation.

E. CONCLUSIONS

While it is true that most of the principal basins of the country have been studied to various degrees of detail, there is still the need to consolidate, evaluate and integrate all these studies and plans into one national master water plan which will address the need to rationalize, integrate and co-ordinate the development of water resources in the country, in order to achieve the objectives of economic and social development. A move in this direction has already been initiated by the National Water Resources Board and is being reviewed by higher authorities.

IV. REPUBLIC OF KOREA: THE HAN RIVER PROJECT – A SUCCESSFUL URBAN RIVER DEVELOPMENT PROJECT

A. INTRODUCTION

The Han River flows through the metropolitan area of Seoul, the political, economic, social and cultural centre of the Republic of Korea as well as its capital city for 600 years, The Han River basin includes a basin area of 26,218 km^2 , about 27 per cent of the national area, and 12 million people, about 30 per cent of the national population. The gross product in the Han River basin exceeds 40 per cent of the gross national product.

The Han River has very important roles. It is a source of water supply, irrigation and hydroelectric power to the citizens of Seoul and people living in the basin. Besides this tangible importance, the Han River provides the citizens with such benefits as a scenic environment, pollution mitigation, climate self-regulation, recreational and athletic space. To maximize these benefits without any major damage to the natural environment, the Han River development project has had very distinct objectives. They are to:

- Improve the urban environment along the Han River in the Seoul metropolitan area to prepare for the 1986 Asian Games and 1988 Olympic Games;
- Create a new rest area for citizens escaping from the stress of urban life;
- Provide recreational space for the public;
- Facilitate the original function of the Han River and to develop the Han River as a potential economic resource;
- Provide a stable water supply and safe flood control, and to expand riverside highways in order to alleviate urban traffic problems.

B. OUTLINE OF THE HAN RIVER BASIN

1. General description of the Han River basin

The Han River basin is located in the centre of the Korean peninsula (figure 7) with a basin area of 26,219 km^2. The river, at 470 km long, is the longest in South Korea. The average width of the basin is 56 km, and its shape is classified as a multiple type mixed with dentritic and fanshape, with a shape coefficient of 0.12. The river is basically composed of two major branches, i.e., the Pukhan River which originates from the Danbal Pass in North Korea, and the Namhan River which originates from the Odae Mountain in the east.

These two major branches of the river merge just upstream of the Paldang Dam, 30 km east of Seout and pass through the Seoul metropolitan area. The river merges with the Imjin River at Tanhyeon, 40 km north-west of Seoul and finally flows into the Yellow Sea.

2. Characteristics of the project area

(a) Natural environment

The project was implemented along the Han River over a 36 km span from the Haengju Bridge in the west to the Amsa-dong in the east. A plan view of the area included in the project is shown in figure 8.

The area of the project is mostly composed of low hills along the river. Elevation of the area along the river varies from 10 to 100 metres. Major geological components of the area are alluvium of the quaternary. This alluvium is mainly composed of silts, sands and gravels. In general, gravels and sands are common upstream while silts are more common downstream where tidal currents reach.

The climate of the project area is temperate with four distinct seasons. The average monthly temperatures and precipitation in the area are shown in table 1.

By Mr. Byung Ha Scoh, Director, Water Resources Engineering Division, Korea Institute of Construction Technology, Republic of Korea.

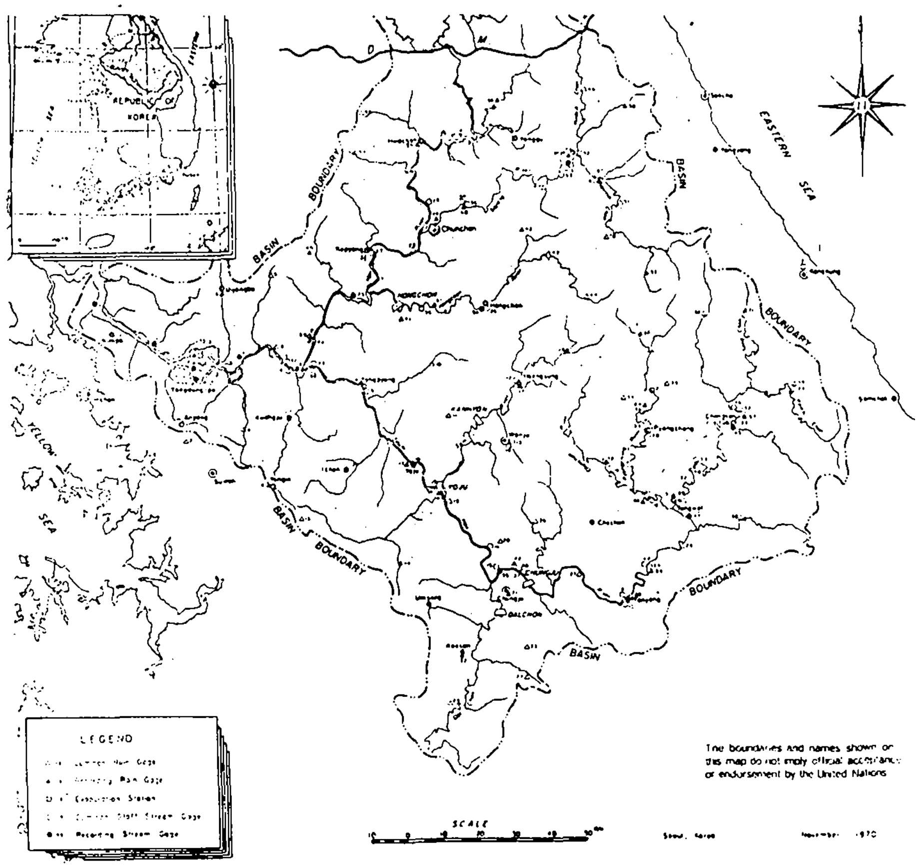

Figure 7. Han River basin

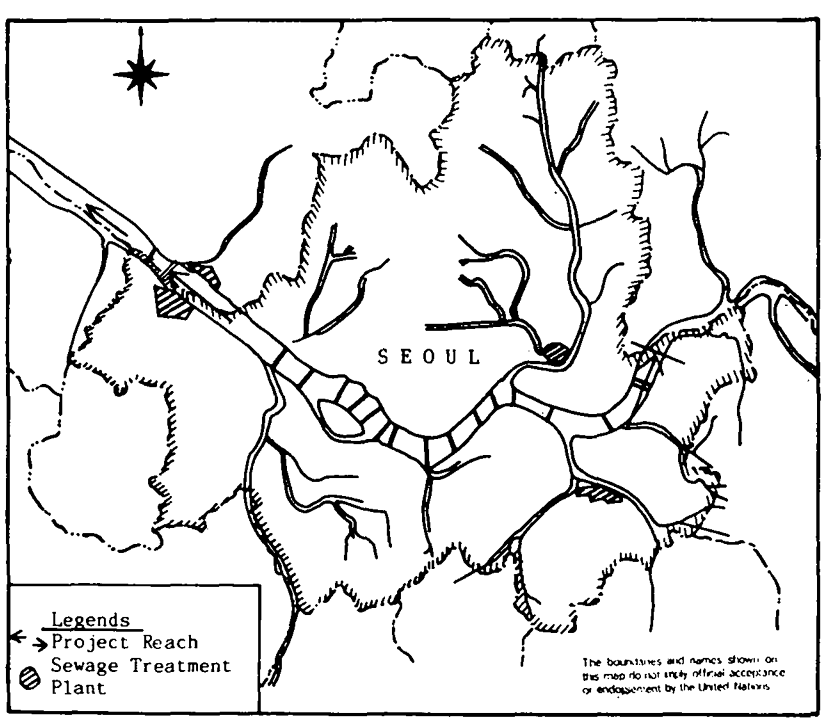

Figure 8. A plan view of the project reach along the Han River

Average monthly temperature and precipitation in the project area

Month	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Average temperature (°C)	−1.9	−1.7	4.2	11.5	16.0	21.1	24.2	22.3	20.4	14.3	6.8	−0.4
Average precipitation (mm)	23	24	40	110	94	115	270	291	97	33	39	25

(1971-1980).

(b) Social and cultural environment

The population within the area of this project was about 1,624,000 in 1980, which was about 19 per cent of total population in Seoul (population: 8,307,000). The population density is slightly larger than the average population density of Seoul (129 persons/ha) in 1980. Wards with especially large population density include Dongjak-Gu (Ward), Kangdong-Gu, whose population density exceeds 200 persons/ha.

The population distribution within the area of the project is as follows: The Kangnam District (southern shore) includes 901,000 persons, 55.5 per cent of the total population of the project area, while the Kangbuk District (northern shore) includes 723,000 persons, 44.5 per cent of the total population.

Natural changes due to frequent floods, the meandering process, and other geological changes within the area have occurred continuously. Manmade changes, however, have been accelerated since the 1960s by changes in land use along the river due to rapid industrialization and urbanization. Of the total area of 80 km^2, land use in the early 1980s was as follows: 55 km^2 for dwelling; 5.4 km^2 for business; 3 km^2 for industry; and 17 km^2 for parks. The total urbanized area is about 53 km^2 or 67 per cent of the total project area.

The total area of public parks in Seoul is 27 km^2 including amusement parks, which corresponds to 2.9 m^2/person. However, the total area of full-scale parks is merely 4.5 km^2 or 0.5 m^2/person. The Han River project can eliminate this shortage of park space and provide a large open space which is easily accessible to citizens.

Since the Han River flows through the metropolitan Seoul area roughly from east to west, riverside highways both on the north and south shores are a major means of east-west transportation. The function of these highways as a major east-west transportation route, however, has reduced rapidly because of rapid increase in urban traffic volume. One of the major objectives of this project, therefore, was to provide eight-lane highways along the south shore in order to accommodate increasing traffic volume.

The metropolitan Seoul area is the centre of national industry as well as commerce. In 1980, the gross national product (GNP) of the metropolitan area exceeded 30 per cent of the total GNP. The leading industry of the metropolitan Seoul area is service, including Social Overhead Capital which exceeds 70 per cent of the total product, while mining and manufacturing industries share 29 per cent and agriculture and forestry share only 1 per cent.

C. MAJOR PROJECTS

The project formally commenced in September 1982 after two years of feasibility study including river-modelling tests and environment impact analysis. The project was completed in September 1986 after four years of construction. Total cost exceeded roughly $US 500 million. The project included six major sub-projects as follows:

1. River straightening and river bed levelling.
2. Riverside land reclamation.
3. Riverside highway construction.
4. Underground sewage network.
5. Utilization of river surface.
6. Environmental preservation.

Each sub-project above is described in detail below.

1. Riverbed levelling

The bed of the Han River from Amsa-dong (east) to the Haengju Bridge (west), a total span of 36 km^2, was levelled to maintain average depth of the river at 2.5 metres and width between 725 and 1,175 metres. The main purpose of this riverbed levelling project was to improve the function of flood control and the living environment in Seoul by turning the river into a great water park and maximizing the utilization of the river as a water surface transportation route. This project was accompanied by subsidiary works to repair or strengthen bridge piers, and to build underwater embankments to maintain an even water level. Works to straighten the uneven riverside and fortify the riverbanks were also undertaken along with the riverbed levelling projects. Sand and gravel collected in the course of this riverbed levelling project was used in the associated construction project.

2. Riverside lands

The Han River Development Project included works to level the deserted wasteland on both sides of the river and convert it into riverside parks where citizens could enjoy sports and other recreational and leisure activities. Nine sports parks and 77 convenient facilities, including driveways and underpasses which facilitate citizens' access to the river, were built on the riverside lands covering an area of more than 6.9 million square metres. Also included in the project was a plan to create riverside resorts with a combined area of 880,000 square metres in the Kwangnaru and Ttuksom areas.

A riverside meadow with an area of more than 3.8 million square metres was also formed as a result of the project. This meadow serves as a fishing site and a classroom where citizens can improve their knowledge of nature by observing migratory birds and fish. A huge parking lot with an area of 130,000 square metres was built in the Chamsil area, along with an 84.6 km-long cycling course and an 8.4 km-long promenade.

3. Olympic Highway

The Olympic Highway is an intra-city expressway linking the east and west of Seoul. It also serves as an exclusive autobahn for sightseeing. Foreign tourists visiting Seoul to see the 1986 Asian Games and the 1988 Summer Olympics could drive non-stop from Kimpo International Airport to the Olympic main stadium in Chamsil along the Olympic Highway, enjoying the beautiful scenery along the riverside.

To build the highway, the existing four-lane autobahn running along the southern bank of the Han River was expanded to an eight-lane autobahn and a new four-lane autobahn was built to cover the 26 km between Amsa-dong and the Yomchang Bridge. A new bank was built for the new four-lane autobahn covering the 10 km between the Yanghwa Bridge and the Haengju Bridge.

This Olympic Highway construction project was accompanied by works to build five new bridges over the Han River, including the 2,070 metre-long Noryang Bridge, which runs parallel to the Han River, erect six new interchanges, and repair five other interchanges.

4. Underground drainage network

The major cause of pollution in the Han River had been the inflow of sewage and waste from residential areas and industrial facilities in metropolitan Seoul. The huge underground drainage network at present intakes only debris and wastes and carries them to the sewage treatment plants, providing a fundamental solution to the Han River pollution. With the existence of the underground drainage system, the revival of the polluted Han River has become a matter of time.

5. Utilization of river surface

The Han River development project has converted the river's water surface into a paradise of water sport activities. Tourist ships opened regular services on a 21 km-long course between Chamsil and the Haengju Bridge. People can now enjoy boating, water skiing, yachting and swimming. These sports and recreational facilities not only contribute a great deal to the health of the citizens of Seoul but are also added tourist attractions.

6. Environmental preservation

The Han River development project was carried out in such a way as to perfectly preserve the natural surroundings. Bamsum, near Yoido Island, has become a bird preservation site for migratory birds. Additionally, an artificial islet and stream were built on the Banpo riverside so that citizens could study nature there. The river banks were fortified with porous concrete blocks to facilitate the habitation of fish.

D. PROJECT BENEFITS

As a result of the project, direct and indirect, tangible and intangible benefits have been produced. For example, clean and wholesome urban living space was secured. With the new eight-lane Olympic Highway, traffic congestion in the centre of the city has been greatly eased. The integrated sewage system contributes greatly to the improvement of water quality and preservation of the ecosystem. In summary, direct and indirect benefits from the project are as follows:

Direct benefits –

- Flood control;
- Gravel collection and sales;
- Energy saving;

Indirect benefits –

- Water quality improvement;

- Open space for recreation and sports;
- Eased traffic congestion;
- Navigation and water sports;
- Scenic view of urban riverside.

E. FUTURE PLAN

To maximize benefits from the Han River project, the project will be extended beyond the boundary of the metropolitan Seoul area to upstream of the Han River.

The future plan for the Han River project includes the following:

(1) River navigation between Seoul and Danyang (200 km upstream).

(2) Canal construction between downstream of the Han River (Seoul) and west coast (Inchon) – about 10 km.

(3) Barrage downstream of the Han River.

(4) Integrated urban water management for the metropolitan Seoul area.

A feasibility study of navigation between Seoul and upstream of the Han River, a total river reach of 200 km, was recently completed with positive results. A feasibility study of the canal and barrage projects will be conducted in the near future. Research on integrated urban water management for the metropolitan Seoul area is pending.

F. CONCLUSION

The Han River project was successful. Direct and indirect benefits from the project have been enormous. No major negative results from the project have been revealed yet.

A few minor problems include local riverbed scours and depositions, which had been expected, and minor entrophication due to impoundment of water. Locally, the changed riverbed is regularly levelled by filling and dredging. Entrophication in the dry winter season when river discharge is small is eased by regularly releasing a large quantity of water from an upstream reservoir.

No major flood has passed through the project reach since the completion of the project. Riverbed changes to a larger extent are expected when a big flood passes through the reach. Monitoring the project reach and a continuous survey of possible problems that may occur in the project area, therefore, are important.

V. SRI LANKA: SOME EXPERIENCES AND PROBLEMS ENCOUNTERED IN PREPARING WATER PLANS

A. INTRODUCTION

Sri Lanka with a land area of 65,000 km^2 can be divided into 103 component natural river basins and another 94 small coastal basins. Some of the river basins are very small. The hydrographic pattern is generally governed by the relief, and with the hills in the centre of the island a radial pattern of rivers is in existance. The Mahaweli is the largest river draining 10,500 km^2.

The monsoon rains, mostly dependent on prevailing winds (the south-west monsoon from May to September, and the north-east monsoon, from December to February), bring an average annual rainfall varying from below 1,000 mm to 5,000 mm in places. A significant feature of the climatological characteristics is the possibility of identifying a "dry zone" and "wet zone" with their boundaries along the 1,900 mm isohyet. The monsoons correspond to the cultivation seasons, basically for paddy, the *yala* and *maha*.

Sri Lanka has a fairly well conceived hydrological information system which includes over 700 daily read rainfall stations, with records for over 100 years at some of them. There are over 100 stream-gauging stations, which have records for periods of about 40 years. The available network is considered sufficient for planning purposes and for gathering information for project formulation. Some information on ground-water potential is available.

Sufficient information is also available on soils and land classes for purposes of land-use planning. So, it can be stated without much reservation that Sri Lanka has a good data base for water resources development. But what about the planning process itself?

It may be appropriate to mention here that recent trends illustrate that the precipitation and rainfall intensities have declined in recent times. This is subject to further analysis before establishing it as a confirmed fact. However, it could influence the present thinking and planning process to some degree on the use of water resources in future projections.

In discussing the experiences and problems involved in the preparation of water plans, it is necessary to examine the trends of development in water resources and the socio-economic setting at each stage in the island's history.

Sri Lanka has a long history of association with irrigation. An ancient hydraulic divilization existed well over 2,500 years ago. The ancients developed an irrigation system that grew in size and complexity to sustain a large population in the past in the dry zone areas of the island. This system had technical features which are noteworthy today, even by modern standards. But the system fell into disuse after the twelfth century. However, by the turn of the last century the rulers of the day who recognized the potential that lay in the remains of the system commenced restoring some parts of it. By the middle of this century, most of these works were recommissioned and, with the emphasis laid on food production and alleviating the poverty of the peasantry and farmer population, settlement schemes were opened up under irrigated agriculture. Thus by the middle of this century water resources had been developed to a substantial standard based on the ancient pattern. The designs of these works were primarily for one season of paddy cultivation only. The average size of each farmer family holding was either one ha or two ha of wetland paddy and a smaller highland allotment.

New and multipurpose projects, such as the Gal Oya Development, Walawe and Mahaweli schemes were undertaken in the second half of this century as the demand for development of water resources grew with increases in population.

A special feature in the water resources development of the country is the existance of a large number of minor irrigation works, estimated to be around 25,000. Each of these serve an area of generally less then 80 ha. Most of them are in working condition after being rehabilitated and they serve the local farming population. Therefore, any water plan has to necessarily take into consideration the existence of these irrigation works as a project or river basin plan has to accomodate or modify them and embrace the present users. This sometimes raises issues such as size of holding and incorporating the lands and facilities into a main system or network.

B. FACTORS AFFECTING WATER PLANS

When looking at the Sri Lankan experience, a noteworthy factor that has influenced the planning process is the late realization of the fact that water is either a resource,

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or is becoming a limited commodity. The past trend has been to take water availability for granted. It was considered sufficient to design earlier projects for one season of paddy only. Sometimes the availability of water was over-estimated, leading to the modification or augmentation of these works with other sources at later stages. The increase in demand for land and water together with the increases in population has led to the realization of the need to maximize the returns from each unit quantity of water delivered to the farm. This understanding which is now a basis for future planning was rather late to take root. Strict water management practices are therefore of more recent origin.

The settlement schemes under irrigation now support a larger population than when they were first commissioned. Some of them are 30-40 years old and the problems of the second and third generations, the off-spring of the original settlers, are a growing concern. Consequently, a multiplicity of issues concerning land and water have been raised, including tenancy problems and fragmentation. This process has led to encroachment on reservations, excess cultivation and overloading the delivery system, and added demands for water. Rehabilitation plans for such older schemes have to therefore take into account this social background and the strains on the physical system.

Another feature which is inter-related to other socio-economic issues is the emphasis now laid on increasing productivity through the existing irrigation infrastructure, by increasing irrigation and overall efficiency in contrast with new investments or new works. There is a certain "shyness" in the planning process over venturing deeper into even promising new projects because of this attitude. Projects which indicate low economic returns at current price levels are pushed back at the planning stage either to give way for another competing project in another sector, or to lay greater emphasis on rehabilitating older schemes with lesser capital investment for greater productivity. This approach to some degree affects the forward march in preparing comprehensive master plans for water.

This same question, the financial limitation and financial capabilities preventing even plans from proceeding further, gives rise to another situation for a different approach to emerge. As there are long waiting lists of identified projects competing with each other to be processed, and being kept on stand-by rather than going in for a comprehensive master plan, ad-hoc plans which appear attractive at times receive greater attention and popular support. Examples can be sited from the food-drive strategies and labour intensive items selected in the last decade. This necessity is well understood according to each situation.

C. PLANNING APPROACH

In the earlier phase, an examination of the water potential of river basins in Sri Lanka has identified a general basic plan for each of the basins, which include possible reservoir sites and land capabilities, using available limited data. More specific plans for each basin or individual project selection, and assigning of priority for a full feasibility study, had to suit the socio-political and investment decisions at each stage. They were governed or influenced by financial availability and the willingness of agencies prepared to render technical assistance and/or financial support.

Under this approach, although a master plan has not emerged for the entire country yet, river basin plans have been prepared for selected larger rivers. The Mahaweli Master Plan, which is the largest of them all and which has been subsequently implemented, covers a major part of the country and a large share of arable land and total available hydropower potential. Similar plans have been identified for other rivers and zones such as the south-east dry zone, and the south-west wet zone rivers.

The survey carried out by UNDP on the Mahaweli River (early 1960s) concluded that it would be possible to provide irrigation for 360,000 ha of land by regulating and storing the water of this river, (7,350 MCM million m^3 per year). In addition hydro-power potential was estimated at about 460 MW of installed generating capacity.

One could even argue that although a master water plan has not emerged for the whole country, yet the objectives of having such a plan have been achieved to some degree.

The economic aspects of the issues, in terms of the overall development strategies, show that main emphasis for a considerable length of time were on:

(a) The short-run achievement of more effective utilization of irrigated land for the immediate future;

(b) Well-planned and selected new multi-purpose projects for the long run.

This approach, designed to increase the economic rate of growth and improve the overall situation of the economy as a whole, requires selected projects with related components which yield high returns on capital and which are feasible from wider angles such as manpower, employment training and skills etc.

D. ISSUES AND PROBLEMS OF PLANNING A LEGAL FRAMEWORK

The water laws in Sri Lanka have been developed over time to accommodate needs as they arose. Available legislation which has been enacted on this basis, such as the Irrigation Ordinance, Agrarian Services Law etc, deals with particular aspects only and an "Umbrella Law" covering the water resources in the country does not exist. There had been some thinking on the legal framework that should be in existance to consolidate all aspects of water resources. Some draft legislation to encompass all the resources, uses etc, had been contemplated and is in the process of being prepared. This is also related to the national water policies and with the present devolution of powers to the provinces further legislation in this regard on allocations could be desirable.

It has been already stated that Sri Lanka's experience had been to go in for short-term plans and long-term individual projects. One reason for this development has been the changing functions of the ministries involved in agriculture, lands, irrigation, power etc. With such changes in function, emphasis tends to shift and consistancy in thinking in one direction could digress.

An example could be cited on the establishment of a Water Resources Board in 1960. The original objectives and aims in setting up this organization included, among other things, the objective of acting in an advisory capacity and in preparing comprehensive integrated plans for conservation, use, control and development of water resources in the country and formulation of national policies on allocation etc. The function of this body subsequently changed and was at one time limited to ground water exploration and an implementing agency for subjects such as tube wells.

It is also observed that even in planning at project levels, various alternatives and possibilities do not receive the attention due from all parties concerned as they are not adequately brought out at each stage of planning for constructive feedback. This is a problem of communication and feedback. Public discussion and views of experienced individuals and institutions are heard only at rather late stages. It is felt that planning in a subject like water resources, where the alternatives are several and wide, must necessarily tap the wider reservoir of experiences and knowledge of several individuals. Consultations are few, reflecting a shortcoming in the process and in the system. A methodology and a medium is most desirable in this area.

It is, however, appreciated that commitment and will exist for the preparation of good water plans in many quarters. They include the experts, policy makers and decision makers, political interests, public concerns, non-governmental organizations, regional interest groups, sector groups and last but not the least the recipients or beneficiaries or water users. Why do they not get together and communicate?

The frustration of competent personnel and the brain drain are also having a negative effect on such commitment. Improving communication and feedback and also job satisfaction is therefore much desirable to accelerate the planning process and prepare water plans for optimum use of resources.

The non-existance of a central mechanism for co-ordinating all water interests at the national level is also a setback. The need for an advisory panel on water resources at the national level, to advise on and look after the interests of different sectors, regions and the many uses and allocations, has also been felt for sometime.

