WATERAID

Technical Handbook

3rd Edition 1993

> This handbook assumes that the user has a basic engineering knowledge and should not be used by persons without such skills.

WaterAid is most grateful to all the volunteer advisers who have helped compile this revision of the handbook.

Foreword to 3rd Edition

Engineers in the field may not have ready access to technical literature, and may be faced with unforeseen problems which need a quick solution.

Obviously, when time and circumstance permit, guidance should be obtained from an engineering adviser, but where this is not possible, a reference handbook directed to the problems common to WaterAid work may be of value.

Suggestions as to content were sought in the latter part of 1985. Data and notes were compiled, and a first edition issued in 1987. Following helpful comment, some corrections and additions were made for the 2nd edition, issued in 1988, with a supplement in 1990.

Late in 1991 a comprehensive review was made of experience in use; a number of constructive suggestions were made, and have been incorporated in this 3rd Edition. Principal changes include Outline Designs based on WaterAid experience; an extended note on sanitation; and comprehensive revision of the E and M Section. There are also a number of smaller revisions and additions. It is important that outdated material be destroyed.

There are two Sections, dealing with Civil Engineering and Electrical/Mechanical aspects respectively. It is intended to prepare a supplement, or separate publication, on Health Education.

Please bear in mind:

1. This handbook is for the use of WaterAid personnel.

2. Whilst every effort is made to ensure that facts are correct and advice sound, a cross check is always wise.

3. It is not intended for use by laymen, or as a substitute for more detailed and comprehensive books or papers.

Section 1 - Civil Engineering

These notes are arranged in 5 groups, separated by coloured dividers.

			Divider
1 - General	Sheets prefaced	G -	Blue
2 - Basic Data	" "	B -	Yellow
3 - Formulae	" "	F -	Grey
4 - Technical Notes	" "	T -	Red
5 - Outline Designs	" "	D -	Blue

A subject Index appears at the front of each Group.

Section 2 - Electrical and Mechanical

There are three groups, each with a subject index.

			Divider
1.	Electrical	- Sheets prefaced E -	Yellow
2.	Mechanical	- Sheets prefaced M -	Grey
3.	Miscellaneous	- Sheets prefaced X -	Red

The format and page numbering is designed to allow updated pages to be inserted from time to time. On the left is the issue code, month and/or year (D/93 is Issue D, 1993). On the right is the reference number from the index (eg G4) followed by the page in that item (eg G4/3)

INDEX - GROUP 1

Group 1 - General

Introduction

This handbook is issued by WaterAid for the use of its field personnel.

It assumes a basic knowledge of engineering or similar scientific discipline.

It makes no claims to be comprehensive but the looseleaf format will enable additions to be made, and suggestions will be welcome.

Whilst every effort has been made to ensure accuracy, the possibility of error cannot be discounted, and earliest possible notification of any identified errors would be appreciated.

A short bibliography of useful reference books will be found in G3.

Design Philosophy and Check List

The WaterAid Ethos statement is the background to all our work. Application will vary with circumstances and with government or other authority requirements and regulations. Within these general constraints