VI. USSR: MASTER PLANS OF MULTIPURPOSE WATER USE AND CONSERVATION – PRESENT STATUS AND TRENDS

A. OBJECTIVES AND GOALS

General, basin and territorial master plans in the USSR for multipurpose water use and conservation, henceforth to be referred as the master water plan, aim at outlining major water management activities to meet the anticipated water demands of the population and economic sectors, as well as water conservation purposes and the abatement of hazardous impacts.

The general master water plan outlines the principal characteristics of the development of water management in the USSR. It presents a water management basis for the National Master Plan on the development and allocation of productive forces in the USSR, for sectoral development plans, territorial development plans, and is tightly interlinked with them.

Basin master water plans are detailed for basins of rivers and other water bodies, based on the main provisions of the general master water plan.

Territorial master water plans are formulated for economic regions of the State, Union and autonomous republics, territories and districts, based on the provisions of the general and basin master plans.

Master plans for multipurpose water use and conservation are subdivided into all-Union and republican types.

All-Union master water plans include:

- A general master plan for multipurpose water use and conservation;
- Basin master plans for water bodies, the multipurpose use and conservation of which is referred to the relevent authority in the USSR;
- Basin master water plans when a basin is situated on a territory of two or more republics, as well as when a basin is situated on a territory of one Union republic but the anticipated measures might change the water supply conditions in the areas of other republics;
- Territorial master water plans when planned measures entail changes in water supply of two or more Union republics.

The rest, basin and territorial master water plans, are referred to as plans of republican importance.

Master plans of all-Union importance are being formulated by the USSR Ministry for Land Reclamation and Water Management, with the assistance of the USSR Power Ministry as well as specialized institutions of other ministries and agencies.

The general master water plan also takes into account priority programmes for the development of scientific and technical aspects in the field of multi-objective water use and conservation.

Procedures for formulation of republican master plans are authorized by the councils of ministers of Union republics.

Long-term and annual programmes for the development of master water plans are compiled by the USSR Ministry for Land Reclamation and Water Management which considers the motions of republican councils of ministers, approves them and agrees with the State Planning Committee of the USSR (Gosplan).

All-Union master water plans are submitted to the Gosplan by the USSR Ministry of Land Reclamation and Water Management, agreed upon with the Gosstroy (USSR State Committee on Construction) and then authorized by the Gosplan. Republican master water plans submitted by republican water management agencies are authorized by the councils of ministers of Union republics or their Gosplans.

The procedures for agreement of the formulated master water plans with other ministries, agencies and organizations are set up by the Gosplan or republican councils of ministers, respectively.

The formulation of master water plans is based on the following documents:

- Government programmes and guidelines aimed at the solution of economic and social problems for a long-term period;
- A comprehensive programme of scientific and technological progress for 20 years and scientific forecasts;

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- Concepts of development and allocation of productive forces of the USSR for a planning period (prepared by the council based on productive forces studies, and scientific and research by the economy institute of the Gosplan).
- Water demands from republical ministries, agencies and councils of ministers outlined in accordance with the approved alternative of the development of sectoral and territorial master plans.

A master plan is used for preparing draft guidelines for economic and social development in the USSR, lists of authorized construction projects and lists of projects to be designed within the five-year planning period. A master plan serves as an initial data-base for conducting feasibility studies for the construction of water projects.

The measures outlined in master plans should be aimed at the rational use and conservation of water, based on advanced manufacturing technology, application of low-water and waterless processes, reduction of consumptive water losses in irrigation and water supplying systems, efficient and comprehensive use of local water supplies, streamflow regulation, interbasin water transfers, reduction of untreated wastewater disposal, alleviation of inundations and waterlogging in settlements, agricultural areas and other projects.

B. PRACTICES FOR FORMULATION OF MASTER PLANS ON MULTIPURPOSE WATER USE AND CONSERVATION

Master plans are formulated for a period of not less than 15 years. Data from the State Water Cadastre, the inventories of the USSR State Committee of Hydrometeorology and Ministry of Geology are being used in assessing surface and ground-water resources, and design characteristics of water resources development projects. Additionally, for major water projects, surveillance data have also been acquired and used.

The compilation of master water plans begins in the last year of a five-year planned period and is completed in the third year of the successive planned five-year period.

Master plans of all-Union importance are detailed in several stages.

In the first stage, during the first quarter of the first year of a five-year period, the USSR Ministry for Land Reclamation and Water Management collects information from the sectoral master plans of ministries and agencies of the USSR and from the territorial master plans on production and allocation of consumptive water uses of the republican councils of ministers.

These data comprise: water uses and consumption, disposal of wastewater by categories and pollutants discharged into water bodies, flow regimen and releases on an areal/basin basis (tentative demands).

The above are used in formulating master plans which include water requirements indicated by ministries, agencies and councils of ministers of Union republics, and updated water demands of the population and economic sectors. In the first quarter of the second year of the five-year planned period, subject to the decision of the USSR Ministry for Land Reclamation and Water Management, the revised demands for water resources are prepared. Based on those revised demands a list and terms of construction of water projects, capital costs, shares of ministries and agencies in these investments, water-use limits by ministries, agencies, Union republics, territories and districts and autonomous republics, and by water management sub-areas of 27 major river basins, are compiled. The revised draft general master plan is submitted to the Gosplan for agreement in the third quarter of the second year.

In the third, concluding stage, the final drafts of the master plans are furnished. In the third quarter of the third year of the five-year planned period, the plans are approved by the USSR Ministry for Land Reclamation and Water Management, agreed with the councils of ministers of Union republics, USSR ministries of power, health and fisheries, the State Committee on Construction (Gosstroy), and submitted to the State Planning Committee for authorization in the fourth quarter.

C. BASIC PROBLEMS

In the "Concepts" and "Guidelines for economic and social development of the USSR" water management issues should be closely interconnected with the mainframe of socio-economic development and nature conservation. The assessment of the ecological and socio-economic efficiency of planned water conservation measures has been made in the "Long-term State programme of conservation of the natural environment and rational use of natural resources of the USSR for a period up to 2005".

The conservation of natural environment is envisaged through:

- Selection of sites and delineation of boundaries for reclaimed areas; allocation of organizational, social and management undertakings;
- Application of advanced techniques for drainage, irrigation, and application of fertilizers, technology and materials, and automated control facilities;
- Measures to reduce the negative impacts of reclamation and water management on the en-

vironment (control of the groundwater table on adjacent areas, wastewater treatment, use of irrigation return water, equipment of headworks with fish-protection devices etc.);

- Preservation of valuable and unique water bodies against deterioration caused by human activities or a combination of adverse natural factors;
- Promotion of measures to improve fertility of reclaimed areas, wind and water erosion control, as well as protection of economic projects (industrial, transport, agricultural etc.) from hazardous impact of water (flood control, mud-flow control).

It should be noted that flood control measures do not always correspond with nature conservation. For instance, the construction of flood control storages implies a number of nature conservation problems.

In feasibility studies on water management the following objectives should be kept in mind:

- Improvement of the ecological feasibility compared with previous periods (extensive development and large-scale nature transformation projects).
- Optimization of water-use limits (taking into account water-saving and waste-free technologies, optimal irrigation rates etc.) and effective control over their accomplishment.
- Improvement of the methodology used to obtain relevant data on streamflow and water use.
- Elaboration of techniques for water quality forecasts in compliance with measures necessary to maintaining standard water quality of natural sources.
- Improved methods of compiling water management budgets differentiated by natural zoning and comprising both quantitative and qualitative characteristics of water.
- Development of optimization techniques for water-use allocation for various purposes, taking into consideration the technological, ecological and economic factors and their priorities in concrete conditions.

An important task is also the provision of scientific guidance and co-ordination of all works on improvement of national water-use strategy as well as the scientific background for feasibility studies.

D. CONSTRUCTION OF RECLAMATION PROJECTS

In view of the new strategy for natural resources usage, radical changes have taken place in planning for the highest water-consuming sector, irrigation (53 per cent of the total water withdrawal), and related water management activities.

The future priority trend in land reclamation is characterized by the rehabilitation/improvement of reclamation systems and the increase of fertility in irrigated areas.

Aimed at determining the scope of works to be accomplished for rehabilitation of the existing systems, an assessment of irrigated and drainage lands has been carried out, taking data from the Indicative Reclamation Inventory (1986) and the Inventory of Irrigated and Drained Lands (1987). In the assessment different characteristics were considered: the groundwater table and salinity, salinization of irrigated lands, erosion potential, degradation of the fertile layer, the water regime of drained lands, bush cover, wind erosion effects and acidity.

It is planned to update the data on the status of reclaimed lands, particularly through the broader application of remote sensing.

An analysis of the status of reclaimed lands by characteristics was used in substantiating the requirements for conducting various actions aimed at the improvement of usage and conservation of soils. The actions include construction of drainage, levelling and leaching, gypsum application, erosion control, landscape management, measures for rehabilitating deteriorated irrigation soils (potash application or other combinations containing calcium, organic fertilizers, and incorporating deep ploughing) as well as appropriate activities on drained lands. Simultaneously, the technical level of the reclamation systems has been evaluated and conclusions drawn concerning their modernization.

At present, surface irrigation is applied in the USSR on more than half of the total irrigated area. Two thirds of the area possesses unlined irrigation networks, characterized by low conveyance efficiencies, land-use factors and voluminous labour factor in irrigation, and intensive water erosion processes leading to the necessity for rehabilitation.

It was determined that 45 per cent of irrigated and 16 per cent of drainage lands required technical improvement. Hence, the bulk of the irrigated lands (80 per cent) was to be comprehensively rehabilitated (remodelling of irrigation and collector networks and related measures).

Works are envisaged in other areas:

- Construction and remodelling of collector and drainage networks (12 per cent);
- Capital levelling (4 per cent);
- Improvement of water supply (4 per cent).

The tentative scale and measures of the planned improvements in major irrigated zones of the country (central Asian basins of the Amudarya and Syrdarya rivers) for the period of 1991-2005 can be represented as follows:

– Comprehensive rehabilitation	Amudarya	1.28 million ha
of irrigation network	Syrdarya	1.52 million ha
including rehabilitation of collector	Amudarya	0.85 million ha
and drainage network	Syrdarya	0.80 million ha
– Rehabilitation of collector and drainage network on areas	Amudarya	0.52 million ha
not subject to comprehensive rehabilitation	Syrdarya	0.04 million ha

The accomplishment of these measures on a national scale will make it possible to reduce the water consumption in irrigation by almost 20 cubic km^3 a year.

Part Three

REPORT OF THE EXPERT GROUP MEETING TO REVIEW AND FINALIZE DRAFT GUIDELINES FOR THE PREPARATION OF NATIONAL MASTER WATER PLANS

Bangkok, 8-12 May 1989

I. INTRODUCTION

A water resources plan, consistent with the overall economic, social and environmental policies of a country is an important and necessary element to ensure that water resources contribute to its development objectives. The United Nations Water Conference, held at Mar del Plata, Argentina in 1977, recommended that countries should formulate master plans for river basins to provide a long-term perspective for planning, consistent with their overall economic and social policies.

As a follow-up to and implementation of the Mar del Plata Action Plan, the ESCAP secretariat in 1984 conducted a survey on the status of and prospects for water resources development at the national level. The survey indicated that a large number of countries in the region needed assistance in the formulation of a master water plan. Recognizing this urgent need, the ESCAP secretariat undertook a study and prepared a report on the preparation of national master water plans which was presented to the ESCAP Committee on Natural Resources at its twelfth session in 1985. The report describes the contents of such a plan, data requirements for its compilation, and the methodology involved in its compilation. The Committee, after consideration of the report, suggested that a manual or set of guidelines on the subject be prepared, to assist the countries in their efforts to prepare or review their national master water plans. This suggestion was subsequently endorsed by the Commission at its forty-second session in 1986.

As a direct response to the above suggestion, the ESCAP secretariat prepared a set of draft guidelines which was discussed and reviewed at the Expert Group Meeting.

II. ORGANIZATION OF THE MEETING

The Expert Group Meeting to Review and Finalize Draft Guidelines for the Preparation of National Master Water Plans was held at Bangkok from 8 to 12 May 1989.

A. ATTENDANCE

The meeting was attended by experts nominated by the Governments of China, Malaysia, the Philippines, the Republic of Korea, Sri Lanka, Thailand and the Union of Soviet Socialist Republics (see annex). The following United Nations organizations and specialized agencies were represented: Food and Agriculture Organization of the United Nations (FAO), United Nations Educational, Scientific and Cultural Organization (UNESCO), World Health Organization (WHO) and the World Bank. Representatives of the Interim Committee for Co-ordination of Investigations of the Lower Mekong River Basin and the International Training Centre for Water Resources Management (CEFIGRE) also attended the meeting.

B. OPENING OF THE MEETING

The Executive Secretary of ESCAP, in his opening statement, stressed the importance of preparing national master water plans to ensure that a country's water resources development contributed to its overall development objectives.

The ESCAP secretariat, recognizing the urgent need of countries for assistance in the formulation of their national master water plans, had prepared a set of draft guidelines for the preparation of national master plans which were before the Meeting for review and finalization.

The task of formulating guidelines that were generally applicable to all the countries and areas in the region would be a challenging one in view of the vast expanse of the ESCAP region, the large variation in the physical and geographical characteristics of countries as well as in the levels of their socio-economic development. He expressed hope and confidence that the experts would be able to finalize a set of guidelines which would be useful and beneficial to countries in the region.

Finally, he informed the Meeting that after the finalization and the adoption of the guidelines, it was planned to promote the application of the guidelines among development planners of countries through information exchange and training.

C. ELECTION OF OFFICERS

Mr. Lim Teik Keat (Malaysia) was elected Chairman, Mr. L.T. Wijesuriya (Sri Lanka), Vice-Chairman, and Mr. M.O. Baltazar (Philippines), Rapporteur.

D. ADOPTION OF THE AGENDA

The following agenda was adopted:

(a) Opening of the Meeting.

(b) Election of officers.

(c) Adoption of the agenda.

(d) Presentation and discussion of draft guidelines.

(e) Review of draft guidelines in working groups.

(f) Other matters.

(g) Adoption of the finalized guidelines and report of the Meeting.

III. PRESENTATION AND DISCUSSION OF DRAFT GUIDELINES

(Item 4 of the agenda)

Under this agenda item, the ESCAP secretariat presented document NR/NMWP/1 which contained draft guidelines for the preparation of national master water plans. Country papers regarding countries' experiences and problems in preparing water plans were then presented and statements were made by United Nations agencies and other international organizations concerning their activities to assist countries in the field of water resources planning.

A. EXPERIENCE AND PROBLEMS OF COUNTRIES IN PREPARING PLANS FOR WATER RESOURCES DEVELOPMENT

1. China

Along with the expansion of modernization, construction and also population growth, China was facing serious problems in water resources development, although enormous achievements had been made in the past 40 years. To solve the problems, which included water resources management, flood control, water supply, hydropower generation, soil erosion control, water pollution control and the existing project improvement, several activities connected with the national master water plan had been carried out:

(a) An outline of water development in China (draft);

(b) A study on the rational use, and balancing supply and requirements of water resources in China;

(c) Revision of comprehensive water planning for every major river basin;

(d) Some mass inter-basin water transfer plans, including south-to-north water transfers;

(e) Other plans at the national level.

In the light of specific conditions in China, the following characteristics should be considered on the preparation of a national master water plan in the country:

(a) The plan should be combined with the establishment and perfecting of the water resource management system;

(b) Flood control should still be an important issue in the plan;

(c) Long-term arrangements should be made on a comprehensive basis to solve the water shortage problems;

(d) The selection of measures in the near future should constitute the major demonstration activities of master water plans.

2. Malaysia

On the whole, Malaysia had abundant water resources. Nevertheless, owing to temporal and spatial variations, there was a need for its proper management if the country was to be free of water resources constraints. A national master water plan had been prepared based on an overview of water resources, current and future needs, and water problems.

Among the problems faced in preparing the master water plan were:

(a) Setting up of a data base;

(b) Obtaining long-term plans;

(c) Lack of co-ordination among water-related sectors;

(d) Federal State responsibilities;

(e) Rapid changes in the situation;

(f) Uneven distribution of supply and demand;

(g) Increased awareness of the environment.

3. The Philippines

The Philippines had abundant water resources and over a long period its development and utilization of water resources had evolved without the benefit of a broad planning framework which would consider available resource supply and existing needs.

The planning and implementation of water resources development projects and related land resources were the concern of about 42 national and regional agencies placed under 12 of the more than 20 executive departments, such that project identification and planning were often prepared to meet the targets of the concerned agency with little or no regard to the needs of others. The situation had resulted in overlapping of activities and competition for the right to develop the same water resources.

The former National Water Resources Council, currently known as the National Water Resources Board, had been established in 1974 to co-ordinate and integrate all activities related to water resources development and management, in order to achieve scientific and orderly development and management of all water resources of the Philippines consistent with the principle of utilization, conservation and protection to meet current and future needs.

The Philippines had had a variety of experiences in the preparation of water plans in the form of water resources surveys, comprehensive basin feasibility studies, basin framework planning studies as well as sectoral master plan studies. The major problems usually encountered in such studies were, first, the availability of data; even if they were available, problems might arise as to the accuracy, reliability, timing and coverage of the data; and second, the lack of consultation with the people to be affected during the planning process. Recent activities, however, indicated a move towards the solution of those problems. To further address the need to rationalize, integrate and co-ordinate the development of water resources in the country, a proposal had already been initiated by the National Water Resources Board to develop a national master water plan.

4. Republic of Korea

The Han River project for improvement of the urban environment along the river within the Seoul area had been completed in 1986 after four years of construction. The project comprised major sub-projects such as river-bed levelling, riverside land reclamation and highway construction, underground sewerage networks and environmental preservation etc.

As a result of the project, the city of Seoul had been able to secure cleaner urban living conditions and recreational space. In addition, traffic congestion in the centre of the city had been greatly eased. Water quality had also greatly improved owing to the integrated sewage system construction. To maximize benefits from the project, some plans were being investigated and formulated for the future.

No major negative impact had been observed as yet from the project, but some minor problems were expected. Those included river-bed scours and depositions; and eutrophication owing to impoundment of water etc. River-bed changes were also expected after a big flood. Measures to solve those problems in the project area should be formulated undertaking continuous surveys and studies in the future.

5. Sri Lanka

Sri Lankan water resources were mainly derived from monsoon rain. A data base was available with records over a long period on hydrological information. Recent trends indicated that precipitation had declined over the past few years.

The country had a long history of irrigation. Many ancient works had been restored for agricultural purposes in recent times. The existence of a large number of minor irrigation works was a special feature which needed to be taken into consideration in planning the development of basins.

Scarcity of water resources, influenced by the demands of increasing population, had been acknowledged recently. In the new planning approach, increasing productivity through the existing irrigation infrastructure therefore ranked as a high priority. Water management and rehabilitation programmes attempted to achieve that objective.

Rather than evolving a comprehensive master plan as a whole, individual projects had been given greater emphasis in the planning process. Investment consideration and other factors had contributed to that trend.

The change in priorities and policies had affected the progress in the formulation of a master plan; lack of co-ordination among agencies involved, and the lack of communication were some of the features affecting the planning framework.

A comprehensive water law consolidating all existing legislation was considered opportune. A central mechanism to co-ordinate and advise on all water interests was also felt desirable.

6. Thailand

Although the Government of Thailand had set up a national water board to oversee all activities relating to water resources development and planning, no concrete master plan had yet been established. However, the water resources development plans for all major river basins had been formulated and updated as necessary. Major problems relating to the development of a national master water plan included:

(a) Lack of a systematic and reliable data base, particularly insufficient long-term hydrological records, insufficient records on actual water use in irrigation projects and others, insufficient data relating to the planning process, such as potential land resources, and ineffective co-ordination among the many agencies working in the areas of water resources development;

(b) Dynamic changes in development, particularly the problems of urbanization of irrigation areas and the increase in the amount of water allocated to domestic consumption, and so on;

(c) The increased importance of environmental considerations in the development of all large-scale projects.

The above factors resulted in difficulties in the promotion of a concrete long-term national master water plan. Such difficulties were further aggravated by the lack of qualified personnel in the water sector.

7. Union of Soviet Socialist Republics

General basin and territorial master plans for multipurpose water use and conservation had been formulated, aiming at outlining major water management activities to meet the anticipated water demand of the population and economic sectors, as well as water conservation purposes and abatement of its hazardous impacts.

Master plans were formulated for a period of not less than 15 years. The compilation of master water plans started in the last year of the first five-year plan period and were completed in the third year of the successive five-year plan period.

In the "Concepts" and "Guidelines for economic and social development of the USSR", which were being developed, the water management problems should be closely interconnected with the mainframe of socio-economic development and nature conservation. In view of the new strategy of natural resources use, radical changes had taken place in planning for the sector consuming the most water – irrigation (53 per cent of the total water withdrawal) – and related water management activities.

The trend of future priorities in land reclamation was characterized by rehabilitation/improvement of reclamation systems and the increase in fertility of irrigated lands.

It was determined that 45 per cent of irrigated and 16 per cent of drainage lands required technical improvement. Hence, the bulk of the irrigation land (80 per cent) was to be comprehensively rehabilitated (remodelling of irrigation and collector networks and related measures).

In feasibility studies for water management, the following basic scientific problems were to be solved: improvement of the ecological feasibility as compared with the previous periods (extensive development and large-scale nature transformation projects); optimization of water-use limits (with the account of water-saving and waste-free technologies, optimal irrigation rates etc.,) and effective control over their accomplishment; improvement in the methodology of obtaining relevant data on streamflow and water use; elaboration of techniques for water quality forecasts in compliance with measures necessary to maintain standard water quality in natural sources; improved methods for compiling water management budgets differentiated by natural zoning, and comprising both quantitative and qualitative characteristics of water; development of optimization techniques for water-use allocation for various purposes, taking into consideration the technological, ecological and economic factors and their priorities in concrete conditions.

An important task was also the provision of scientific guidance and co-ordination of all works on improvement of national water-use strategy and scientific background for feasibility studies.

B. ACTIVITIES OF UNITED NATIONS AGENCIES AND OTHER INTERNATIONAL ORGANIZATIONS TO ASSIST COUNTRIES IN WATER RESOURCES PLANNING

1. United Nations Educational, Scientific and Cultural Organization

The representative of UNESCO gave a brief introduction to the organizational structure of UNESCO and its Regional Offices. UNESCO had been actively involved in the field of hydrology and water resources through the International Hydrological Decade and the International Hydrological Programme (IHP). The major objectives of IHP were:

(a) To develop scientific and technological bases for the rational management of water resources with respect to both quantity and quality;

(b) To intensify the study of water resources and their management in order to achieve rational development for the benefit of all mankind;

(c) To stress the necessity for research and teaching of hydrology throughout the world, to enable countries to evaluate their water resources satisfactorily and to use them to their best advantage;

(d) To find solutions to the specific water resources problems of countries in different geographical conditions and at different levels of technological and economic development.

The aims and objectives of IHP were very similar to those of the draft guidelines. Most of the substantive material of the individual chapters of the guidelines were being pursued under IHP, specifically the chapter on manpower development. Under IHP, UNESCO had a very strong programme in education and training; a separate committee was functioning.

He gave a brief explanation of the functioning of IHP, its Intergovernmental Council, formulation and implementation of activities through working groups, rapporteurs etc., the role of IHP National Committees, and some of the IHP III and IHP IV projects.

Although UNESCO had not been involved from the beginning in the preparation of the guidelines, it could provide substantial background material from its various water science activities. The representative would explore the possibility of establishing a mechanism for greater co-ordination between ESCAP and UNESCO. Reference was made to some programmes of the Regional Office of Science and Technology for South and Central Asia (ROSTSCA) and the Asian Regional Co-ordinating Committee on Hydrology (ARCCOH).

2. World Bank activities in the ESCAP region related to water resources management

The World Bank had several ongoing projects related to water resources management in the ESCAP region. The nature of those projects varied from multi-purpose dam projects (hydropower, irrigation, fisheries, water supply, etc.) and pollution control projects to low-cost rural water supply and sanitation projects. Often those projects also included components aiming to strengthen the host country capacity to develop sound integrated national water management policies.

In addition to the above normal World Bank activities (lending programmes), the Bank was also executing, on behalf of UNDP, a number of regional and global programmes related to the International Drinking Water Supply and Sanitation Decade activities.

The objectives of the project, "Water supply and sanitation sector development for Asia ", which has site offices in Dhaka, Bangladesh, were to:

(a) Improve sector planning and investment programming;

(b) Generate additional domestic and external resources for the development of the sector through the funding of studies and investment projects;

(c) Increase domestic capital savings through more cost-effective design of systems, maximum use of low-cost technologies, cost recovery and greater community participation;

(d) Strengthen sector institutions through training;

(e) Promote and support regional co-operation.

The project was currently being implemented in the following countries: Bangladesh, Burma, China, India, Indonesia, Lao People's Democratic Republic, Malaysia, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam. Activities varied from country to country, from sector studies to computer training courses in water supply management.

The UNDP-World Bank water and sanitation programme, mainly concentrating on rural areas, was promoting low-cost water supply and sanitation development through pilot and demonstration projects. The programme consisted of the following five areas of activity (a total of nine projects): water supply for low-income communities; sanitation for low-income communities; integrated resource recovery (waste management and recycling); low-cost water supply and sanitation in sector development; and project preparation, international training network for water and waste management.

The project was currently being implemented in Bangladesh, China, India, Indonesia, Pakistan, Philippines, Sri Lanka and Thailand.

3. World Health Organization

The representative of WHO stated that the organization was interested in ESCAP activities, particularly in the preparation of national master water plans, as those fitted in exactly with WHO involvement in the implementation of the International Drinking Water Supply and Sanitation Decade (1981-1990), and the integration of water supply and sanitation into national primary health care programmes, the key approach to Health for All by the Year 2000. In 1984, WHO had published guidelines for drinking water quality which were helping many countries to set their own standards within the bounds of those guidelines. The aim of the Decade was to intensify efforts to extend water supply and sanitation services to the unserved, and to improve the services of those inadequately served. To that end, WHO considered the ESCAP endeavours a significant step towards the achievement of the Decade goals.

4. International Training Centre for Water Resources Management

The representative of CEFIGRE thanked the ESCAP secretariat for inviting the Centre to participate in the Expert Group Meeting. She also expressed CEFIGRE appreciation of having the opportunity to work with experts from many countries and various organizations responsible for water development. As CEFIGRE had also been created from the Mar del Plata Conference and assigned the responsibility for manpower development for the water sector, the Centre looked forward to making further contributions to that activity.

IV. REVIEW OF DRAFT GUIDELINES IN WORKING GROUPS

(Item 5 of the agenda)

To enable an in-depth review of the draft guidelines contained in document NR/NMWP/1, the Meeting was divided into two working groups, each group reviewing specific chapters within the area of competence of its members.

In reviewing the draft guidelines, the Meeting had before it document NR/NMWP/2, which contained the comments, suggestions and contributions provided by countries and agencies to the ESCAP secretariat before the Expert Group Meeting.

The draft guidelines as reviewed and enhanced by the two working groups were then discussed, finalized and adopted at a plenary session attended by all experts.

V. OTHER MATTERS

(Item 6 of the agenda)

The Meeting put on record its appreciation to the Government of the USSR for making available to ESCAP the services of an expert in the preparation of the draft guidelines, as well as to the Governments of China, India, Malaysia, Pakistan, the Philippines, the Republic of Korea, Sri Lanka and Thailand for designating their experts who had made valuable contributions to enhancing the usefulness of the guidelines. The Meeting also expressed its appreciation of the assistance and co-operation rendered by FAO, UNESCO, WHO, the World Bank, CEFIGRE and the Mekong Secretariat in the finalization of the guidelines.

VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

Some of the main areas in which most countries faced major constraints in developing their water resources were lack of adequate and reliable data, co-ordination and institutional aspects, and assessment of water and human resources development in that sector. All those constraints could be significantly reduced or alleviated by the formulation and implementation of a national master water plan in each country.

National master water plans would ensure that water resources development plans were consistent with the overall economic, social and environmental policies of the countries concerned, and would therefore contribute to their development objectives.

B. RECOMMENDATIONS DIRECTED AT THE NATIONAL LEVEL

Those countries which had not yet formulated a national master water plan should give serious consideration to it; in that regard, the application of ESCAP guidelines for the preparation of national master water plans would be useful and beneficial.

Countries which had not yet established a central mechanism or a body for co-ordinating all water interests at the national level should consider establishing one to ensure an interdisciplinary approach to the integrated and co-ordinated development of water resources.

Countries should take necessary steps to improve the water data systems, including networks for collecting all categories of data for the planning, development and management of water resources. In that regard, computerization of water resources data was strongly recommended.

Development of human resources in the water sector should be given high priority. Greater efforts would be required in education and training of all levels of personnel. In addition to the arrangements countries had at the national level, regional co-operation would be useful in filling deficiencies in training needs. Countries which had training potential could accept trainees from other member States.

C. RECOMMENDATIONS DIRECTED AT THE REGIONAL LEVEL

The guidelines for the preparation of national master water plans should be disseminated to all countries in the region, and their comments and information on future experience should be solicited. Consideration should also be given to the organization of a workshop or seminar for the introduction of the guidelines and the promotion of their use in the countries of the region, based on such comments.

The United Nations and other international organizations should assist countries in formulating their national master water plans based on the guidelines. In that regard, consideration should be given to fielding advisory missions to interested countries to assist them in the formulation or review of their national master water plans.

It was also recommended that the current version of the guidelines for the preparation of national master water plans should be reviewed and updated from time to time in the future as new material and information on experience gained accumulated to justify such revisions.

VII. ADOPTION OF THE REPORT

The Meeting adopted its report and the revised draft guidelines at the closing session held on 12 May 1989.

Annex

LIST OF EXPERTS

CHINA

Mr. Chen Chunhuai, Vice-Director, Planning Office of South-to-North Water Transfers, Ministry of Water Resources, Beijing.

MALAYSIA

Mr. Lim Teik Keat, Chief, Water Resources Unit, Department of Drainage and Irrigation, Kuala Lumpur.

PHILIPPINES

Mr. M.O. Baltazar, Chief Water Resources Staff Officer, National Water Resources Board, Quezon City.

REPUBLIC OF KOREA

Mr. Byung Ha Seoh, Director, Water Resources Engineering Division, Korea Institute of Construction Technology, Seoul.

SRI LANKA

Mr. L.T. Wijesuriya, Senior Deputy Director, Irrigation Department, Colombo.

THAILAND

Mr. Boonyok Vadhanaphuti, Senior Expert for Water Resources Planning and Development, Royal Irrigation Department, Bangkok.

Mr. Ritthirong Jaiyasin, Chief of Water Resources Development Project, Provincial Waterworks Authority of Thailand, Bangkok.

UNION OF SOVIET SOCIALIST REPUBLICS

Mr. V.A. Vladimirov, Chief, Water Cadastre Department, Ministry for Land Reclamation and Water Management, Moscow.

Part Four

MANUAL FOR PLANNING, DESIGN, OPERATION AND MAINTENANCE OF IRRIGATION SYSTEMS

I. INTEGRATED APPROACH TO PLANNING OF PROJECTS FOR IRRIGATED AGRICULTURE

Irrigation and drainage projects are, as a rule, very costly undertakings and need heavy initial investment. In order to draw maximum benefit from the investment, it is essential that planning of all irrigation and drainage projects should take into full account both the long-term as well as short-term agriculture policies. Therefore the project facilities should be flexible enough to accommodate foreseeable changes in agricultural developments and practices.

Irrigated agriculture is a complex multidisciplinary subject. Some of the important disciplines are agronomy, soil and water sciences, hydrology, geology, engineering, sociology, agricultural economies, construction science etc. In spite of this, often engineering undertakings and agricultural activities operate in isolation to the detriment of agricultural production. Therefore a multidisciplinary approach to planning is required.

Irrigated agriculture is the biggest consumer of water. Although water is seldom found in abundance for, or in accordance to irrigation requirements, yet wastage of water is widespread. Overall project efficiencies as low as 20-30 per cent are common in the less developed countries. This is because virtually no importance is attached to water management on the farms. In recent years there has been a growing awareness of the importance and the need for efficient delivery of irrigation water, removal of excess water and judicious use of water on the farms. This can be achieved by a well-designed and well-managed on-farm irrigation system. Therefore a modern irrigation system should necessarily be equipped with on-farm water management facilities.

Many of the older irrigation projects were designed on the basis of assumed water duty, i.e. the number of hectares which could be irrigated by a unit volume of water. It is well known that requirement of water by a crop is not constant during its life cycle but is dependent on its evapotranspiration rate. Therefore planning of modern irrigation and drainage projects should no longer be based on emperical formulae, but should be planned on the concept of crop evapotranspiration.

Older projects usually include design of facilities from the source to the farms in great detail. Beyond that, distribution of the water is generally grossly neglected and left entirely to the best judgement of the farmers. The farmers, who are generally less informed about the modern irrigation practices of water application and water management, tend to apply water less efficiently according to their traditional cultural beliefs and practices. They are usually reluctant to change their practices which results in wastage of much of the water. If looked at from their angle this attitude would appear to be generally right because most of the farmers have small holdings and are living at or near subsistence level. They therefore cannot afford to take a financial risk by scrapping all which they have in favour of trying a new method about which they know nothing. However, if they had the opportunity of observing on a model farm new irrigation methods and agricultural practices, they would perhaps be more receptive to change.

Irrigation and drainage projects normally have a long gestation period, i.e. the period between the start of construction and the time from which the benefits start accruing. However, with careful planning, this period can be shortened. Efforts should be made to ensure that even during construction, the project should start supplying irrigation water to a part of the land so that financial returns from heavy investment can start accruing even before the project has been completed. Therefore, effort should be made to plan projects with short gestation periods or which will begin to supply irrigation water to the fields before the project has been completed.

In places where farm labour is in short supply, efforts should be made to achieve maximum automation of the water delivery system.

II. IRRIGATION WATER REQUIREMENTS

A. PROJECT COMPONENTS

Irrigation water requirements of a project generally consist of two components, namely crop water requirements and efficiency of the system. Older systems are designed on the basis of Duty method, whereas in the newer projects crop water is calculated by taking into account the climatic factors.

Cropping calendar: The optimum sowing and harvesting dates of crops are called the cropping calendar.

Cropping intensity: If total irrigable area is cultivated each season, the land quickly loses its fertility. Therefore, only a part of this area is cultivated each season in rotation. The percentage of the total area which is cultivated every season is called the intensity of irrigation. The ratio of the area planted under certain crops to the cultural commanded area (CCA) of a project for a season is called the cropping intensity of that season. The total of the cropping intensities in a year is called the annual cropping intensity.

Cropping pattern: The types of crops grown in different parts of the country vary widely according to the importance of these areas. The proportion of the area under different crops also varies from year to year and from farmer to farmer. So the way a farmer proportions his available area under various crops is called the cropping pattern. The adoption of a particular cropping pattern on a farm is an individual management decision.

To propose a cropping pattern for either a new or an existing project where crop diversification is to be undertaken, field surveys should be carried out first through which the percentages of the areas under different crops are determined. With the knowledge of the type of soils, availability of water, farmers' preferences and the country's requirements, a new cropping pattern is evolved. It must be understood that the new cropping pattern should not be very much different from the existing one otherwise farmers will the hesitate to adopt it.

Crop water requirements – evapotranspiration needs: One important consideration of the cropping pattern is the consequent water requirements of crops. Therefore, the water requirement of an area based on a particular cropping pattern depends upon the type of crops for which water is provided. In areas where more than one crop is to be grown, such crops should be selected that do not result in a very high water requirement during certain months and a very low water requirement during others. Crops with such varying demand will create problems in the operation and maintenance of the irrigation system.

The quantity of water supplied to the field should be sufficient to meet the requirement of the crops. The size and cost of an irrigation system depends upon the amount of water to be conveyed to the fields for crop production, which in turn depends upon the requirement of each crop. Incorrect estimation of the requirements will result in designing either a smaller or a bigger sized system than is

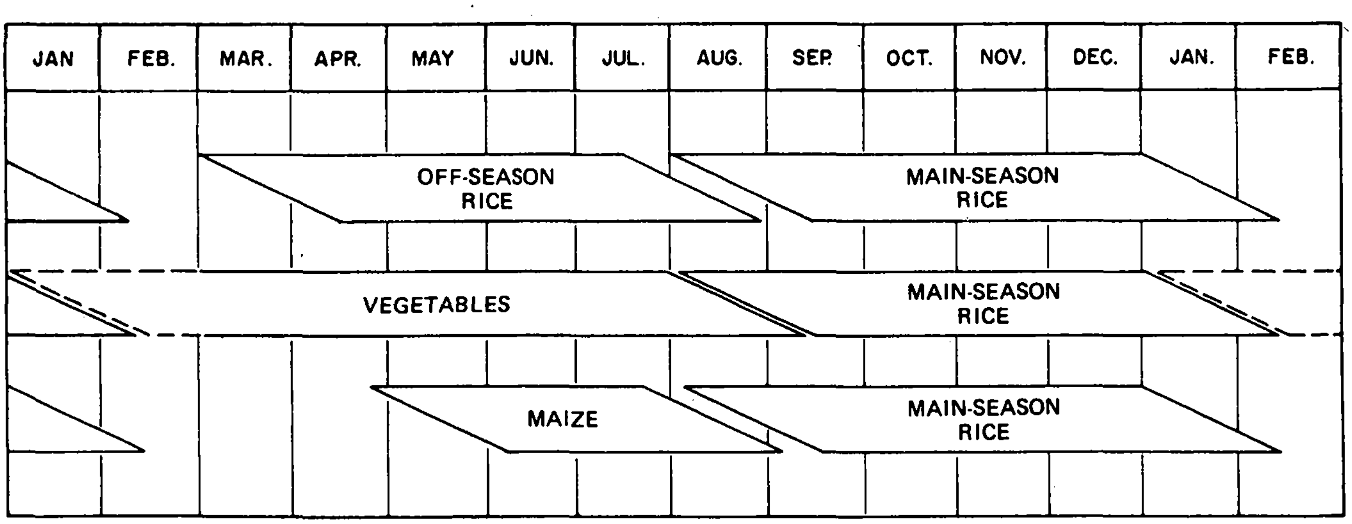


Figure 1. Cropping pattern and calendar

necessary. Therefore, for optimum utilization of land and water resources and for obtaining optimum benefits from an irrigation project, the correct estimation of water requirements of crops becomes very important.

Factors affecting water requirement of crops: The water requirement of crops depends upon the factors listed below:

(a) Soil texture and structure;

(b) Depth of ground-water table;

(c) Slope of the land;

(d) Land drainage;

(e) Climatological conditions, rainfall, temperatures, wind movement, humidity;

(f) Irrigation methods;

(g) Irrigation efficiency.

The water requirement of crops can be calculated by various methods. However, the most common method is the crop consumptive use method based on evapotranspiration needs of crops.

Crop consumptive use is defined as the quantity of water beneficially used by the crop. It includes transpiration from crop plants plus the water evaporated from bare land and water surfaces in the area occupied by the crop. Since the amount of water consumed by the plants is very small, the total amount of water required to support a crop is for all purposes taken as equal to evaporation plus transpiration; therefore the two terms are combined and called evapotranspiration. The method to determine crop consumptive use is also called the evapotranspiration method.

B. ESTIMATION OF CROP WATER REQUIREMENTS

If a crop is grown under non-restricting soil and water conditions, its water requirements are equal to its water loss through evapotranspiration and are denoted by ET crop.

$$\text{ET crop} = \text{Kc} \cdot \text{ETo}$$

Where:

Kc = Crop co-efficient

ETo = Evapotranspiration of reference crops

Therefore, if Kc and ETo are known, ET crop can be calculated.

ETo is the evapotranspiration of a reference crop which is the evapotranspiration from an extensive area of 8 to 15 cm well-watered tall, green grass cover of uniform height and completely shading the ground. Alfafa has also been frequently selected as a reference crop.

Kc is referred to as a crop co-efficient incorporating the effects of crop growth stage, crop density and other cultural factors effecting ET. These are determined experimentally. Table 1 gives the values of Kc for different crops. However, these are only approximate. Kc values should be found experimentally.

The various methods to calculate ETo are the:

(a) Blaney-Criddle method;

(b) Pan evaporation method;

(c) Modified Penman method;

(d) Radiation method.

Of the four methods listed above, the modified Penman method gives best results but is also most involved. The error possibility is considered as ±10 per cent. The pan evaporation method is considered as the next most accurate with an error possibility of ±15 per cent. Next is the radiation method. The Blaney-Criddle method gives rough results and is therefore good for reconnaissance level studies. The modified Penman method should be used for feasibility level studies and for detailed design level works.

All the methods are dependent on climatic data. The various climatic data used in these methods are temperature, humidity, wind, sunshine, radiation, evaporation etc.

For a detailed description of these methods, refer to Crop Water Requirements, FAO Irrigation and Drainage Paper No. 24 (revised 1977), FAO, Rome.

C. THE BLANEY-CRIDDLE METHOD

The Blaney-Criddle method is based on the principle that ET is proportional to the product of day length percentage and mean air temperature.

Calculation of ETo by this method is dependent upon monthly climatic data only. ETo by this method should be calculated for periods not less than one month.

$$\text{ETo} = C\,[p\,(0.46T + 8)]\ \text{mm/day}$$

Where:

ETo = Evapotranspiration of the reference crop in mm/day for the month considered

T = Mean daily temperature in °C over the month considered

Table 1. Crop coefficient (Kc) of field and vegetable crops for different stages of crop growth and prevailing climatic conditions

Crop	Humidity		RHmin >70%		RHmin <20%	
	Wind m/sec		0-5	5-8	0-5	5-8
	Crop stage					
All field crops	initial crop dev.	1 2	Use Fig. 7 by interpolation			
Artichokes (perennial-clean cultivated)	mid-season at harvest or maturity	3 4	.95 .9	.95 .9	1.0 .95	1.05 1.0
Barley		3 4	1.05 .25	1.1 .25	1.15 .2	1.2 .2
Beans (green)		3 4	.95 .85	.95 .85	1.0 .9	1.05 .9
Beans (dry) Pulses		3 4	1.05 .3	1.1 .3	1.15 .25	1.2 .25
Beets (table)		3 4	1.0 .9	1.0 .9	1.05 .95	1.1 1.0
Carrots		3 4	1.0 .7	1.05 .75	1.1 .8	1.15 .85
Castorbeans		3 4	1.05 .5	1.1 .5	1.15 .5	1.2 .5
Celery		3 4	1.0 .9	1.05 .95	1.1 1.0	1.15 1.05
Corn (sweet) (maize)		3 4	1.05 .95	1.1 1.0	1.15 1.05	1.2 1.1
Corn (grain) (maize)		3 4	1.05 .55	1.1 .55	1.15 .6	1.2 .6
Cotton		3 4	1.05 .65	1.15 .65	1.2 .65	1.25 .7
Crucifers (cabbage, cauliflower, broccoli, Brussel sprouts)		3 4	.95 .80	1.0 .85	1.05 .9	1.1 .95
Cucumbers Fresh market Machine harvest		3 4 4	.9 .7 .85	.9 .7 .85	.95 .75 .95	1.0 .8 1.0
Egg plant (aubergine)		3 4	.95 .8	1.0 .85	1.05 .85	1.1 .9
Flax		3 4	1.0 .25	1.05 .25	1.1 .2	1.15 .2
Grain		3 4	1.05 .3	1.1 .3	1.15 .25	1.2 .25
Lentil		3 4	1.05 .3	1.1 .3	1.15 .25	1.2 .25
Lettuce		3 4	.95 .9	.95 .9	1.0 .9	1.05 1.0
Melons		3 4	.95 .65	.95 .65	1.0 .75	1.05 .75
Millet		3 4	1.0 .3	1.05 .3	1.1 .25	1.15 .25
Oats	mid-season harvest/maturity	3 4	1.05 .25	1.1 .25	1.15 .2	1.2 .2
Onion (dry)		3 4	.95 .75	.95 .75	1.05 .8	1.1 .85
(green)		3 4	.95 .95	.95 .95	1.0 1.0	1.05 1.05

Table 1 *(continued)*

Crop		Humidity / Wind m/sec	RHmin > 70% 0-5	RHmin > 70% 5-8	RHmin < 20% 0-5	RHmin < 20% 5-8
Peanuts (Groundnuts)		3	.95	1.0	1.05	1.1
		4	.55	.55	.6	.6
Peas		3	1.05	1.1	1.15	1.2
		4	.95	1.0	1.05	1.1
Peppers (fresh)		3	.95	1.0	1.05	1.1
		4	.8	.85	.85	.9
Potatoes		3	1.05	1.1	1.15	1.2
		4	.7	.7	.75	.75
Radishes		3	.8	.8	.85	.9
		4	.75	.75	.8	.85
Safflower		3	1.05	1.1	1.15	1.2
		4	.25	.25	.2	.2
Sorghum		3	1.0	1.05	1.1	1.15
		4	.5	.5	.55	.55
Soybeans		3	1.0	1.05	1.1	1.15
		4	.45	.45	.45	.45
Spinach		3	.95	.95	1.0	1.05
		4	.9	.9	.95	1.0
Squash		3	.9	.9	.95	1.0
		4	.7	.7	.75	.8
Sugarbeet		3	1.05	1.1	1.15	1.2
		4	.9	.95	1.0	1.0
	no irrigation last month	4	.6	.6	.6	.6
Sunflowers		3	1.05	1.1	1.15	1.2
		4	.4	.4	.35	.35
Tomatoes		3	1.05	1.1	1.2	1.25
		4	.6	.6	.65	.65
Wheat		3	1.05	1.1	1.15	1.2
		4	.25	.25	.2	.2

Source: FAO Irrigation & Drainage Paper 24, Revised, 1977, FAO, Rome.

NB: Many cool-season crops cannot grow in dry, hot climates. Values of kc are given for latter conditions since they may occur occasionally, and result in the need for higher kc values, especially for tall rough crops.

p = Mean daily percentage of total annual daytime hours (table 2)

C = A factor

The value of p is given in FAO paper No. 24 (revised) and reproduced in table 2. ETo can be estimated with the help of figure 10 using calculated values of p (0.46T + 8). The value of p (0.46T + 8) is plotted on X-axis and ETo on Y-axis for: (a) three levels of minimum humidity (RHmin); (b) three levels of the ratio of actual to maximum sunshine hours (r/N); and (c) three levels of daytime wind conditions at 2 m height (U day).

Example

Calculate ETo for project area by Blaney-Criddle method, latitude 31° 33′ N, altitude 215 above MSL. The mean daily temperature is 33.9°C over the month of June. The minimum relative humidity, daytime wind speed and sunshine are estimated as medium, low and low to medium, respectively.

Table 2. Mean daily percentage (p) of annual daytime hours for different latitudes

Latitude	*North*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*
	South[1]	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*
60°		.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
58		.16	.21	.26	.32	.37	.40	.39	.34	.28	.23	.18	.15
56		.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
54		.18	.22	.26	.31	.36	.38	.37	.33	.28	.23	.19	.17
52		.19	.22	.27	.31	.35	.37	.36	.33	.28	.24	.20	.17
50		.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
48		.20	.23	.27	.31	.34	.36	.35	.32	.28	.24	.21	.19
46		.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
44		.21	.24	.27	.30	.33	.35	.34	.31	.28	.25	.22	.20
42		.21	.24	.27	.30	.33	.34	.33	.31	.28	.25	.22	.21
40		.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35		.23	.25	.27	.29	.31	32	.32	.30	.28	.25	.23	.22
30		.24	.25	.27	.29	.31	.32	.31	.30	.28	.26	.24	.23
25		.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20		.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15		.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10		.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5		.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0		.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

Source: FAO, Irrigation and Drainage Paper No. 24, revised 1977, FAO Rome.

[1] Southern latitudes: apply six-month difference as shown.

Calculation

p = 0.32 against latitude 31°33′N (table 2)

$$f = p\,(0.46T + 8)$$
$$= 0.32\,(0.46 \times 33.9 + 8)$$
$$= 7.55$$

From Graphs V and VIII and line 1 of figure 2 for f = 7.55, RHmin as medium, daytime wind speed as low and sunshine being low to medium, we get:

$$ETo = \frac{6.7 + 7.7}{2} = 7.2 \text{ mm/day}$$

$$ETo = 7.2 \times 30 = 216 \text{ mm/day}$$

D. PAN EVAPORATION METHOD

Evaporation from a surface indicates integrated effects of radiation, wind temperature and humidity. Evaporation is measured by an instrument called an evaporation pan and is denoted by E pan. This value can be used to estimate ETo by relating it by an empirical coefficient Kp called pan-coefficient.

$$ETo = Kp \cdot E\ pan$$

Where:

E pan = Pan evaporation in mm/day

Kp = Pan coefficient

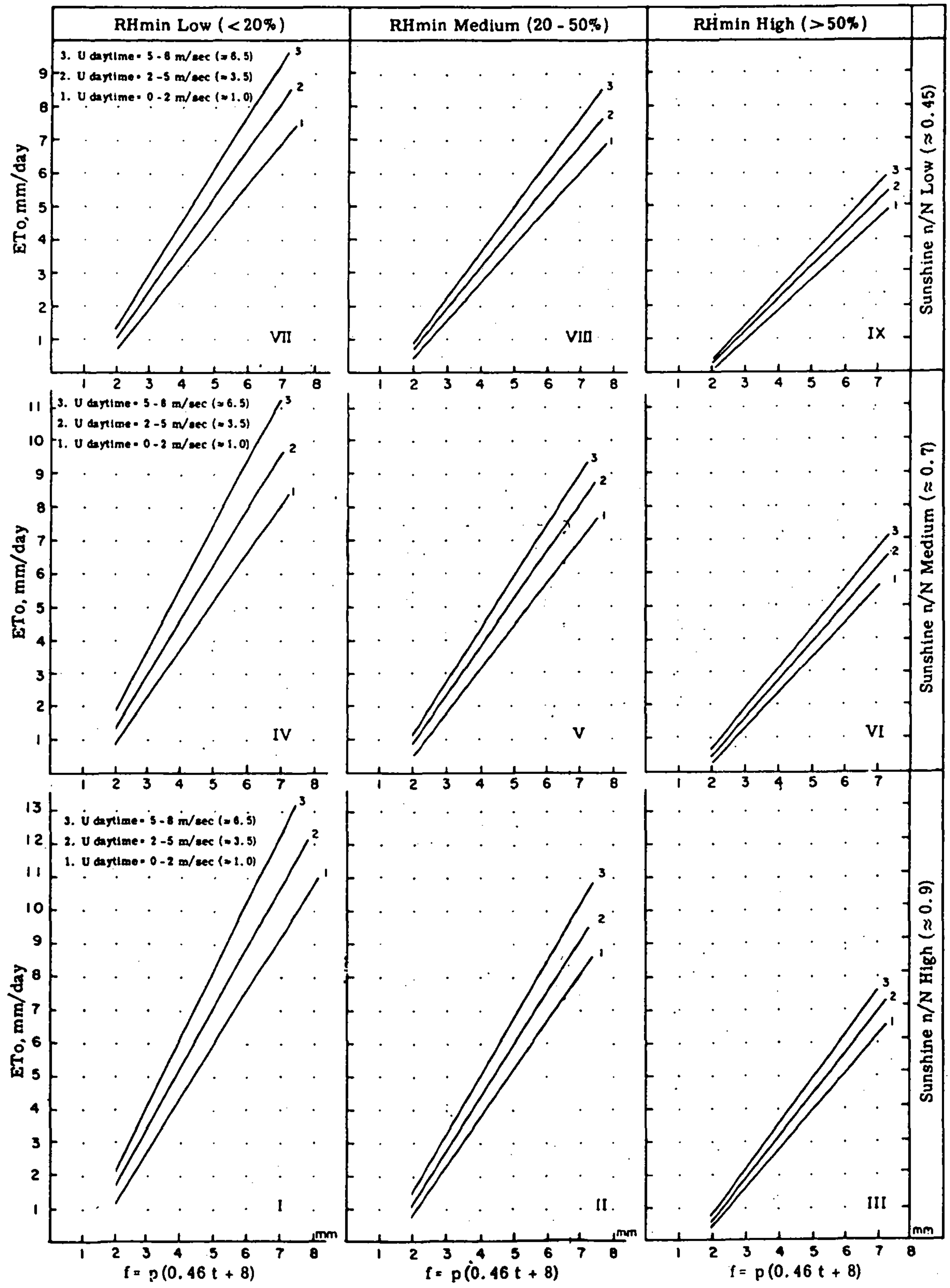
The value of Kp for a class A pan for different ground cover and level of mean relative humidity and 24 hours' wind is given in table 3 (FAO paper No. 24, revised and reproduced)

Example

Calculate ETo during the month of June in a project area by the pan evaporation method. A class A pan is located in the project area. The value of Epan = 267 mm/month. RHmean is medium and wind is light. The pan is placed in short green crops and the wind side distance of the green crop is 100 m.

Solution

Given Epan = 267 mm/month or 8.9 mm/day



Source: FAO, Irrigation and Drainage Paper No. 24, Revised 1977. FAO, Rome.

Figure 2. Prediction of ETo from Blaney-Criddle factor for different conditions of minimum relative humidity, sunshine duration and daytime wind

Table 3. Pan Coefficient (Kp) for a class A pan for different groundcover and levels of mean relative humidity and 24-hour wind

Class A pan	*Case A: Pan placed in short green cropped area*				*Case B[1]: Pan placed in dry fallow area*			
RHmean %		*low <40*	*medium 40-70*	*high >70*		*low <40*	*medium 40-70*	*high >70*
Wind km/day	*Windward side distance of green crop m*				*Windward side distance of dry fallow m*			
Light	1	.55	.65	.75	1	.7	.8	.85
<175	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1 000	.75	.85	.85	1 000	.5	.6	.7
Moderate	1	.5	.6	.65	1	.65	.75	.8
175-425	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75	.8	100	.5	.6	.65
	1 000	.7	.8	.8	1 000	.45	.55	.6
Strong	1	.45	.5	.6	1	.6	.65	.7
425-700	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1 000	.65	.7	.75	1 000	.4	.45	.55
Very strong	1	.4	.45	.5	1	.5	.6	.65
>700	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1 000	.55	.6	.65	1 000	.35	.4	.45

Source: FAO Irrigation and Drainage Paper No. 24, revised 1977, FAO, Rome.

Note: For extensive areas of bare-fallow soils and no agricultural development, reduce Kpn by 20 per cent under hot, windy conditions, and by 5-10 per cent for moderate wind, temperature and humidity conditions.

RHmean = medium

Wind = moderate

Pan location = within cropped area

Pan type = class A and not screened

$\therefore$ Kp = 0.8

ETo = Kp x Epan

= 0.8 x 8.9

= 7.12 mm/day

$\therefore$ ETo = 7.12 x 30

= 214 mm/month

E. RADIATION METHOD

This method is suggested for areas where available climatic data include measured air temperature, sunshine and cloudiness or radiation, but no measured data of wind and humidity. Humidity and wind may be estimated from published data or estimated from data of nearby areas.

$$ETo = C\,(W \cdot Rs)\ \text{mm/day}$$

Where:

ETo = reference crop evapotranspiration in mm/day

Rs = solar radiation in equivalent evaporation in mm/day

W = weighting factor

C = adjustment factor

Solar radiation (Rs)

$$Rs = (0.25 + 0.50\frac{n}{N})\,Ra$$

Hence Ra is the amount of radiation received at the top of the atmosphere and is dependent on latitude and the time of year only. Its values are given in table 4 in mm/day. W is the actual measured bright sunshine hours and N the maximum possible sunshine hours. Values of N for different months and latitudes are given in table 5. Data on W should be collected in the project area. Values of both W and N are given in hours. Weighting factor (W).

The values of W are related to temperature and altitude and are given in table 6. Where maximum and minimum temperatures are given as Tmax and Tmin, mean temperature is used as Tmean.

$$\text{Tmean} = \frac{\text{Tmax} + \text{Tmin}}{2}$$

Figure 11 gives plot of ETo against W.Rs for different conditions of mean relative humidity and day-time wind.

Example

Calculate ETo for project area latitude 31° 33′ N, altitude 215 m above MSL by the radiation method. The mean daily temperature is 33.9°C over the month of June, Sunshine mean is equal to 11.5 h/day, day-time wind is moderate, RHmean medium.

Calculation

$$\therefore \quad \text{Rs} = (0.25 + 0.50\,\frac{n}{N})\ \text{Ra}$$

$$\text{Ra} = 17 \text{ mm/day (table 4)}$$

$$\text{W} = 11.5 \text{ h/day}$$

$$\text{N} = 14 \text{ h/day}$$

$$\therefore \quad \text{Rs} = (0.25 + 0.5 \times \frac{11.5}{14})\ 17 \text{ mm/day}$$

$$= 11.22$$

$$\text{W} = 0.82 \text{ (table 6)}$$

$$\therefore \quad \text{W} \cdot \text{Rs} = 9.20$$

ETo is read from figure 3, Block II and III, line 2 as

$$\frac{9.5 + 8.6}{2} = 9.05 \text{ mm/day.}$$

F. MODIFIED PENMAN METHOD

The original method, proposed in 1948, has recently been slightly modified. It utilizes measured data on temperature, humidity, wind and sunshine, and gives the most satisfactory results. The equation of the modified Penman method is given below.

$$\text{ETo} = \text{C}\,[\text{W} \cdot \text{Rn} + (1 - \text{W}) \cdot f(u) \cdot (\text{ea} - \text{ed})]$$

Where:

W = weighting factor

Rn = net radiation in equivalent evaporation in mm/day

f(u) = wind function

(ea – ed) = saturated vapour pressure

C = adjustment factor

The method has been discussed in detail in FAO Irrigation and Drainage Paper No. 24, (revised) 1977, FAO, Rome.

Calculation of ET crop

$$\text{ET crop} = \text{Kc} \cdot \text{ETo}$$

Where:

ETo is calculated by one of the methods described earlier.

Kc is chosen from table 1 or determined experimentally for each area.

Example

Calculate ET crop of citrus fruit for the month of June when trees cover 50 per cent of ground cover and clean cultivated area. Use Blaney-Criddle method.

ETo by Blaney-Criddle method = 216 mm/day

Kc for citrus in June = 0.55

ET crop = 0.55 x 215

= 119 mm/day month

1. <u>Leaching requirements</u>

Every type of soil contains salts. To maintain a favourable salt balance and prevent salts travelling upwards to the surface, additive water is required to leach the salts down-wards. This additive water should be provided in the system.

Procedures for estimating leaching requirements are presented in detail in FAO Irrigation and Drainage Paper No. 29, FAO, Rome and should be consulted.

2. <u>Effective rainfall</u>

Effective rainfall in the context of crop water requirements is the position of rainfall that contributes to meeting the ET requirement of a crop and should be deducted from ET crop.

Effective rainfall can be calculated by either of the two methods developed by the USBR. The method suit-

Table 4. Extraterrestrial radiation (Ra) expressed in equivalent evaporation in mm/day

Northern Hemisphere													Southern Hemisphere											
Jan	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Lat*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	18.2
4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	14.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

Source: FAO Irrigation and Drainage Paper No. 24, revised 1977, FAO, Rome.

Table 5. Mean daily duration of maximum possible sunshine hours (N) for different months and latitudes

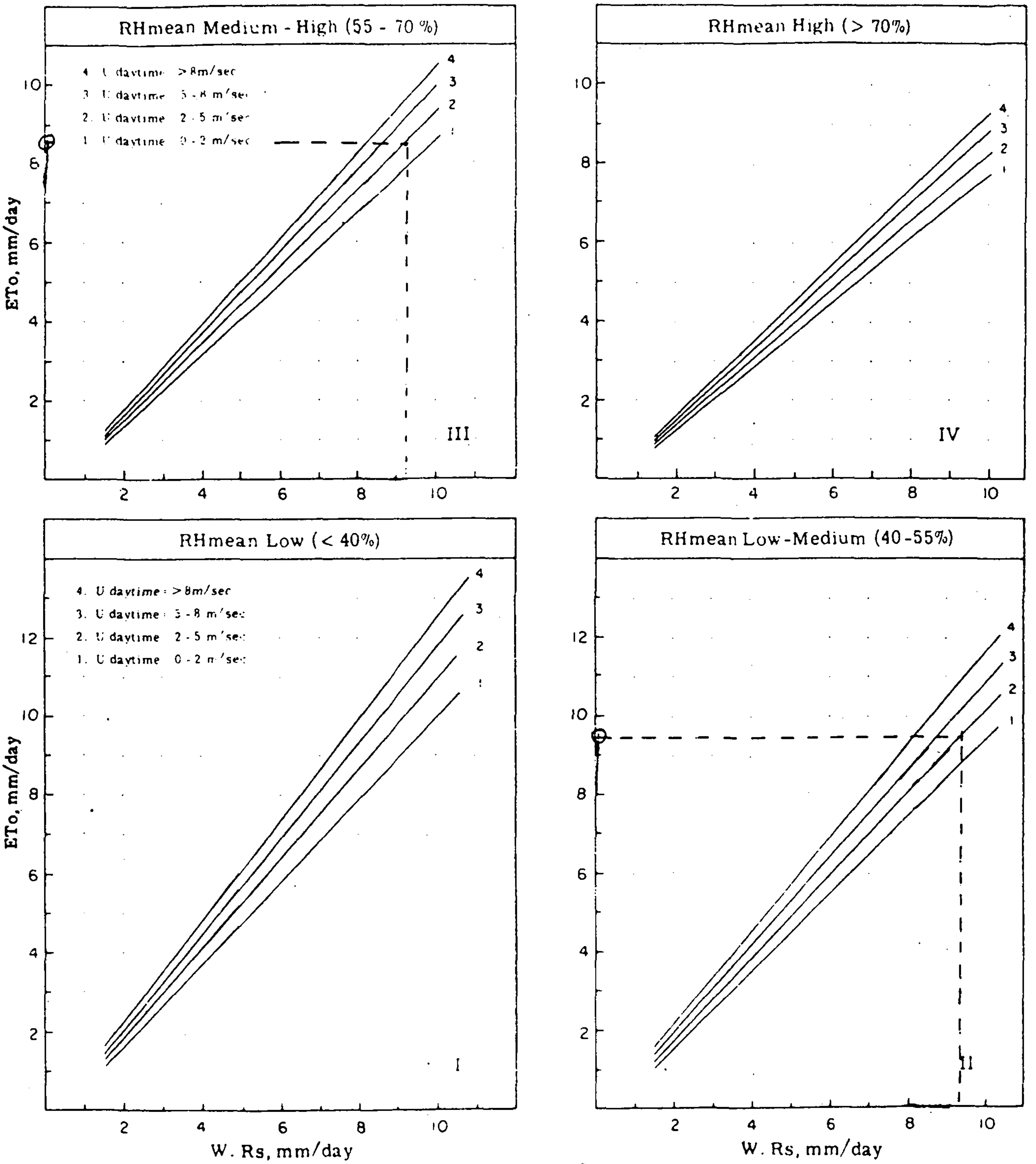
Northern Lats	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*
Southern Lats	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*
50	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1

Source: FAO Irrigation and Drainage Paper No. 24, revised 1977, FAO, Rome.

Table 6. Values of weighting factor (W) for the effect of radiation on ETo at different temperatures and altitudes

Temperature $^{\circ}C$	*2*	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*	*20*	*22*	*24*	*26*	*28*	*30*	*32*	*34*	*36*	*38*	*40*
W at altitude m																				
0	0.43	.46	.49	.52	.55	.58	.61	.64	.66	.68	.71	.73	.75	.77	.78	.80	.82	.83	.84	.85
500	.45	.48	.51	.54	.57	.60	.62	.65	.67	.70	.72	.74	.76	.78	.79	.81	.82	.84	.85	.86
1 000	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.80	.82	.83	.85	.86	.87
2 000	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88
3 000	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.88	.88	.89
4 000	.55	.58	.61	.64	.66	.69	.71	.73	.76	.78	.79	.81	.83	.84	.85	.86	.88	.89	.90	.90

Source: FAO Irrigation and Drainage Paper No. 24, revised 1977, FAO, Rome.



Source: FAO Irrigation and Drainage Paper No. 24, revised 1977, FAO, Rome.

Figure 3. Prediction of ETo from W.Rs for different conditions of mean relative humidity and daytime wind

able to arid and semi-arid areas uses measured rainfall in the project area to predict monthly effective rainfall by factors given in table 7.

Table 7. Effective precipitation based on increments of monthly rainfall (United States Bureau of Reclamation method)

Precipitation increment range		*Per cent*	*Effective precipitation accumulated range*	
mm	*in.*		*mm*	*in.*
0.0- 25.4	0-1	90-100	22.9- 25.4	0.90-1.00
25.4- 50.8	1-2	85- 95	44.4- 49.5	1.75-1.95
50.8- 76.2	2-3	75- 90	63.5- 72.4	2.50-2.85
76.2-101.6	3-4	50- 80	76.2- 92.7	3.00-3.65
101.6-127.0	4-5	30- 60	83.8-107.9	3.30-4.25
127.0-152.4	5-6	10- 40	86.4-118.1	3.40-4.65
Over 152.4	Over 6	0- 10	86.4-120.6	3.40-4.75

3. Irrigation efficiency

The gross irrigation water requirements are different from the net irrigation water requirements. The difference in the two requirements takes into account the water losses in diversion or storage, conveyance and in water application methods. This difference is expressed as irrigation efficiency and denoted as Ei.

$$Ei = Es \cdot Ec \cdot Eu$$

Where:

Es = reservoir storage efficiency

Ec = water conveyance efficiency

Eu = water application efficiency, and given as

$$Es = \frac{\text{Volume of water available from reservoir for irrigation}}{\text{Volume of water delivered to the reservoir for irrigation}}$$

$$Ec = \frac{\text{Volume of water delivered to point of use by conveyance system}}{\text{Volume of water introduced in the conveyance system}}$$

$$Eu = \frac{\text{Volume of irrigation water required for irrigation}}{\text{Volume of water delivered to the area}}$$

To determine the gross water requirement, the net water requirement is divided by the irrigation efficiency.

4. Calculation of irrigation water requirements of a project area

To calculate irrigation water requirements of a project area, ET crop of each individual crop for each month or a shorter period is calculated. In the case of reconnaissance level work, crop water requirements on a monthly basis should be calculated, whereas in the case of feasibility or detailed design stage, this should be calculated on a 10-daily basis, i.e., for 1-10, 11-20 and 21-30 periods each month. The water requirements so calculated are tabulated and added vertically. Water requirement for leaching is then added to it whereas rainfall during the period is subtracted from the total. By multiplying the results by the efficiency factor, the total water requirement of a crop for a period and for the adopted unit area is determined. Water requirements are calculated for a unit area which in the case of big projects may be equal to 1,000 ha or, in the case of small projects, be equal to a unit hectare. The water requirements may be expressed in terms of cusecs or hectare metres or acre feet. However, the total volume of water required should also be determined. This is particularly important if the source of water is a reservoir. This is illustrated in table 8.

5. Design capacity of irrigation systems

The design capacity of irrigation systems should meet peak evapotranspiration requirements for the period. This should also be equal to gross water requirements calculated by taking into account the leaching requirements, effective rainfall, efficiency etc.

Table 8. Water requirement

Crops	Int %	Area Ac	Water Requirement AF/CFS																																			
			Jan			Feb			Mar			Apr			May			June			July			Aug			Sept			Oct			Nov			Dec		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Water requirement in AF.																																						
Effective rainfall (inches)																																						
Cropped acrage (acres)																																						
Rainfall on cropped area (AF)																																						
Water requirement (AF)																																						
Water requirement (cfs)																																						
Efficiency																																						
Net water requirement (AF) (cfs)																																						

III. WATER AVAILABILITY – SURFACE WATER HYDROLOGY

Hydrology is the science which deals with the occurrence, circulation and distribution of water on the earth's surface and beneath it. An irrigation engineer is interested in it because he deals with water in planning, design and operation of water resources projects like dams, reservoirs, barrages, canals etc.

Since the logical start of any hydrological study is the understanding of the occurrence of water on the earth, it is necessary to understand the hydrological cycle.

A. THE HYDROLOGICAL CYCLE

The continuous circulation of moisture and water on our planet is called the hydrological cycle. This cycle does not have a beginning or an end. Since three-fourths of the earth's surface is covered by oceans, it is customary to start the cycle from the surface of the sea.

Radiation from the sun evaporates water from the oceans' surface. The resulting vapours rise and condense to form clouds. Under certain climatic conditions the cloud results in precipitation in the form of rain, hail or snow. The precipitation that falls on the earth's surface is the source of all water on this planet. The water on the earth's surface is dispersed in three main ways, i.e., evaporation and transpiration, surface run-off, and infiltration to the ground water reservoir.

A part of the water which falls on the earth, soaks the foliage and the earth's surface. The plants, after consuming a part of this water, return most of it to the atmosphere by transpiration. The portion of the water which falls on the earth's surface either flows over it and enters streams and rivers, which ultimately discharge it into the sea, or infiltrates the earth's surface and joins the ground water reservoir. A part of the underground water reappears in the form of springs or wells under artesian pressure. A substantial part of the surface and ground water is also returned to the atmosphere through evaporation. The hydrologic cycle is thus the system by which nature circulates water from oceans through the atmosphere and then returns it to the sea through both overland and underground routes. Figure 4 shows a simplified diagram of this hydrological cycle.

Main sources of irrigation water to irrigation systems in non-granery areas are rivers and streams, although in new areas it can be springs, ground water etc., in addition to surface water. Whether the streams and rivers are big or small, all are rainfed.

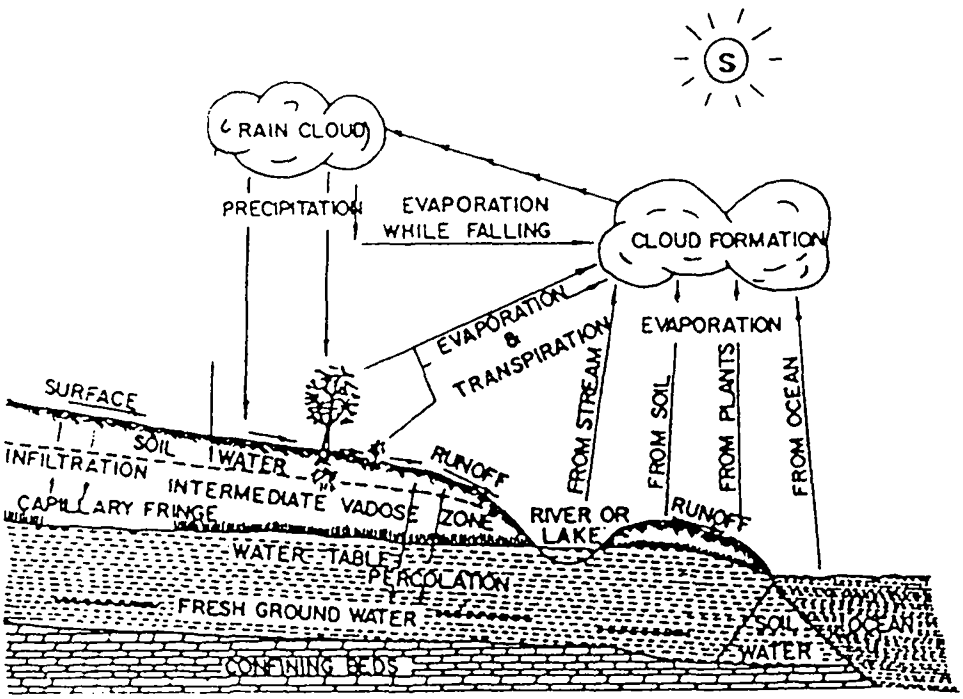


Figure 4. Hydrological cycle of the earth's water resources

In planning an irrigation project, two types of studies are required, namely: (a) run-off determination; and (b) flood peak determination. These are described below.

B. PRECIPITATION

The fall of moisture over the earth's surface from the atmosphere is known as precipitation. Precipitation includes drizzle, rain, frost, snow, hail, rime, snow pellets etc. A large percentage of precipitation falling on the earth's surface is returned to the sea by surface run-off or underground.

Rainfall is measured as the equivalent vertical depth of water collected over a level surface in the area where rainfall has occurred. It is measured in inches or mm.

C. RAIN GAUGE

The instrument used to measure rainfall is called a rain gauge. Rain gauges are of two types: recording (auto graphic) or non-recording (manually read).

The recording rain gauges are of three types:

(a) Float type;

(b) Weighing type;

(c) Tipping bucket type.

D. AVERAGE PRECIPITATION OVER A DRAINAGE BASIN

Computation of average precipitation over a drainage basin is required in many types of hydrological problems. The three methods commonly used to work out the average precipitation are the:

(a) Arithmetic mean method;

(b) Thiessen Polygon or aerial weighing method;

(c) Isohyetal method.

Of all the methods, the isohyetal method is the most accurate. In this method, the locations of rain gauge stations do not alter the calculations.

E. RUN-OFF

Run-off is defined as that portion of precipitation which somehow appears in surface streams or rivers. Therefore, the water which flows in a stream or river is the run-off from the basins drained by that stream or river.

The run-off from a basin can be computed by the following methods:

(a) Direct streamflow measurement;

(b) Empirical formulae.

Direct streamflow measurement is carried out by the area-velocity method. In this method, the sectional area of the stream is multiplied by the average velocity of the stream. The area is measured by the method of section and the average velocity is obtained at 0.6 of the depth of the section by one of the methods given below:

(a) Wading measurement;

(b) Bridge measurement;

(c) Doat measurement;

(d) Cahh-way measurement.

F. EMPIRICAL FORMULAE

Many empirical formulae have been developed to predict run-off from rainfall. The most common is called the run-off-rainfall coefficient method. In this method, run-off and the rainfall can be correlated with the run-off relationship, by the expression:

$$R = KP$$

Where:

R = run-off in inches

P = rainfall in inches

K = run-off co-efficient

The run-off co-efficient naturally depends upon all the factors which affect the run-off. This method is applicable for the analysis of run-off of small catchments and should be used with caution for large catchments. The values of K (in percentage) for various classified catchments and for average rainfall conditions are given in table 9.

Table 9. Barlow's table

Class	*Description of catchment*	*Run-off co-efficient (K)*
A	Flat, cultivated and black cotton soils	0.10
B	Flat, partly cultivated various soils	0.15
C	Average	0.20
D	Hills and plains with little cultivation	0.35
E	Very hilly and steep with hardly any cultivation	0.45

For non-average rainfall conditions, the values in table 9 have to be multiplied by figures in table 10.

Table 10. Barlow's coefficients

Nature of season	*Class of catchment*				
	A	*B*	*C*	*D*	*E*
Light rain, no heavy downpour average or varying rainfall	0.70	0.80	0.80	0.80	0.80
No continuous downpour	1.00	1.00	1.00	1.00	1.00
Continuous downpour	1.50	1.50	1.60	1.70	1.80

The Lacey formula

$$R = \frac{P^2}{P + \frac{120F}{S}}$$

Where:

- R = runoff in inches
- P = rainfall in inches
- S = a catchment factor
- F = rainfall duration factor

To determine catchment factor (S), Lacey divided catchments into five classes (table 11), and to determine rainfall duration factor (F), he divided rainfall into three classes (table 12).

Table 11. Lacey's catchment factor (S)

Class	*Description*	*S*
A	Flat, cultivated and black cotton soils	0.25
B	Flat, partly cultivated various soils	0.60
C	Average	1.00
D	Hills and plains with little cultivation	1.70
E	Very hilly and steep, with hardly any cultivation	3.45

Table 12. Lacey's rainfall duration factor (F)

Class of rainfall	*F*
Very short	0.50
Standard length	1.00
Very long	1.50

G. FLOODS, PEAK FLOWS OR MAXIMUM RATES OF RUN-OFF

Any high flow (run-off) in a stream which overtops its natural or artificial bank in any of its reaches is called a flood.

The various methods to estimate the magnitude of floods or peak flows are:

(a) Past flood marks;
(b) Emperical flood formulae;
(c) Flood frequency analysis;
(d) Unit hydrograph method.

1. Past flood marks

After the passage of each flood, marks in the form of deposited brushes, logs, alluvial matters or scars on the banks are left by floating debris etc., on old trees, on the river banks, bridge piers and similar structures. People living along a river or a stream are also a good source of information about the height that floods have reached in the past. Sometimes information obtained from these people can be reliable and sometimes it may be totally wrong, underrated or exaggerated. It will thus be good practice to enquire among a large number of people of conflicting interests so that exaggeration or suppression of facts are eliminated

Having ascertained the level up to which the water might have risen during past floods, the next step will be to determine the cross-section and the longitudinal slope of the river by conducting surveys of the water level, both upstream and downstream of the point of observation. Mean velocity of the river can be determined by Chezy's formula or by any other suitable formulae. The flood discharge of the river would be equal to the product of the mean velocity of flow and cross-sectional area of the stream corresponding to the highest flood level.

2. Emperical flood formulae

For rough estimation of flood discharges, many emperical formulae have been developed. These are:

(a) W.P. Creager' formula

$$Q = 4{,}600\, CA^{(0.894\, A^{-0.048})}$$

- Q = Flood discharge in cfs
- A = Catchment area in sq miles
- C = 30 to 100

For ordinary floods lower values can be adopted and for maximum flood higher values can be used.

(b) Fanning formula

$$Q = CA^{5/6}$$

Q = Flood discharge in cfs

A = Catchment area in sq miles

C = 2.54

(c) The Rational formula

The relation between rainfall and peak run-off, i.e., the flood has been represented by many emperical formulae. The Rational formula is, however, the most popular and commonly used. The formula is given by:

$$Q = CIA$$

Where:

Q = the peak discharge in cusecs

C = run-off co-efficient

I = average rainfall intensity in inches per hour of duration equal to the time of concentration of the basin

A = area of the catchment in acres

The time of concentration of the basin can be calculated from California Highway Division's formula:

$$t_c = 0.00013 \frac{L^{0.77}}{S^{0.385}}$$

Where:

t_c = time of concentration in hours

L = length of basin in miles measured in a straight line from the gauging station to the farthest point on the basin

S = ratio in ft to L, of the fall of the basin from the farthest point on the basin to the outlet of run-off

The Rational formula is recommended for small catchments but is still used by many engineers for large areas.

The values of run-off co-efficient C are given in table 13.

Table 13. Run-off coefficient for Rational formula

Drainage area	*C (Hilly)*	*C (Plain)*
Less than 50 sq miles	0.6	0.30
50 to 100 sq miles	0.5	0.25
More than 100 sq miles	0.4	0.20

The emperical formulae do not take into account the variation of rainfall intensity from one area of the catchment to another area. There is also no rational basis for adoption of different co-efficients. Therefore, the results obtained by using emperical formulae are suitable only for very rough estimates. They should, however, not be used for detailed design purposes. The Rational formula is known to give good results for small catchment areas. For larger catchments, the unit hydrograph method or synthetic hydrograph method should be used. The synthetic unit hydrograph method is especially suitable and recommended for estimating floods in areas where climatological data are short or are discontinuous.

Example

A stream drains a hilly catchment area of 1.87 sq miles. Intensity of rainfall for a return period of 30 years is 3.70 inches per hour. Find out the 30-year return period peak discharge. Assume C = 0.60.

Rational formula

$$Q = CIA$$

Q = Peak discharge cfs

C = Co-efficient of run-off

I = Intensity of rainfall inches/hour

A = Catchment area in acres

C = 0.60

I = 3.70 inches/hour

A = 1.87 x 640 acres

Q = 0.60 x 3.70 x 1.87 x 640
= 26.57 cfs

3. Flood frequency analysis

In this method, the prediction of future floods is based upon the past record. Therefore, flood frequency analysis is possible if hydrological data for a large number of previous years are available.

4. Unit hydrograph method

In this method, a unit hydrograph is utilized for predicting the direct run-off hydrographs of other streams of like duration.

H. STAGE DISCHARGE RELATIONSHIP

The frequency of discharge measurements varies from station to station, depending on such factors as stability of the stream section, and importance and accessibility of the stations. For such stations which are not easily accessible, it is convenient to estimate the discharge without actually measuring it by indirect methods, one of which is by the use of a rating curve (figure 5). However, the rating curve or stage discharge relationship, which is a plot of heights against corresponding discharge, is first developed for a particular station with the help of gauge heights and corresponding discharges collected for a sufficiently long period. This curve can then be used to determine the discharge corresponding to any gauge height.

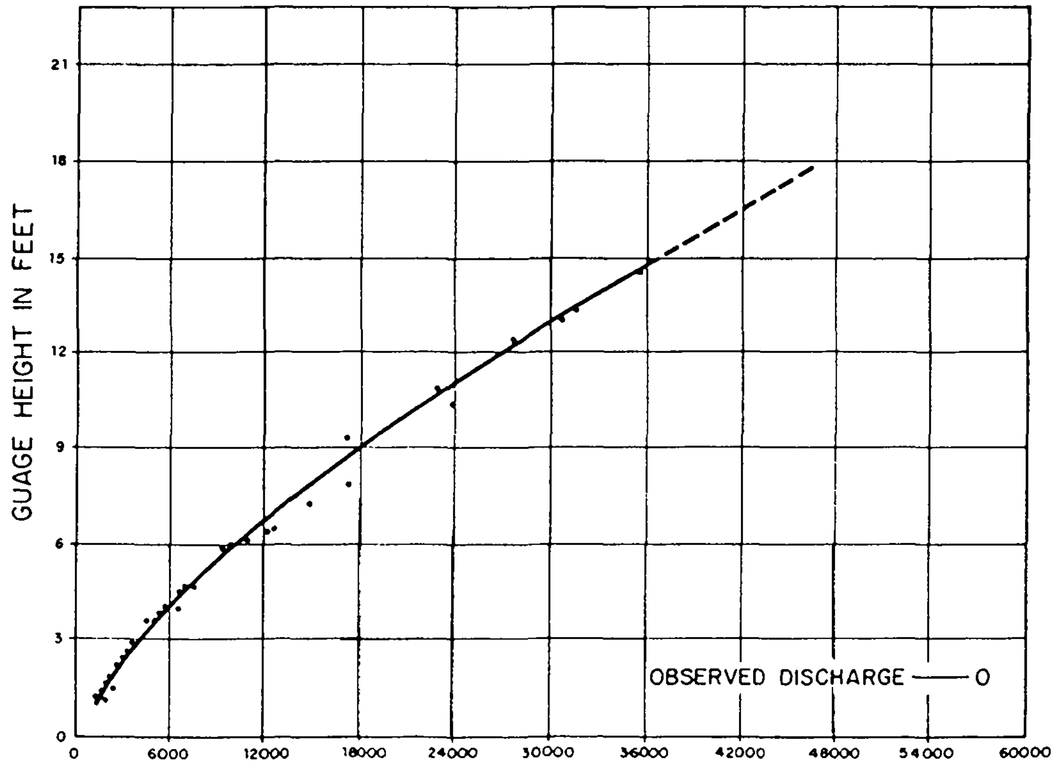


Figure 5. Stage discharge relationship (rating table)

IV. IRRIGATION SYSTEMS: AVAILABLE OPTIONS

The various methods by which irrigation water is applied to the fields can be broadly classified as follows:

(a) Surface irrigation system;

(b) Sub-irrigation system;

(c) Sprinkler irrigation system;

(d) Drip irrigation system.

A. SURFACE IRRIGATION SYSTEM

In a surface irrigation system, the source of water supply is either the stored water from a reservoir or a natural lake or water diverted from streams or rivers. Storage is created by construction of a dam across a river or stream, whereas diversion of water is accomplished by construction of a weir or a barrage. The water is then conveyed to the fields by a network of canals. When canals are taken off directly from a river without the use of storage or diversion structures, the canals are called inundation canals. These were the earliest types of canal. The water levels and discharge into inundation canals are subjected to fluctuation of supplies in the river from which they are supplied. If the level of water in the river drops considerably, the inundation canal goes dry. As and when the water level rises, the canal can again start drawing water. These canals are therefore subject to the fluctuation in the river water level.

As a latter development, diversion structures were constructed across the rivers to divert water into the canals. These structures, known as weirs or barrages, ensure supply of water into the canal even if there are fluctuations in the water levels of the river. A weir or a barrage-fed canal which runs throughout the year is called a perennial canal.

A canal whose bed and banks are made of earth is called an earthen or unlined canal. If the bed and banks are provided with lining, it is called a lined canal.

If water enters a canal system by the hydraulic gradient between the levels of water in the river and the canal it is called a gravity canal. If the source of water is located at a level below that of a canal, the water is lifted by pump. Such canals are called lift canals.

To convey the water up to the fields, a canal system is constructed in the form of a network comprising of a main canal which is divided and sub-divided into smaller canals and then field ditches.

B. SUB-IRRIGATION SYSTEM

A sub-irrigation system can be defined as a system by which the elevation of the ground water table is regulated by artificially adding water to the subsoil, thus maintaining the depth of ground water at a level which is most beneficial to the roots of the crops. In sub-irrigation system, water infilterates into the soil through sub-surface pipes. In this way the water table is maintained at a pre-determined depth so that crops can derive their water needs from it. Sub-irrigation is limited to areas where the soil is relatively permeable for a considerable depth and where surface slopes are gentle and natural drainage is restricted. Moreover, it must be practical to hold the ground-water table at a particular depth.

Sub-irrigation is widely practised in humid areas, whereas in arid and semi-arid areas its application is limited to areas conducive to sub-irrigation.

C. SPRINKLER IRRIGATION SYSTEM

Sprinkler irrigation, i.e., the spraying of water onto crops in a field from nozzles or holes in a pipe, is generally considered in cases where the amount of available water is limited, the local topography is undulating and expensive to level, and where the soil is porous. The system consists of main pipes, lateral pipes and nozzles for sprinkling water uniformly over the field to be irrigated. Sprinkler systems have the advantages of high water application efficiency, low erosion, easy land preparation, and intensive and easily verifiable irrigation rates. On the other hand they require heavy initial investment, installation of pipe systems, power for pumping, and are subject to choking up of the nozzles. Sprinkling is also adversely affected by strong winds. Heavy, clayey soils usually cannot be irrigated by sprinkler systems.

D. DRIP IRRIGATION SYSTEM

Drip irrigation is a method by which water is applied frequently at a slow rate to soil in the root zone by mechanical devices. It has been in use in Europe for the last several decades. Some of the common names by which this system is known include the drip, trickle, localized, micro-irrigation system etc. This method is still in the development stage and is being tried in arid as well as in humid areas. It is being used for a variety of crops, climates and soils. The crops for which it is suitable are grapes, fruit trees, vegetables, sugar cane etc.

V. SURFACE IRRIGATION SYSTEM

A. HEAD WORKS

The structure installed at the start of a canal system for inletting the designed discharge is called the head work. This structure can be a weir, sluice or a syphon. This is provided with gates, which can be vertical screw gates or, in the case of a big canal, radial gates.

B. CONVEYANCE SYSTEM LAYOUT AND DESIGN

An irrigation canal is an artificially prepared channel, usually trapezoidal in section, which is used to convey water for long distances from the source to the field. The canals are of two types, viz. unlined or lined. If the banks of the canal are left unprotected, they are called unlined canals, and if protected by impervious material, they are called lined canals.

C. A CANAL NETWORK

In Malaysia, a water conveyance system consists of four types of canals. These are: primary canals (feeder or main), secondary canals, tertiary canals and quaternaries. Figure 6 shows the layout of a canal network.

1. Primary canal (feeder or main)

A canal taking off directly from a river, barrage or a reservoir, and which conveys water to the main patches of land for further distribution, is called a primary canal. It is also called a feeder or main canal. Since the primary purpose

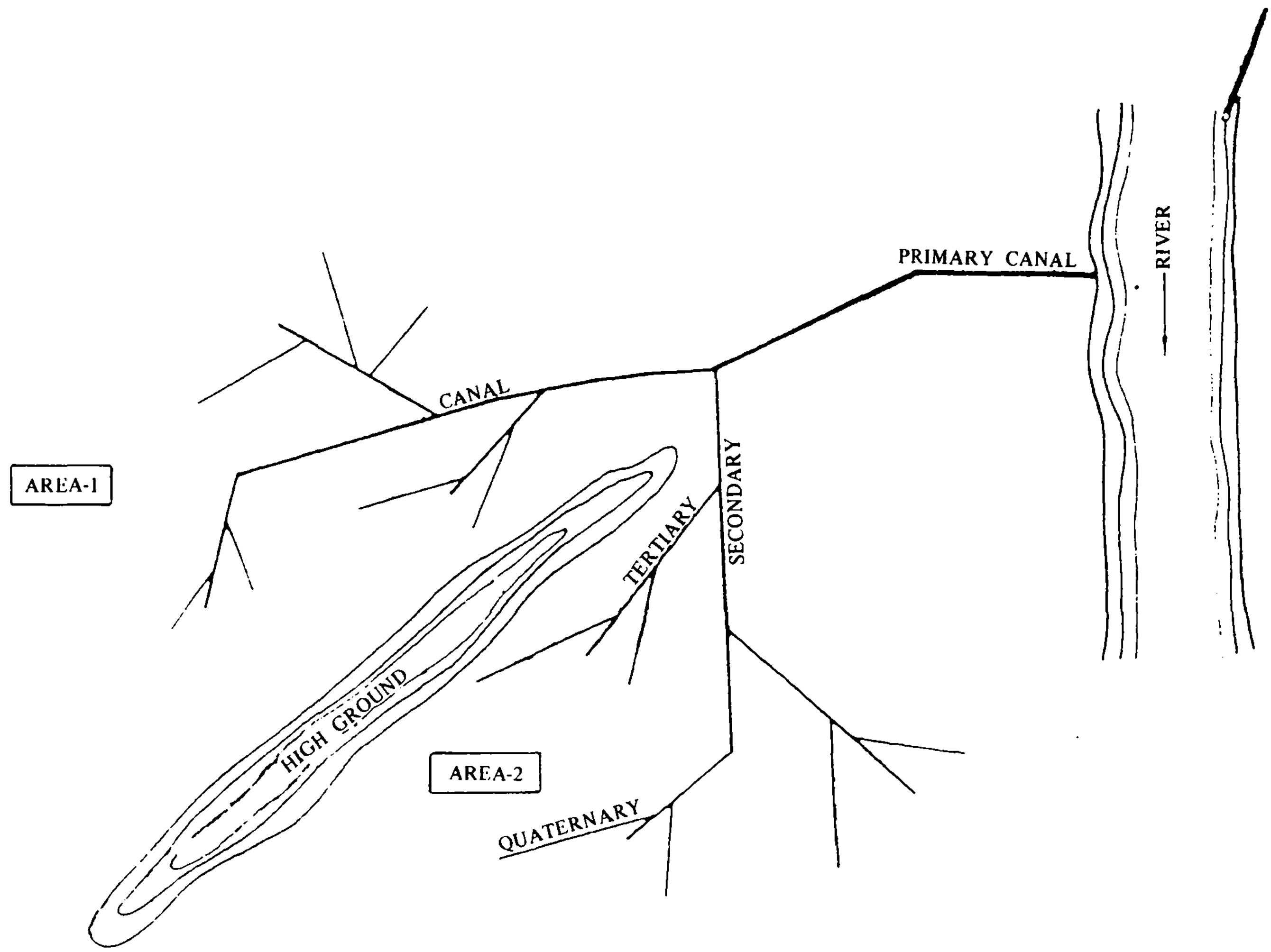


Figure 6. Network of canals

of the canal is to convey water only, distribution to the field is not provided by the canal. However, in exceptional cases, direct distribution may be permitted.

2. Secondary canals

Since it is not possible to convey irrigation water to the total command area through one main canal, it is usually desirable to take off more than one smaller capacity canal from the main canal. These smaller capacity canals are called branch canals, the alignment and discharge capacity of which are fixed in such a way that they supply water to a portion or a specified part of the command area. The discharge capacities of the branch canals are calculated according to the area they will serve.

3. Tertiary canals

Usually the size of the branch canals is quite big so that direct irrigation from them is usually not feasible. Therefore they are further sub-divided into smaller canals called tertiary canals. Branch canals act as the main canal for tertiary canals.

Tertiary canals or tertiaries are smaller capacity canals taking off from a secondary canal. The tertiaries serve irrigation needs of small sub-divisions of the total command area of the canal.

4. Quaternary canals

These are sub-divisions of tertiaries. They are small in length and carry discharges equivalent to the total discharge of 10 to 15 irrigation water outlets.

5. Water courses

They are field channels which take off from a quaternary and which ultimately carry water to the fields. In exceptional circumstance, direct outlets are provided from secondary canals or even the primary canals. In such a situation, water courses convey water to the fielde directly from the secondary or the primary canal. .

D. UNLINED CANALS

Discharge of a canal is given by:

$$Q = AV$$

Where:

A = area of the canal section

V = velocity

Formulae for determining velocity in sediment-free and sediment-charged water are given below:

1. Sediment-free water

Velocity of flow of sediment-free water in an unlined section is given by Manning formula:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Where:

V = velocity of water in ft/sec

S = slope in ft/ft

R = hydraulic mean depth

n = co-efficient of roughness

Table 14. Values of Manning's coefficient 'n'

Sr. No.	*Type of lining*	*'n'*
1.	Portland cement concrete lining	0.014
2.	Asphaltic concrete lining (machine placed)	0.014
3.	Brick lining covered with cement plaster	0.014
4.	Soil cement, well finished	0.015
5.	Soil cement, rough as a gravel surface	0.016
6.	Pre-cast concrete block lining	0.015-0.017
7.	Brick lining with exposed brick surface design value	0.0146
	Actual measured value of 'n' on the same lining after deterioration	0.018-0.02
8.	Shotcrete lining, smoothed	0.016
9.	Shotcrete lining (average)	0.017
10.	Wooden flumes	0.016-0.020
11.	Compacted earth lining, small canals	0.025
12.	Compacted earth lining, large canals	0.0225-0.020

2. Sediment-charged water – variables affecting flow in earthen channels

Flow in earthen channels, carrying sediment-charged water is influenced by many complex and uncertain factors. Major factors which influence the flow in, and the stability of the earthen channel section are boundary materials, discharge, sediment in transport, hydraulic slope etc. Sediment in transport is the single most important factor on which canal slope, bed width and water depth are dependent.

There are two approaches to the design of an earthen channel – the emperical approach and the rational approach. By emperical approach, canal section is determined on the basis of observed data of regime channels. In the case of rational approach, the canal section is determined by using the theory of mechanics. This is more or less a theoretical approach. In many countries canals are designed by the emperical approach. However, the latest theory is Lacey's theory. A complete description of Lacey's silt theory is given in "Irrigation canals" reference No. 5. In addition, some other theories have since been put forward but they have not been favoured in carrying out designs, although they are theoretically sound. These are Leopold and Maddock. Simon and Albertson, Mushtaq and Rehman etc.

3. Lacey's regime theory

Gerald Lacey, on the basis of his experience in the Indo-Pakistan sub-continent, published two papers in the Journal of the Institute of Civil Engineers, London, in 1929 and 1939, in which he presented a set of formulae for the design of unlined canals in alluvium. His concept and the formulae have since been accepted and several canal systems involving hundreds of miles have since been designed and constructed based on his formulae. These canal systems are working satisfactorily. Research has also proved that the dimensions of the observed sections of running canals conform closely to the designed dimensions. Therefore, Lacey's regime theory has been accepted as a sound basis for the design of unlined canals.

A channel or canal which is neither silting nor scouring is said to be in regime. In artificially excavated channels, there can be two types of regimes, viz. the 'initial' regime and the 'final' regime.

A silt transporting channel excavated in alluvium is considered to be in regime when it is stable physically and also maintains dynamic equilibrium between the forces generating and maintaining the channel cross-section and slope. By physical stability, it is meant that the channel neither silts nor scours. For the establishment of regime, the fundamental requirements are that the channel carries a constant discharge, silt grade, silt charges and flows in the incoherent alluvium of the same character to that transported in the channel. In addition to the above factors, the regime in the channel also depends upon the channel conditions or irregularities. The latter may be due to bends or irregularities in the channel bed.

The following formulae presented by Lacey determine the regime section and slope of the unlined channel.

$$V = 1.1547\sqrt{fR}$$

$$V = 16\, R^{2/3}\, S^{1/3}$$

$$V = \frac{1.346}{Na}\, R^{3/4}\, S^{1/2}$$

$$R = 0.474\left(\frac{Q}{f}\right)^{1/3}$$

$$S = 0.000542\,\frac{f^{5/3}}{Q^{1/6}}$$

$$P = 2.67\, Q^{1/2}$$

$$Na = 0.0225\, f^{1/4}$$

$$f = 0.75\,\frac{V^2}{R}$$

$$A = 1.26\,\frac{Q^{5/6}}{f^{1/3}}$$

Where:

- Q = discharge
- V = non-silting, non-scouring velocity, i.e., regime velocity
- f = Lacey's silt factor
- R = hydraulic mean depth
- S = hydraulic slope
- A = area of the section of the prism

Example

Design an earthen channel with full supply discharge of 200 cfs and silt factor 1.0.

Solution

F S Q = 200 cusecs

f = 1.0

Area, A

$$A = 1.26\,\frac{Q^{5/6}}{f^{1/3}}$$

$$= 104 \text{ S ft}$$

Wetted perimeter, P

$$P = 2.67\, Q^{1/2}$$

$$= 37.75 \text{ ft}$$

Bed width, B, and depth, D, with 1/2: 1 side slope

$$A = BD + 0.5D^2$$

$$P = B + 2.236D$$

Solving the two equations for B and D, we get

$$BD + 0.5D^2 = 104$$

$$B + 2.236\,D = 37.75$$

$$D(37.75 - 2.236D) + 0.5D^2 = 104$$

$$1.736D^2 - 37.75D + 104 = 0$$

$$\therefore \quad D = 3.26 \text{ ft}$$

$$\text{and } B = 30.45 \text{ ft}$$

Hydraulic Slope, S

$$S = 0.0005423 \frac{f^{3/5}}{Q^{1/6}}$$

$$= 0.000224$$

or 1:4,464

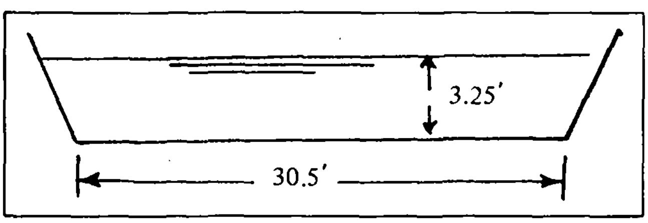


Figure 7. B and D section of earthen channel

Adopt bed width	=	30.50 ft
Full supply depth	=	3.25 ft
Bed slope	=	1:4,464

E. LINED CANALS

A canal where the prism has been protected with impervious material, mainly to stop seepage through it or to improve its hydraulic perfomance, is called a lined canal.

The most economical form of a channel section is that which has the maximum cross-section area for the minimum wetted perimeter. The lined channel section can be moulded to many shapes, ranging from semi-circular to trapezoidal. However, for most of the smaller and medium-sized channels, trapezoidal sections are used, and for very large canals, a trapezoidal section with rounded corners is used.

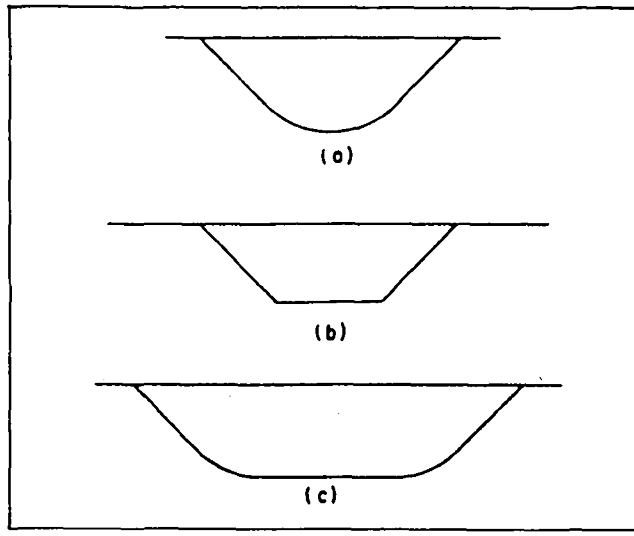


Figure 8. Trapezoidal cross-sections.

The side slopes of the section are kept at the angle of response. Based on the consideration of stability of slopes, the side slopes of lined channels are kept between 1¼:1 to 1½:1.

The discharge through a channel is given by:

$$Q = AV$$

Velocity V is given by Manning's formula:

$$V = \frac{1.486}{N} R^{2/3} S^{1/2}$$

When:

V	=	velocity of water in ft/sec
S	=	slope in ft/ft
R	=	hydraulic radius
n	=	co-efficient of roughness

The value of n can be read from table 4.

Usually the velocities allowed in hard surface linings range between 2.5 and 8 ft/sec. General guidelines given in the Design Manual for Water Conveyance Systems, Drainage and Irrigation Department, Malaysia, 1980, may be used. However, exhaustive treatment of the subject has been given in "Irrigation Canals" reference No. 5.

Example

A lined canal has a full supply capacity of 750 cfs. It will be lined with pre-cast concrete block lining. The slope of the country is very steep and the canal will be aligned with an hydraulic slope of 1:5,000. The channel will have a trapezoidal section with side slopes at 1:1. Design the section when B = D.

Solution

$Q = 750$ cfs

$S = 1{:}5{,}000$

$n = 0.015$ for pre-cast concrete block lining

$$\text{Perimeter } P = D + 2\sqrt{2D} = 3.828D$$

$$\text{Area } A = 2D^2$$

$$R = \frac{A}{P} = \frac{2D^2}{3.828D} = 0.522D$$

Substituting in velocity equation

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} = \frac{1.486}{0.015} (0.522D)^{2/3} \left(\frac{1}{5{,}000}\right)^{1/2} = 0.908D^{2/3}$$

$$\text{Since } Q = AV$$

$$750 = (2D^2)\, 0.908D^{2/3} = 1.816D^{8/3}$$

$$D^{8/3} = \frac{750}{1.816} = 413.0$$

$$\therefore \quad D = 9.6 \text{ ft}$$

$$\text{and} \quad B = 9.6 \text{ ft}$$

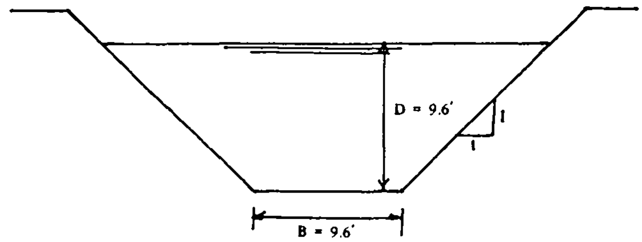


Figure 9. Trapezoidal cross-section of lined canal when B = D

F. STRUCTURES FOR A WATER CONVEYANCE SYSTEM

To admit regulated discharge into a canal (primary, secondary, tertiary and quaternary) and to exercise control on discharge, full supply level, velocity of flow and to protect the system from flood damage, various types of structures are required. These are listed below:

(a) Head regulators;

(b) Cross regulators;

(c) Falls;

(d) Escapes;

(e) Aqueducts;

(f) Super passages;

(g) Drainage culverts;

(h) Flumes and outlets.

A detailed description of the design criteria is available in "Design of Low-Head Hydraulic Structures", Water Resources Series No. 45, United Nations, New York, 1973. Reference No. 14.

VI. SURFACE IRRIGATION SYSTEM AND DESIGN

The success of every irrigation system depends upon the efficient conveyance and utilization of water on the farms. In this section, the conveyance of water from canal outlets to the farms and the various methods of its application to the fields are described.

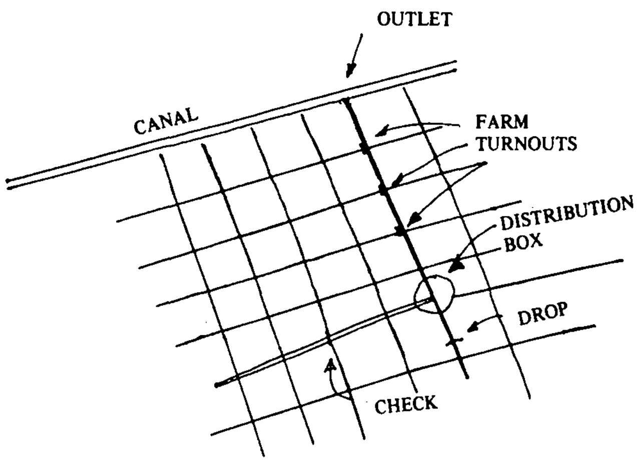


Figure 10. Layout of surface irrigation system network

Structures beyond a canal outlet required to convey and distribute water to the farmer's field are the:

(a) Water course;

(b) Distribution box;

(c) Check structure;

(d) Drop structure;

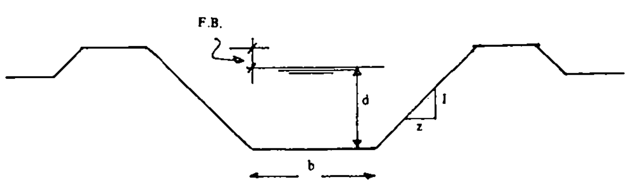
(e) Turnouts.

A. WATER COURSE

A water channel beyond a canal outlet which conveys water to the farmer's field is called a water course. A water course can be earthen or lined.

1. Earthen water course

A typical cross-section of an earthen water course is shown below.



d = water depth

Z = side slope

Figure 11. Section of an earthen water course

The designed discharge of a water course is kept equal to the designed discharge of the outlet. The full supply level in the water course is kept in such a way that it is slightly (three in.) higher than the general level of the field. A minimum free board equal to one-third of the full supply water depth is provided. The side slopes of the water course prism for various types of soils are provided in table 15.

Table 15. Side slopes of water course prism

Sr. No.	*Soil types*	*Excavated section Z*	*Fill section Z*
1.	Loams, silty clay, silt loams, clays	1:1	1.5:1
2.	Sandy loam	1.5:1	2:1
3.	Loamy sands and sands	2:1	3:1

A water course section with the largest hydraulic radius is considered to be hydraulically the most efficient. Such a section should have the following dimensions:

Side slopes	*Bed width*
1:1	0.8d
1.5:1	0.6d
2:1	0.5d

Where:

d = full supply water depth.

The discharge in a channel is equal to:

$$Q = AV$$

Where:

Q = discharge in cfs

A = area in sq ft

V = velocity in ft/sec

The velocity V is given by Manning's formula:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

V, n, R and S have the usual meanings. The value of n for an earthen canal is 0.025.

Area of the section $A = bd + Zd^2$

Perimeter $P = b + 2d\sqrt{Z^2 + 1}$

Hydraulic radius $R = \frac{A}{P}$

Example

Design the section of an earthen water course for a discharge of 2.25 cfs, horizontal slope 1:8,000, n = 0.025. Assume side slope of the section as 1.5:1.

Given

$Q = 2.25$ cfs

$n = 0.025$

$S = 1{:}8{,}000$

$Z = 1.5{:}1$

Solution

Area $A = bd + 1.5d^2$

Perimeter $P = b + 3.6d$

Hydraulic radius $R = \frac{A}{P} = \frac{bd + 1.5d^2}{b + 3.6d}$

Assume $b = d$

$$\therefore R = \frac{b^2 + 1.5b^2}{b + 3.6b} = \frac{2.5b^2}{4.6b} = 0.54b$$

$$Q = \frac{1.486}{n} R^{2/3} S^{1/2} = \frac{1.486}{n} \times (0.54b)^{2/3} \cdot \left(\frac{1}{8{,}000}\right)^{1/2}$$

$$2.25 = \frac{1.486}{0.025} (0.54b)^{2/3} \cdot \left(\frac{1}{8{,}000}\right)^{1/2}$$

$\therefore b = 1.6$

and $d = 1.6$

2. Lined water course

A lined water course is usually constructed of brick or concrete. It can have either a rectangular or a trapezoidal section. The maximum designed velocity allowed in a lined section should be less than 7 ft/sec. Higher velocity will damage the lining. Velocity in a lined section is calculated by Manning's formula with appropriate value of roughness co-efficient n. A minimum free board of four inches in a rectangular section and three inches in a trapezoidal section is recommended. Side slopes of 1:1, 1.5:1 and 2:1 may be provided for a trapezoidal section.

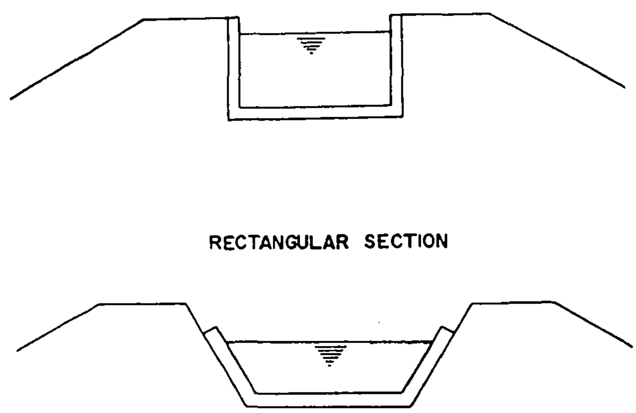


Figure 12. Lined water-course

Example

Design the section of a lined water course for Q = 2.25 cfs. Assume trapezoidal section with pre-cast concrete block lining, side slopes of 2 horizontal, 1 vertical, and longitudinal slope of 0.5 to 1,000.

Solution

Given $Q = 2.25$ cfs

$S = 0.5/1{,}000$

$Z = 1{:}2$

$n = 0.017$ (for concrete section)

$$Q = AV$$

$$A = bd + Zd^2$$

$$P = b + 2d\sqrt{Z^2 + 1}$$

$$R = \frac{A}{P}$$

$$V = \frac{1.486}{n} R^{2/3} \cdot S^{1/2}$$

$$Q = (bd + Zd^2)\left(\frac{1.486}{n} \cdot R^{2/3} \cdot S^{1/2}\right)$$

$$= \frac{1.486}{n} (bd + Zd^2) \left(\frac{bd + Zd^2}{b + 2d\sqrt{Z^2 + 1}}\right)^{2/3}$$

$$\cdot \left(\frac{0.5}{1{,}000}\right)^{1/2}$$

$$= \frac{1.486}{n} \cdot \frac{(bd + Zd^2)^{5/3}}{(b + 2d\sqrt{Z^2 + 1})^{2/3}}$$

$$\cdot \left(\frac{0.5}{1{,}000}\right)^{1/2}$$

$$= \frac{1.486}{0.017} \times \frac{(bd + Zd^2)^{5/3}}{(b + 2d\sqrt{Z^2 + 1})^{2/3}} \times$$

$$\left(\frac{0.5}{1{,}000}\right)^{1/2}$$

Assume $b = 1.4$

$d = 1.0$

$$\therefore \quad Q = \frac{1.486}{0.017} \times \frac{(1.4 \times 1 + \frac{1}{2} \times 1^2)^{5/3}}{(1.4 + 2 \times 1\sqrt{\frac{1^2}{2} + 1})^{2/3}}$$

$$\times \left(\frac{0.5}{1{,}000}\right)^{1/2}$$

$$= 87.4 \times 1.233 \times 0.022$$

$$= 2.37 \text{ cfs}$$

The assumed section is sufficient to pass the discharge.

Adopt $b = 1.4$ ft

$d = 1.0$ ft

With side slopes of 2 horizontal and 1 vertical.

Example

Design the section of a lined water course for Q = 2.25 cfs with trapezoidal section of concrete blocks with b = d and with longitudinal slope of 0.5/1,000 and side slopes of 1 vertical and 2 horizontal.

Solution

Given $Q = 2.25$ cfs

$S = 0.5/1{,}000$

$n = 0.017$

$Z = 1{:}2$

$$Q = AV$$

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

$$A = bd + Zd^2$$

$$= b^2 + Zb^2 \qquad \text{Assume } (b = d)$$

$$P = b + 2d\sqrt{Z^2 + 1}$$

$$= b + 2b\sqrt{Z^2 + 1}$$

$$\therefore R = \frac{A}{P}$$

$$= \frac{b^2(1 + Z)}{b(1 + 2\sqrt{Z^2 + 1})}$$

$$= \frac{b(1 + Z)}{(1 + 2\sqrt{Z^2 + 1})}$$

$$= \frac{3b}{1 + 2\sqrt{5}} = 0.55b \qquad (Z = 1{:}2)$$

$$\therefore V = \frac{1.486}{0.017} \cdot (0.55b)^{2/3} \cdot \left(\frac{0.5}{1{,}000}\right)^{1/2}$$

$$= 87.4 \times 0.67b^{2/3} \times 0.022$$

$$= 1.288b^{2/3}$$

$$\therefore Q = AV$$

$$2.25 = 3b^2 \cdot 1.288b^{2/3}$$

$$b^{8/3} = \frac{2.25}{3 \times 1.288b^{2/3}}$$

$$\therefore b = 0.93$$

and $d = 0.93$

Adopt $b = 1.0$ ft.

$d = 1.0$ ft.

B. DISTRIBUTION BOX

At the point of bifurcation or trifurcation of a water course into two or three smaller water courses, a structure called distribution box is constructed. It is usually rectangular in shape with the required number of openings for water distribution. It is usually constructed of brick. A typical distribution box is shown below.

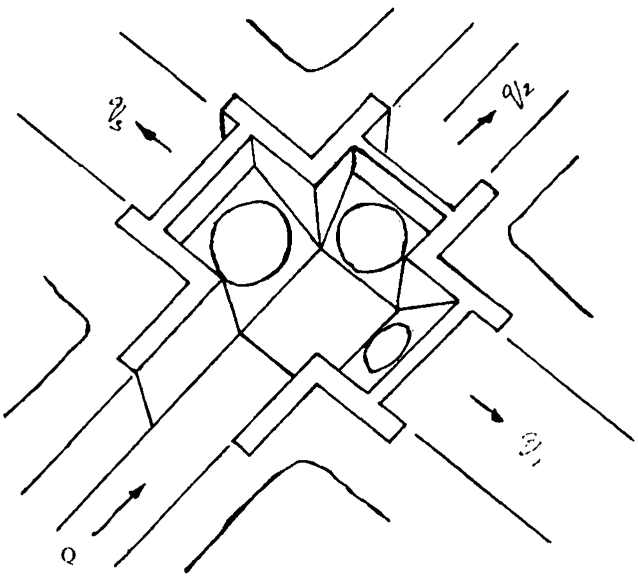


Figure 13. Distribution box

C. CHECK STRUCTURE

A structure required to raise the water level in a water course to feed a turnout is called a check structure. A check structure in a water course is usually of the flash board type as shown below. Grooves are provided in the water course wells through which a wooden plank or board is lowered to raise the water level.

D. DROP STRUCTURE

Where topography is steep, a water course is provided with drops or falls to avoid excessive earth work. A typical drop structure consists of a cistern about nine inches deeper than the bed of the water course. The cistern floor should be made of nine-inch deep concrete.

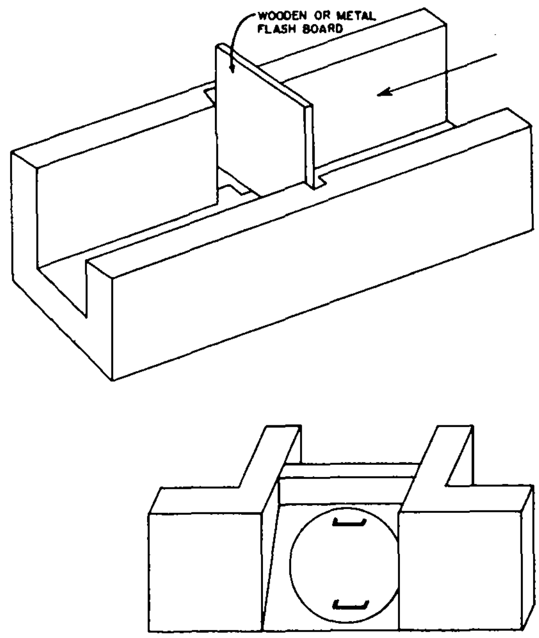


Figure 14. Isometric view of check structure

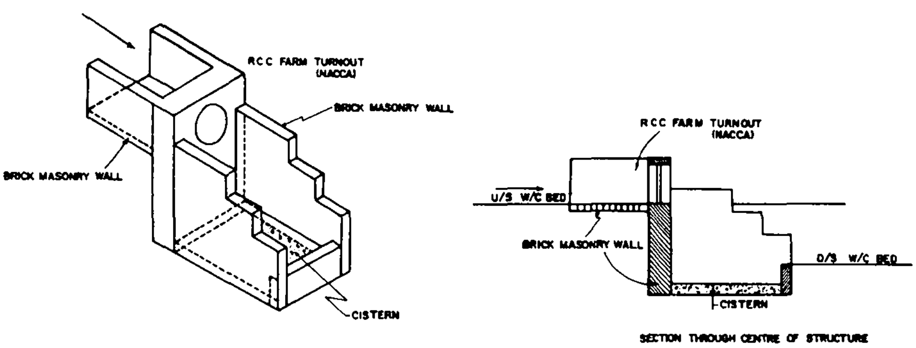


Figure 15. Drop structure

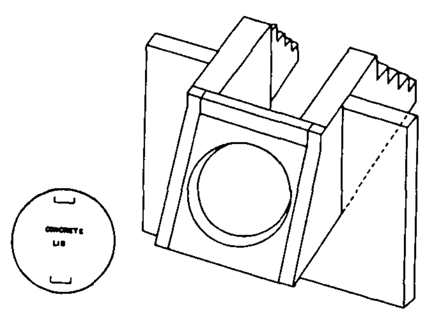


Figure 16. Single turnout

E. FARM TURNOUT

Water from the water course is allowed into the farm through a structure called a farm turnout. Along each water course a number of farm turnouts are constructed. A farm turnout consists of a pre-cast concrete panel with a circular opening and embedded in brick or concrete walls. It is provided with a circular concrete lid to close the opening. These turnouts are usually constructed of sizes ranging between 10 and 30 inches.

Figure 16 shows a single turnout.

VII. WATER APPLICATION METHODS TO FIELDS IN SURFACE IRRIGATION

Irrigation water is applied to the fields by three general methods. The choice of the method depends upon topography, soil characteristics, water availability, crops to be grown and cultural practices. All these factors jointly or individually decide the method to be adopted.

The three methods are:

(a) Flood irrigation method;

(b) Border irrigation method;

(c) Furrow irrigation method.

The most important requirement which these methods have to fulfil is to provide the required depth of water during each irrigation in all areas. This depends upon the field slope and roughness. Another consideration is the erosiveness of the soil, which will limit maximum inflow rate to a field. The topography of a field limits the types of systems which can be used. Those which have rolling terrain, irregular shapes and shallow soils may make it impracticable to irrigate by the above-mentioned methods. On the other hand, flat terrain, fields with regular shapes and deep soils may be adaptable to one of the methods mentioned above. Thus the project area should be surveyed with contour intervals at close distance, while land slopes should be determined. Similarly, auger bore holes will be necessary to determine soil depth and characteristics.

A. FLOOD IRRIGATION

1. Method

In this method, low ridges or low dykes are constructed all around the field, irrespective of its shape. Water is allowed to enter the field without any check, restriction or any guidance to its movement. The water stands in the field and percolates through it, to provide the required moisture for the crops. In this method field losses are very high. Therefore to reduce such losses, the field should be levelled as far as possible.

2. Applicability

This method is applicable to fields of any shape, size and slope, 0.5 to 15 per cent.

3. Soils

This method is particularly useful for fine-textured soils with a low permeability rate. It is also often used for leaching of salts by deep percolation. Where rainfall is very high, adequate drainage facilities should be provided.

B. BORDER IRRIGATION

1. Method

In this method, water is advanced on the field in the form of a sheet in narrow strips constructed on the farm. Therefore the field to be irrigated is divided into a number of narrow strips, generally 5 to 15 m in width and 75 to 300 m in length, separated by low dykes or ridges and gently sloping in its length. The ends of the strips are not usually closed. Each strip is supplied with a farm turnout at its higher end. The rate of supply of water to the border should be such that the amount is just sufficient to reach the end of the strip. When the required amount has been supplied to the strip, the supply is turned off and the water is allowed to infiltrate into the ground. When the irrigation requirement of one strip has been completed,

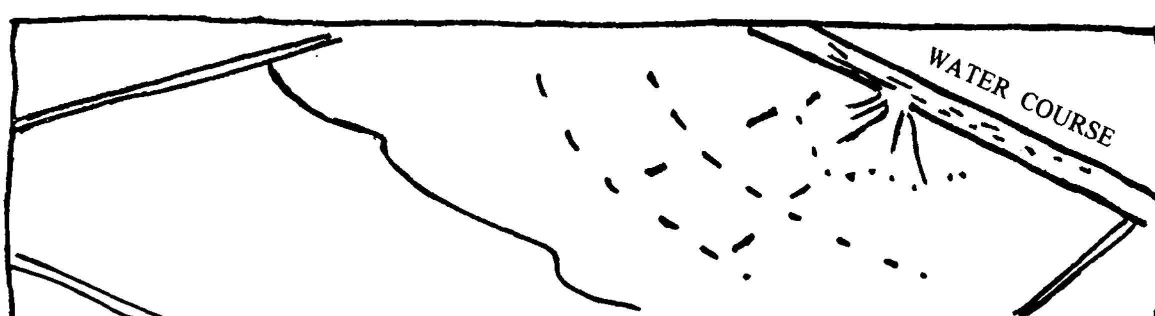


Figure 17. Flood irrigation method

the water is channelled into the next strip and so on. (Figure 18).

2. Applicability

Suitable for land with a slope of up to 5 per cent, this method can be used on a wide range of soils. However, it is not suitable for coarse sandy soil where the intake rate is very high or for those with an extremely low intake rate like fine textured soil.

It is suitable for hay, pasture, grain crops, legumes and grasses, and for irrigating orchards.

3. Advantages

If border strips are designed and installed properly, field irrigation efficiency is very good. Border strips can be constructed by machines, and farm machinery can be used within the strips.

Because of its case of adaptability and water application, this method is widely used. The three requirements of this method are: (a) abundance of water; (b) gentle topography; and (c) careful land levelling.

C. FURROW IRRIGATION

1. Method

In this method, small, evenly spaced, shallow channels are installed down or across the slope of the field to be irrigated. Water is turned in at the high end and conveyed through the small channels to the vicinity of the plants. The spacing of the furrows depends upon the individual crop and the type of soil. Usually, furrows are quite long. It is common practice to construct furrows of 100 to 200 m in length, from 1.5 to 5 m apart. The average slope provided in each furrow in humid areas is usually 0.3 per cent. The depth of the furrows is dependent on the individual crop. Some crops need deep furrows whereas others only require shallow furrows.

Figure 19 shows the layout of furrows. In the first layout, each individual furrow receives water directly from the water course, whereas in the second type a group of three or more furrows receives water. Usually, furrows are supplied from the water course by field syphon tubes. They are available in various diameters, in plastic, aluminium, galvanized iron or rubber. Discharge from a syphon

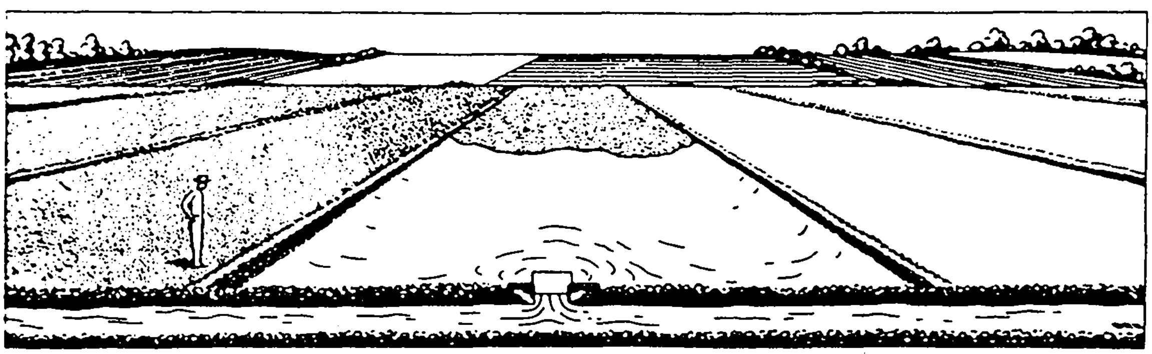


Figure 18. Border irrigation

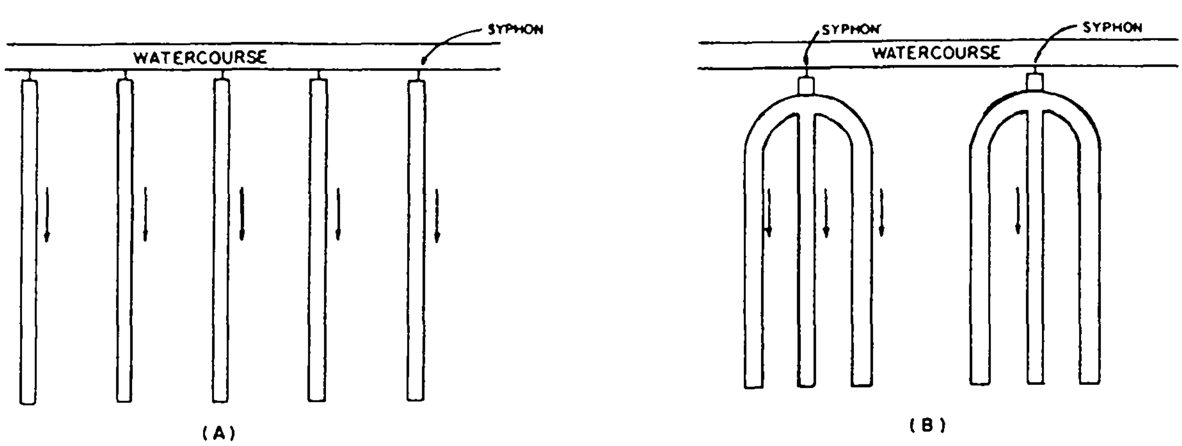


Figure 19. Layout of furrows

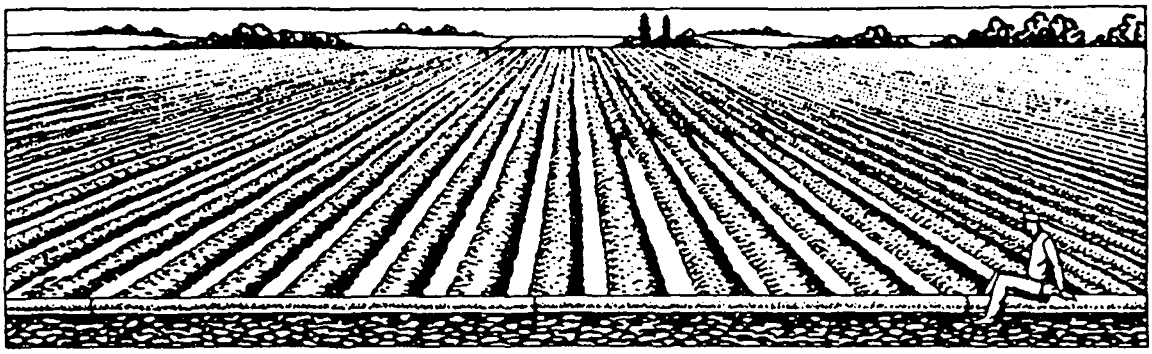


Figure 20. Level furrow irrigation

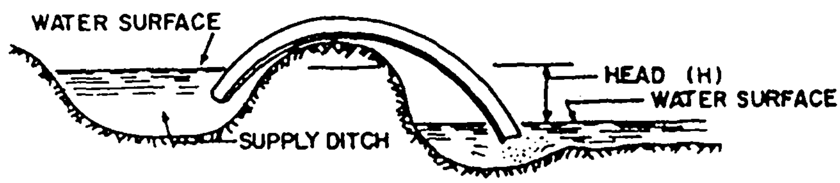


Figure 21. Supply through syphon

tube can be altered by adjusting the height of the tube's ends.

2. Applicability

Row crops such as potatoes, maize, cotton, fruit trees, grapes and vegetables can be irrigated by the furrow irrigation method.

This method is suitable for medium to moderately fine textured soils of relatively high available water-holding capacity and conductivity.

Since in this method, water moves both vertically and horizontally under the surface, it is especially suitable for soils which form a crust.

3. Advantage

Moderate to low initial investment is required in land forming. Furrows can be constructed using ordinary farm implements.

Furrows can also act as drainage channels and can provide adequate drainage in humid areas when connected with a drain at the lower end.

With proper water management practices, moderate to high irrigation efficiency can be achieved.

Table 16 gives discharge in cusecs corresponding to various heads, H, in inches of syphon tubes with internal diameters varying from two to 12 inches.

Table 16. Discharge measurement through syphon

Head H in inches	*Flow in Cubic Feet per Second*							
	Syphon Diameter in Inches							
	2	*3*	*4*	*5*	*6*	*8*	*10*	*12*
2	0.04	0.1	0.16	0.25	0.38	0.68	1.05	1.51
3	–	0.12	0.22	0.29	0.48	0.81	1.3	1.94
4	0.067	0.13	0.25	0.4	0.54	1.0	1.52	2.2
6	0.07	0.17	0.31	0.49	0.61	1.2	1.9	2.65
8	0.087	0.19	0.36	0.51	0.76	1.4	2.2	3.05
9	0.089	0.21	0.4	0.52	0.81	1.5	2.3	3.3
10	0.09	0.22	0.42	0.6	0.9	1.57	2.4	3.46
12	0.11	–	0.45	0.68	0.98	1.7	2.6	3.8

VIII. SUB-IRRIGATION SYSTEM

A sub-irrigation system can be defined as a system by which the elevation of the groundwater table is regulated through artifically adding water to the subsoil. By adding water to the subsoil the depth of ground water is maintained at a level which is most beneficial to the roots of the crops. In a sub-irrigation system, water is infilterated into the soil through sub-surface pipes. In this way the water table is maintained at a pre-determined depth so that crops can derive their water needs from it. Sub-irrigation is limited to areas where the soils are relatively permeable for a considerable depth, where surface slopes are gentle and where natural drainage is restricted. Moreover, it must be practical to hold the ground-water table at a particular depth.

Sub-irrigation is widely practiced in humid areas, whereas in arid and semi-arid areas its application is limited to those areas which are conducive to sub-irrigation.

IX. SPRINKLER IRRIGATION SYSTEM

The method by which irrigation is applied to land in the form of rain is called sprinkler irrigation. This system is adaptable to many crops, soils and topographic conditions, and if designed properly can provide satisfactory service for many years.

This system of irrigation can most advantageously be used where the following conditions exist:

(a) Rolling lands and land with steep slopes;

(b) Soils of high permeability and low water-holding capacity;

(c) Land levelling for good surface irrigation is too costly;

(d) Non-availability of farm labour trained in surface irrigation;

(e) High cost of farm labour.

The advantages of a sprinkler system include:

(a) Minimum wastage of water;

(b) High water application efficiency;

(c) Ability for light frequent irrigation as well as infrequent irrigation at low cost;

(d) Ability to apply fertilizers and pesticides along with the irrigation water;

(e) Frost protection for vegetables, citrus fruits and flower crops;

(f) Reduction of temperatures on hot days for crops such as vegetables and fruits;

(g) Especially suitable for apples.

A. TYPES OF SPRINKLER SYSTEMS

A sprinkler system consists of pumps, pipe lines, laterals, risers and sprinklers. The source of water is located at a higher elevation than the fields and no pump is required, as the water can flow in the pipes under pressure due to gravity. However, in such a system long pipe lines and laterals are required. The gravity sprinkler system is, however, considered to be the best and it is the cheapest method of irrigation.

Sprinklers can be classified into three groups: fixed nozzle; perforated pipe; and rotating type.

Fixed nozzle types, the earliest form of sprinkler, are relatively small pipes, usually of galvanized steel with a single row of small nozzles spaced at regular intervals of two to five feet along the length and installed on posts. Mostly they are permanently installed but in a few cases the posts are permanently installed, while the lines are movable. Since the diameter of the nozzles is small, they get clogged frequently and require regular cleaning.

Perforated pipe sprinklers are most commonly used in nurseries and orchards. With this type, holes are drilled in a variety of patterns into the top side of pipes which are laid on the ground. Fine jets of water under slow pressure irrigate a rectangular strip of land along the pipes, usually covering about a 50 ft wide strip.

Rotating sprinklers are most widely used. These are of various types and shapes, and apply water at a slower rate while using relatively large nozzle openings. Clogged nozzles in such sprinklers are, therefore, less frequent. As a slow rate of application of water is desirable on soils having low infiltration rates, the rotating type of sprinkler is widely used on such soils.

The source of water for a sprinkler system may be a river, lake, stream, canal or well. If the source is located at a higher elevation than the fields, no pumpage will be required and the water can be utilized under gravity. When the source is at a lower elevation pumps are required to develop the required pressure.

Pumping from lakes, streams and canals is usually done by centrifugal pumps. As silt and floating debris is harmful to sprinklers, the intake should placed in water where the silt content is the least. Floating debris should also be kept away from the pump intake.

When pumping is required from deeper levels, i.e., from wells, turbine pumps or submersible pumps are usually used. In the case of higher elevations, multi-stage pumping is utilized.

The sprinkler systems are of various shapes and sizes. However, they can be classified into three main types: (a) solid-set; (b) semi-portable; and (c) portable.

1. Solid-set system

A solid-set system consists of a stationary pump and permanently buried pipe lines and laterals, which are turned off and on as and when required. Such systems are mostly used for irrigation of turfs, parks, golf courses and fruit orchards.

(a) Field layout

The field layout of the system depends upon the crops to be grown, mode of operation, availability of labour, shape of the field, size and topography. In a typical solid-set system, the pump is permanently fixed at the water source, and the mainlines and laterals are permanently buried in the ground. The mainline is usually laid at one end of the field or may be laid through the field. The laterals are laid perpendicular to the mainline and parallel to the row directions. However, the mainlines and laterals can also be laid in any feasible pattern. In most solid-set systems, the risers and sprinklers are installed permanently.

(b) Sprinklers

Sprinklers are manufactured with different nozzle sizes and to withstand different pressures. In a solid-set system, low-flow medium pressure sprinklers are normally used. Sprinkler spacing varies from 10 m by 10 m (33 ft by 33 ft) to 75 m by 75 m (250 ft by 250 ft).

Since sprinklers are continuously being improved, planners and designers should obtain full design and performance data from the manufacturers. The choice of the size of sprinkler, operating pressure under wind, nozzle sizes and discharge for various nozzle sizes will be dependent on the manufacturers' data.

(c) Mainline and laterals – pipe hydraulics

The design of mainlines and laterals is done using the William-Hazen formula. Velocity should by restricted to 5 ft/sec or 1.6 m/sec.

$$H_f\,(100) = K\frac{\left(\frac{Q}{C}\right)^{1.852}}{D^{4.87}}$$

Where:

H_f = friction loss

C = a co-efficient of friction

Q = flow of water in the line L/S, ft^3/sec, gal/min

D = diameter of pipe (mm, ft, in)

K = a constant

The values of C for various materials are as follows:

New steel, aluminum	C = 120
Asbestos	C = 140
Plastic, PVC, PE	C = 150

The values of K:

Q in metric units, K = 1.22×10^{12}

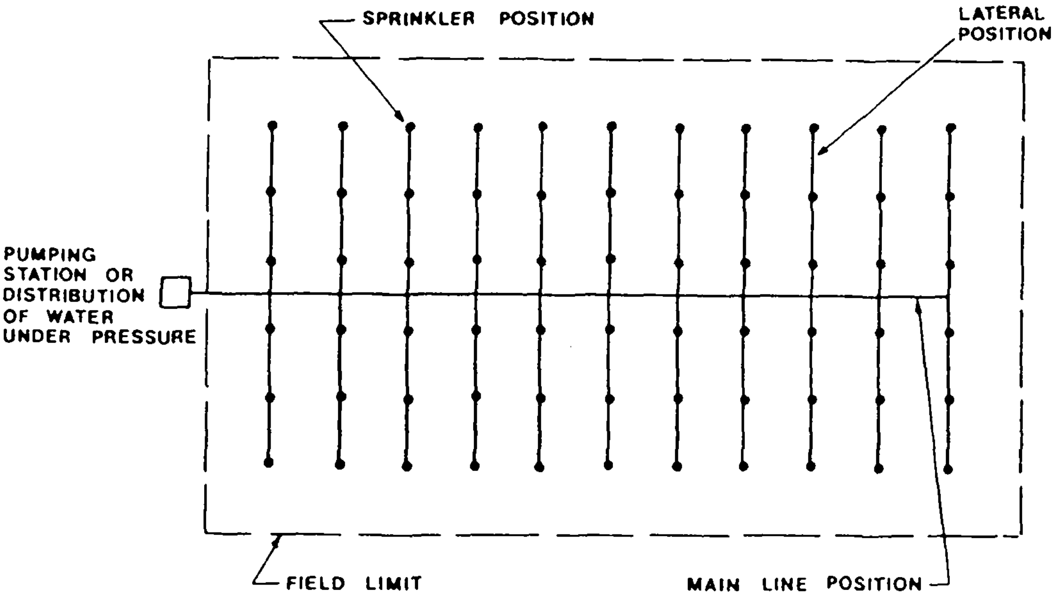
Q in British units, Q in cfs, K = 473

Q in British units, Q in gal/min, K = 10.46

When more than one lateral on a solid-set system is operating at one time, the supply line becomes multi-outlet. Therefore, friction loss must be computed in each segment. This makes the computation quite involved. To simplify the computation of lateral pipe sizes, a range of charts, monographs, tables and computer programmes have been prepared and can be obtained from most of the larger manufacturers or technical publications.

(d) Operation

If the system is used only for irrigation, a portion of the system only is normally operated at one time. Control of the system may be automatic or manual. In labour-short areas, an automatic system is suitable. Similarly, for irrigation of shallow-rooted crops grown on coarse textured soil and requiring frequent irrigation an automatic system may be used.



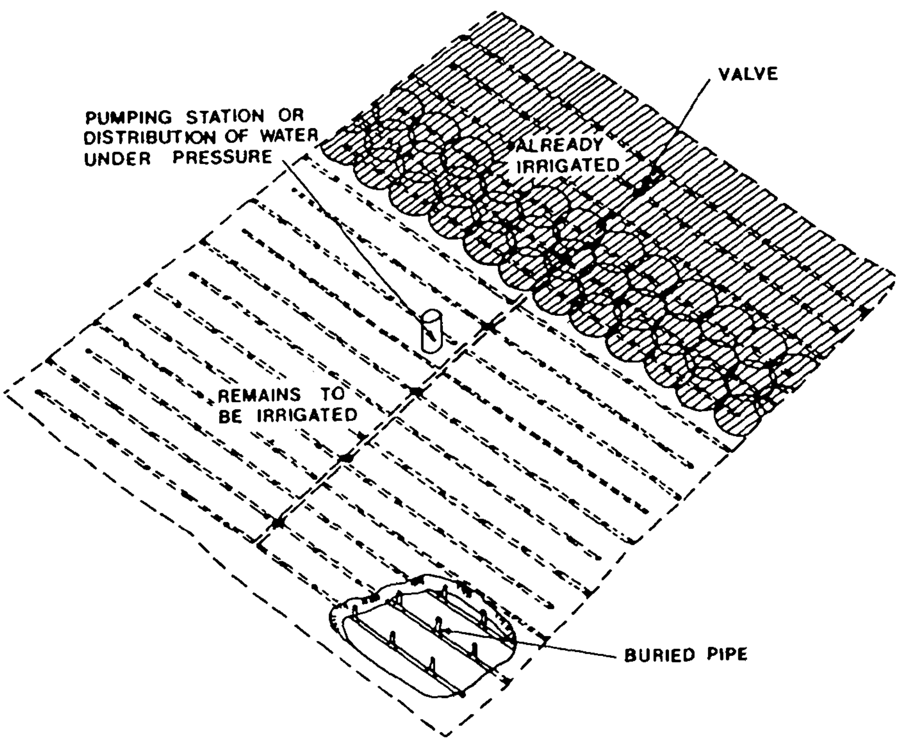


Figure 22. Entirely fixed sprinkler system network

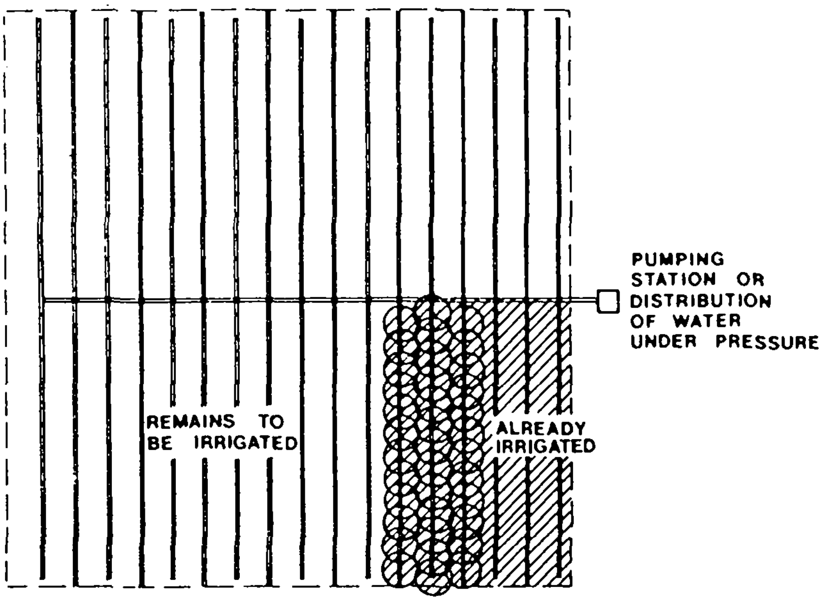


Figure 23. Layout of a pipe network with mobile sprinkler heads (total cover)

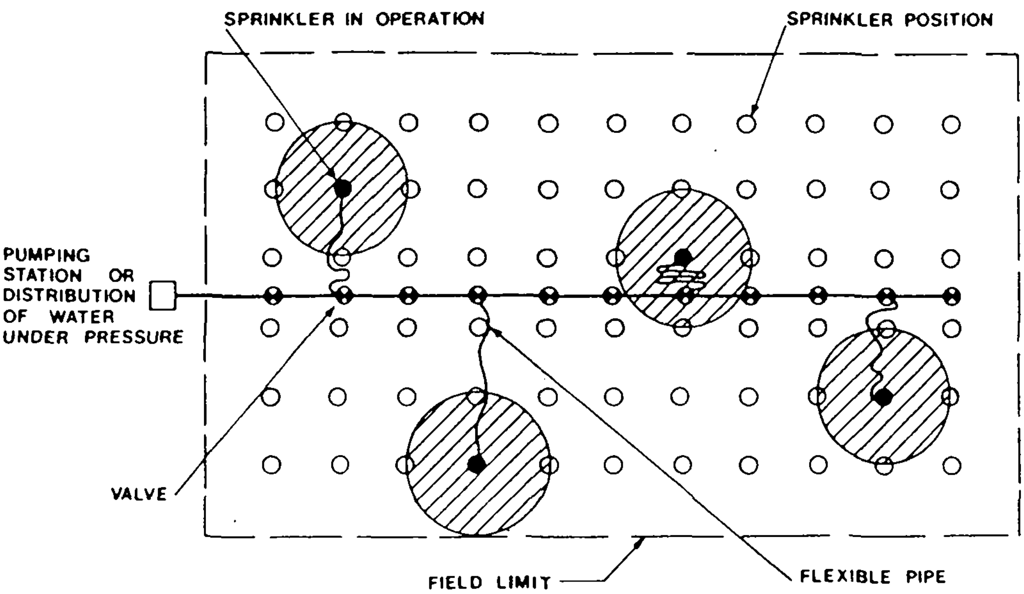


Figure 24. Layout of a pipe network with sprinklers attached to flexible pipes

2. Semi-portable system

A sprinkler system in which the pump is stationary, i.e., it does not move whereas the main and laterals are movable, is called a semi-portable system.

In an effort to reduce the initial investment, only enough sprinklers and risers to irrigate a part of the field at one time are installed. As the irrigation in the area is completed, the sprinklers and risers are moved to other locations.

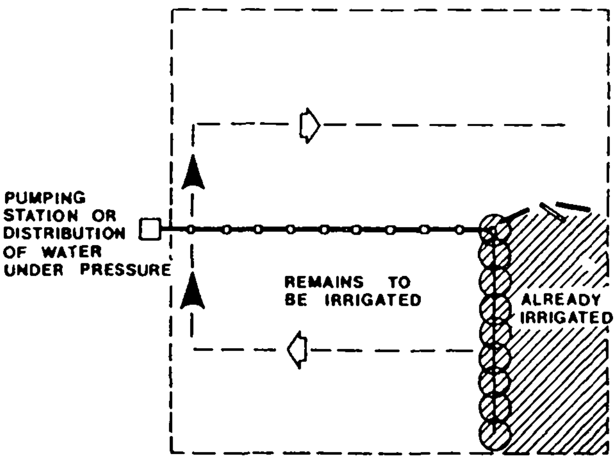


Figure 25. Layout of semi-portable pipe network. Mains and laterals are movable. Pump is stationary.

3. Portable system

Portable systems are those in which all parts of the system are moved from one position to the other.

Methods of movements

For portable and semi-portable systems, various methods are employed by which the mains and the laterals are moved from one field to the other.

These are mainly of two types:

(a) Manually-moved system;

(b) Power-moved system

(i) Side roll system

(ii) End pull system

In the manually-moved system, the laterals and the main are moved to the next position manually. In the power-moved system, mobility is provided either by a tractor or by motors. In the side roll system, laterals act as the axle of a large diameter wheel which is rolled to the next position by a motor. In the end pull system, the pipe and the laterals are pulled to the next position by a tractor.

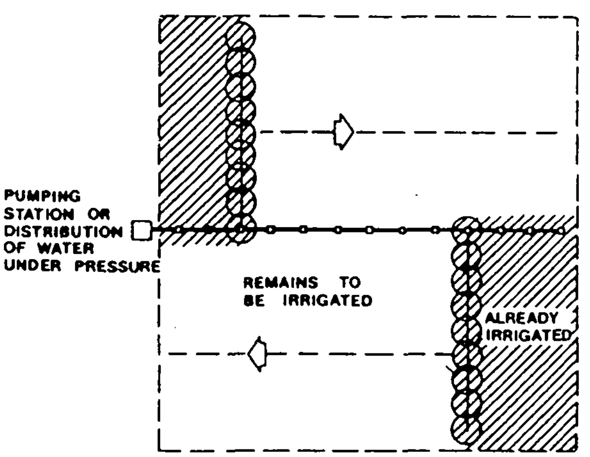


Figure 26. Layout of pipe network with mobile sprinkler laterals. Pump and mains are stationary.

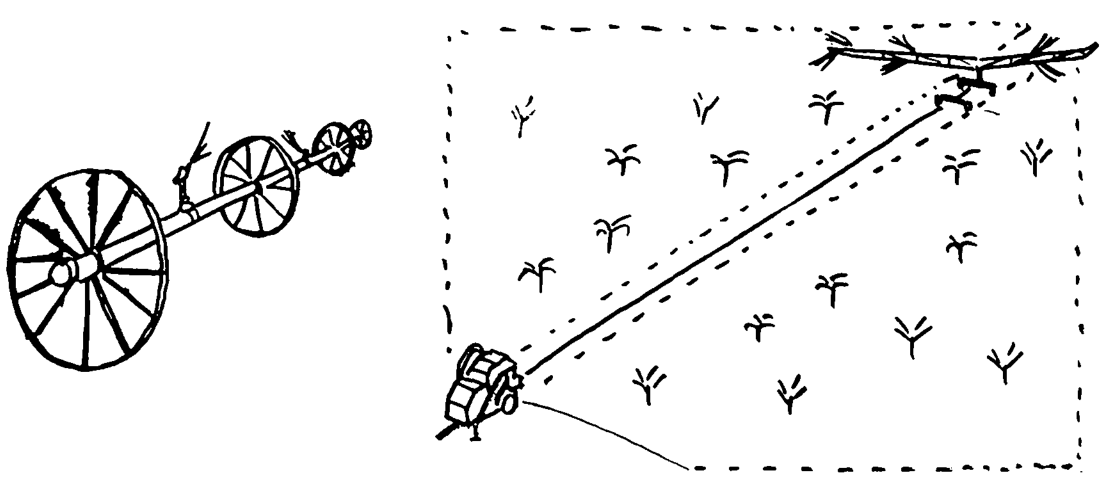


Figure 27. End pull system

X. DRIP IRRIGATION SYSTEM

A. APPLICATION

In the drip irrigation method, water is applied drop by drop in the required quantity directly to the root zone of the plants. This method is suitable in arid areas where temperatures are high and water is in short supply. It has been successfully used to raise fruit, vegetables, cotton, sugarcane, sorghum crops etc. It is highly successful in cases where the cost of water is high or where the land is highly sloping or undulating, where labour is scarce or expensive, or where water quality is marginal. The advantages and disadvantages of the drip irrigation system are:

1. Advantages

(a) The conveyance losses are practically eliminated;

(b) The amount of water used is often less than 50 per cent compared to that used by the surface irrigation method;

(c) High irrigation efficiency is obtained;

(d) It is suitable in water-short areas;

(e) Injection of fertilizer is easy.

2. Disadvantages

(a) Higher initial cost;

(b) High technological knowledge required of operation and maintenance of the system;

(c) Deposition of salt in the pipes, reducing discharge;

(d) Clogging of tricklers by silt, debris etc.

B. THE SYSTEM

The system consists of a pump, storage tank, an extensive network of small diameter pipes and distribution valves called tricklers, emitters or distributors.

1. Pumping system

A pressure pump is used to convey water from the source to a storage tank. For all practical purposes, the components and their dimensions are the same as those required by a sprinkler system. The auxiliary components consist of a check valve, fertilizer tank, fertilizer pump, gate valve, filters and pressure valves.

2. Main feeder and sub-main pipes

The feeder and sub-main pipes are usually of PVC of adequate diameter and strength to convey the required quantity of water under pressure. These pipes are buried in the ground to protect them from sunshine.

The sub-main is connected to the main feeder by various devices such as adapters or pipe tees. It may also be fitted with pressure-regulating valves, flow-control valves, water meter etc. Similarly, the mainline may also be fitted with manual valves to help isolate certain areas of the system, so that irrigation in other areas may be possible even when another part of the system is broken.

3. Laterals lines

Laterals are small diameter pipes usually made of polyethelyne of 1 to 3 cm in diameter, with 14 mm being most common. The laterals are laid on the ground and during ploughing they are collected and moved to one side.

The trickler, emitter, distributor etc. is fitted to the lateral by drilling a hole, whereas the farther end of the lateral is closed either by a pipe fitting or simply by crimping it over.

4. Trickler (emitter, distributor etc.)

This is the main component of the system. It functions like a tiny flow regulator in which the flow rate is controlled by the water pressure, the length of the trickler and its diameter. One end of the trickler is inserted into the side of the lateral by making a pin hole in it. The other end is placed near the plant. The usual arrangement of a trickler near a plant is shown in figure 28.

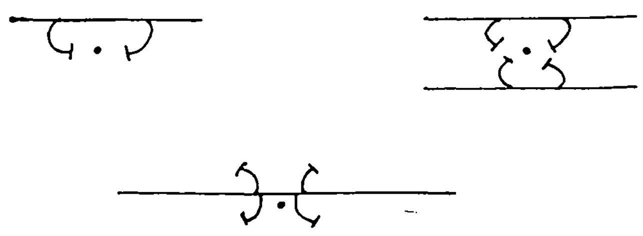
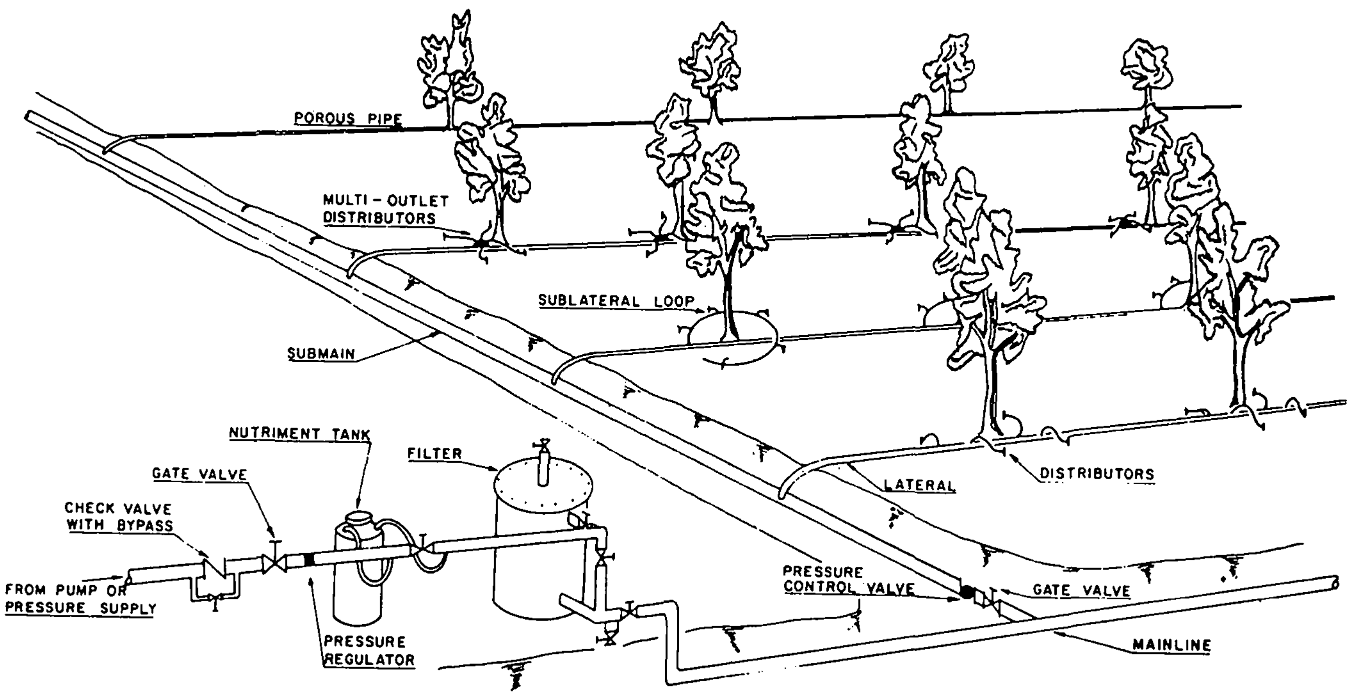


Figure 28. Arrangement of tricklers

Tricklers are of several types including the long path, short orifice, vortex, pressure compensating etc. These are being continuously improved. At the time of planning a project with trickle irrigation, the planner should contact the trade representatives of some of the best-known manufacturers and obtain details of tricklers so that the best can be selected. However, the tricklers should be able to: (a) supply water at 1.0 l/hr; (b) supply water consistently for a long period of time; and (c) withstand various types of weather, sunshine etc.



Source: FAO, Irrigation and Drainage Paper No. 14 FAO, Rome, 1973.

Figure 29. Basic components of a localized irrigation system

XI. OPERATION AND MAINTENANCE

The success of an irrigation system depends upon the timely delivery of irrigation water to the fields in amounts necessary to satisfy the crop water requirements. This can be achieved if the system is operated according to the planned water uses and is maintained with the full appreciation of the principles of hydraulics and geotechnical engineering.

A. OPERATION OF THE SYSTEM

1. Water conveyance system

For an uninterrupted supply of water to the field it is important that the prism of the water conveyance system, which will include canals and water courses, should not only be hydraulically capable of conveying the designed discharge, but the canal banks should also be strong. Since the hydraulic efficiency of the canal section largely depends on the efficient operation and maintenance of the canal system, their importance cannot be ignored. It is therefore essential that the canals should be operated with proper understanding of the laws of hydraulics and soil mechanics.

2. Water inletting procedure

In canals where water is allowed to flow for the first time following construction, or in channels which have remained closed for a long period of time, water should be allowed to enter and attain the full supply level gradually. The sudden opening of such canals is fraught with the danger of breaches in the banks caused by water flowing into hidden cracks, creeks, fissures or holes dug by burrowing animals.

Rapid lowering of the water level may result in sloughing or bank slippage. Since slips cause breaches, rapid lowering should also be avoided; however, this cannot be fully avoided because in the case of a breach in the canal section, the upper supply has to be completely shut off, as a rapid lowering of the water level is necessary.

B. MAINTENANCE OF THE SYSTEM

1. Objective

The objective of maintenance is to keep the irrigation and drainage system working in a satisfactory manner, within the limitations imposed by the initial design.

2. Types of maintenance

The three main types of maintenance are listed below.

(a) Routine or normal maintenance

This includes all work necessary to keep the irrigation system functioning satisfactorily. This is normally done annually.

(b) Special maintenance

This includes repairs of damage caused by unforeseen natural disasters like floods, earthquakes etc.

(c) Deferred maintenance

Any maintenance deferred to a later date due to non-availability of required finances or facilities in a particular year is called deferred maintenance. If maintenance is deferred for a sufficiently long time, then the system deteriorates and may require a special programme to rehabilitate it to its normal state.

3. Maintenance activities

The maintenance activities concern: (a) diversion structure; (b) irrigation network; (c) regulation and distribution structures; and (d) mechanical and electrical systems.

(a) Diversion structures

The maintenance activities for a diversion structure comprise the following elements:

(i) Repairs to masonry structure and floors.

(ii) Keeping the waterway clear to ensure passage of full supply discharge.

(iii) Treatment of scour holes, both on the upstream and downstream side of the structure.

(iv) Weed control in the waterway.

(v) Lubrication of gates and gearings.

(vi) Anti-corrosion treatment.

(vii) Maintenance of the electro-mechanical system.

The maintenance of elements (v), (vi) and (vii) are rather specialized and the manufacturers of the equipment usually provide detailed instructions.

Of the remaining elements, treatment of scour holes is important for the safety of the structure. Scour holes can develop either on the downstream or the upstream side of the structure due to faulty operation or excessive velocities in the channel. Downstream scour holes travel upstream and upstream scour holes move downstream. If left unchecked, the floor may collapse, endangering the structure. Scour holes should therefore be filled by dumping large-sized stones in them. Moreover, the depth and movement of the scour hole should be kept under close watch.

The waterway should be kept clear of floating debris, trees and accumulation of sand. Cuts in the sand bars should be excavated to allow water to wash away the sand.

(b) Irrigation network

The canals in the irrigation network can be either lined or unlined canals.

(i) Lined canals

Lined canals should require little maintenance provided they have been properly constructed. However, routine activities include replacement or repair of damaged portions of the lining, replacement of joints, removal of weeds from joints and removal of silt.

Under normal circumstances, silting does not take place in lined canals. However, if it does occur, it can be removed by manual labour since machinery may damage the lining. Wherever possible, silt should be washed down by the technique of flushing. Weeds should be removed whenever they appear, using chemical control. The main problem with concrete lining is subpressure which may crack the lining or cause its eventual eruption. If not installed during the original construction work, it may be possible to install sub-surface drainage while repairing filters.

(ii) Unlined canals

The main problems experienced with unlined canals are: section maintenance; control of siltation; and control of seepage. These are detailed below.

Canal section

A canal section that has become wide due to scouring should be restored by the method called bank formation. This method is possible where water carries silt. Siltation of the bank is induced by construction of a brush spur in the affected area. The silted banks are considered to be much more resistant to erosion than the natural material.

Hydraulic efficiency of canal section

For hydraulic efficiency of a canal, it is important that the canal prism should conform as closely to the designed dimensions as possible and should have a smoother surface with a low co-efficient of roughness. The flow of water in the prism should be free from all obstructions, either from the floating jungle or from the deposition of silt in the section. Therefore jungle growth from the canal section should be removed as soon as it is noticed. Similarly, silt clearance should be done periodically.

To check the discharge capacity of the canal, periodic discharge measurements should be carried out.

(c) Regulation and distribution structure

Maintenance of regulation and distribution structures is similar to that of diversion structures.

(d) Mechanical and electrical systems

Maintenance of mechanical and electrical systems is rather specialized and the manufacturers of the equipment usually provide detailed instructions.

XII. HYDRAULIC MEASUREMENTS

A. DISCHARGE MEASUREMENTS THROUGH A BARRAGE OR A HEAD WORK

Barrages and canal head regulators are usually sharp-crested weirs. The discharge passing through these structures is computed by applying weir formula.

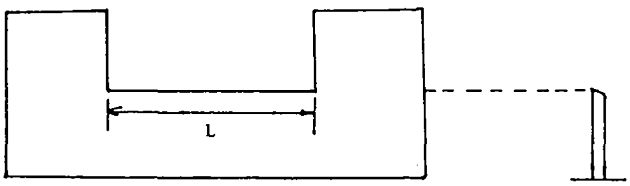


Figure 30. A sharp-crested rectangular weir with end contractions

$$Q = CL'H^{3/2}$$

where:

Q = discharge

L' = effective length of weir

H = depth of water flowing over the weir

Because of the end contractions, the effective length of the weir is equal to:

$$L' = L - 0.2H$$

where:

L' = effective length of weir

L = length of weir from one end to the other

For rectangular sharp-crested weirs, the value of C has been experimentally determined as 3.33.

In case of a barrage or a head regulator with more than one opening, the effective length of the weir becomes:

$$L' = L - 0.2nH$$

Where n is the number of openings.

Therefore, the weir formula for a sharp-crested weir becomes:

$$Q = 3.33\,(L - 0.2nH)\,H^{3/2}$$

In actual operation, a rating curve of discharge vs depth of water passing over a weir is developed and is used to determine the discharge passing over the weir at a particular time.

B. DISCHARGE MEASUREMENT OF A CANAL BY CURRENT METER

The discharge through a canal is measured by a method called the area-velocity method, which includes determination of the sectional area of the unit length of the stream and the mean velocity of water flowing in it. The product of cross-sectional area and velocity gives the discharge. In the case of small canals, the cross-sectional area is measured in one step, whereas if the canal has a big section the area is measured by dividing the section into several vertical strips. The area of each strip is equal to the product of surface length and the average depth of the section. The average depth is measured by lowering a heavy weight into the middle of the section. The velocity is measured by current meter at 0.6 depth below the water surface. The product of area and velocity gives the discharge passing through the section. The sum of the discharges of all the strips gives the discharge of the canal.

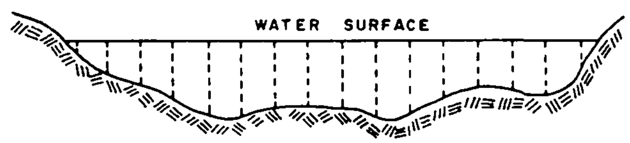


Figure 31. Canal section divided into several vertical strips

C. MEASUREMENT OF DISCHARGE OF A WATER COURSE

The discharge of water courses is usually measured by:

1. Portable flume;
2. V-notch;
3. Weir;
4. Current meter.

1. Portable flume

Parshall designed a portable flume to measure small discharges. The flume has a narrow throat with a converging entrance and diverging exit sides. A typical flume is shown in figure 32.

The various dimensions of the flume are given in figure 33. The flume can be constructed with any convenient throat width. Usually, portable flumes are provided with throat widths equal to three, six or nine inches.

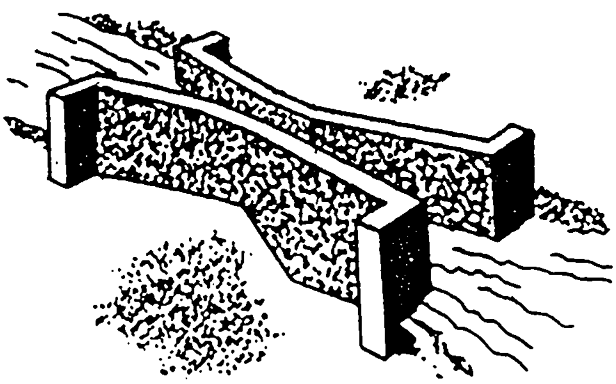


Figure 32. **Parshall flume**

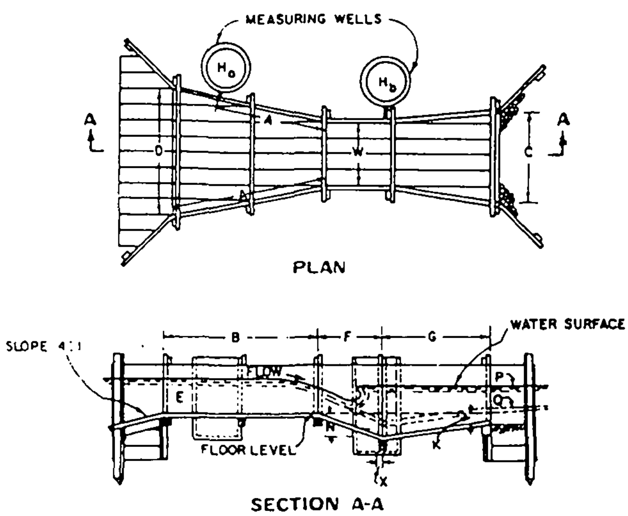


Figure 33. A portable Parshall flume

The length of the throat is kept at twice its width. On the upstream, the sides flare by 1:5 and on the downstream, by 1:6. On the upstream of the throat, the floor is flat and level, whereas the floor in the throat slopes downwards by 1:2.5. From the end of the throat, the floor rises in a slope of 1 in 10. The various dimensions of standard flumes in inches with three-, six- and nine-inch throat widths are given in table 17.

A gauge well is fixed at a distance equal to A on the upstream of the throat. The water head above the floor level is recorded by this well. The discharge corresponding to different heads in the flume are given in table 18. Thus to measure the discharge only the head in feet is noted and the discharge can be read from the table.

Table 17. Standard dimensions of Parshall measuring flumes with throat width of 3, 6 and 9 inches

Dimension, in. (refer figure)	*Throat width (w)* 3	6	9
D	10.19	15.5	22.6
A	18.37	24.4	34.6
B	18.0	24.0	34.0
C	7.0	12.0	15.0
G	12.0	15.0	18.0
F	6.0	12.0	12.0
N	2.25	4.5	4.5
K	1.0	3.0	3.0

Table 18. Discharge through a Parshall flume of various throat widths for varying heads of water

Water head, ha feet	*Throat widths (w)* 3 in.	6 in.	9 in.	12 in.
	Flow in cubic feet per second			
0.10	0.03	0.05	0.09	–
0.20	0.08	0.16	0.26	0.35
0.30	0.15	0.31	0.49	0.64
0.40	0.24	0.48	0.76	0.99
0.50	0.34	0.69	1.06	1.39
0.60	0.45	0.92	1.40	1.84
0.70	0.57	1.17	1.78	2.33
0.80	0.70	1.45	2.18	2.85
0.90	–	1.74	2.61	3.41
1.00	–	2.06	3.07	4.00

2. V-notch

The discharge of a water course can be measured by the use of a portable V-notch if there is a possibility of free-falling water downstream of the notch as shown in figure 34.

A V-notch used for discharge measurements is usually constructed with an angle of 90°. The main precautions to be taken in fixing the notch plate in the water course are:

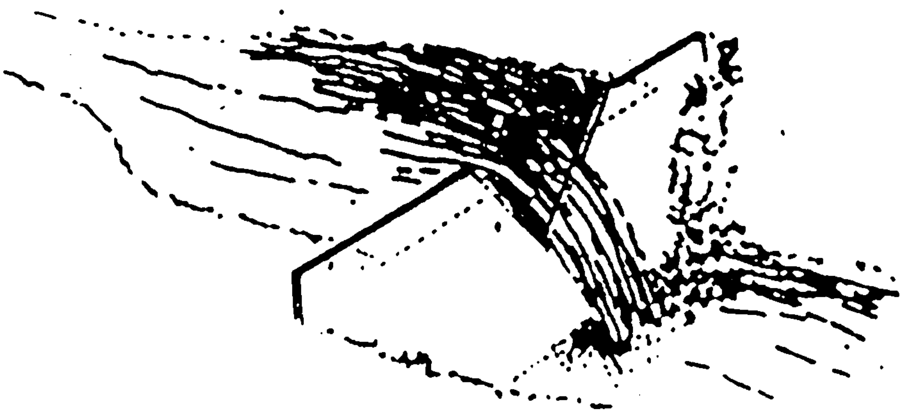


Figure 34. V-notch fitted in a channel

(a) The notch should be fixed in a straight reach of a channel. The straight reach should be about ten times the length of the weir.

(b) The notch plate should be perpendicular to the flow.

(c) A free fall should occur below the notch plate.

(d) The water course should be widened and deepened some distance upstream of the point where the notch is fixed, so that the velocity of approach is lowered to as slow as possible.

A gauge is fixed in the bed of the water course upstream of the notch at a distance equal to 2.5 times the maximum head at the notch, with the zero of the gauge exactly at the apex.

The discharge Q for the 90° notch is given by:

$$Q = 2.47\ H^{5/2}$$

where:

H = the head in ft.

The following table gives discharge in cusecs for various heads.

Table 19. Discharge of V-notch for various heads in cusecs

Head H in ft.	*Discharge*	*Head H in ft.*	*Discharge*
0.1	0.008	0.80	1.43
0.2	0.046	0.90	1.92
0.3	0.125	1.00	2.49
0.4	0.256	1.10	3.15
0.5	0.445	1.20	3.91
0.6	0.700	1.25	4.33
0.7	1.030		

3. Weir

Another method for the direct measurement of the discharge of a small channel or a water course is by the use of a rectangular weir. A rectangular weir installed in a channel results in the contraction of flow at the sides. Such weirs can be fixed in lined rectangular channels or in earthen channels as shown below.

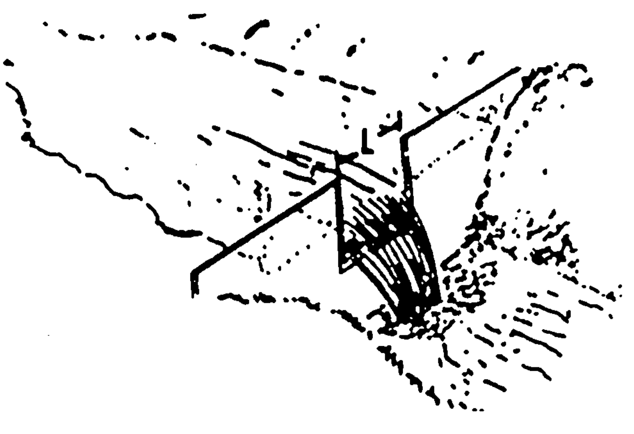


Figure 35. A weir

The precautions to be taken during installation are the same as in the case of a V-notch.

The discharge Q in cusecs is given by the Francis formula.

$$Q = 3.33\ (L - 0.2\ H)\ H^{3/2}$$

where:

H = the head in ft.

Table 20 gives the discharge in cusecs for various heads for weir length L, equal to 1.0 ft.

Table 20. Discharge of a one-foot weir for various heads, in cusecs

Head H in ft.	*Discharge*	*Head H in ft.*	*Discharge*
0.1	0.105	0.55	1.28
0.15	0.191	0.6	1.45
0.2	0.291	0.65	1.63
0.3	0.527	0.75	2.01
0.35	0.661	0.8	2.21
0.4	0.804	0.9	2.62
0.45	0.955	1.0	3.06
0.5	1.11		

D. MEASUREMENT OF SEEPAGE FROM EXISTING CANALS

Various methods are used for measuring the seepage from existing canals, including the inflow-outflow method, the ponding method and shallow-well permeameter method. Of these methods, the ponding method is considered to be the most reliable.

Ponding method

In this method a temporary watertight dyke or bulkhead is constructed across the canal. Canal regulators are sometimes used as watertight dykes. The canal above the dyke is filled with water to a specific measured level. After allowing the water to stand for a set time interval, the level in the canal is recorded. Any drop in the level is obviously due to seepage through that section of the canal. Sufficient water is then added to maintain the original level. This volume of water is equal to the total seepage loss during the set time interval. The volume of water divided by the time determines the rate of seepage loss through the canal prism.

REFERENCES

1. FAO, Integrated Farm Water Management, I & D paper No. 19, 1971.
2. FAO, Crop Water Requirements, I & D Paper No. 24 revised, 1977.
3. Chow, Ven Te, Hand Book of Applied Hydrology, McGrawhill 1964.
4. Siddiqui I.H., Fundamentals of Irrigation and Drainage Engineering, 1989.
5. Siddiqui, I.H. Irrigation Canals, National Book Foundation 1979.
6. Jensen, M.E., Design and Operation of Farm Irrigation Systems, American Society of Agricultural Engineers, 1983.
7. Davis, C.V. and Sorensen, K.E., Hand Book of Applied Hydraulics, McGrawhill 1969.
8. Israelsen, O.W., and Hansen, V.E., Irrigation Principles and Practices, John Wiley & Sons, 1967.
9. FAO, Irrigation Practices and Water Management, I & D paper 1 Rev. 1984.
10. FAO, Mechanized Sprinkler Irrigation, I & D paper No. 35, 1982.
11. FAO, Trickle Irrigation, I & D paper No. 14, 1973.
12. FAO, Organization, Operation and Maintenance of Irrigation Schemes, I & D paper 1982.
13. FAO, Design Criteria for Basin Irrigation System, I & D paper No. 3, 1971.
14. United Nations, Design of Low Head Hydraulic Structures, N.Y., 1973.

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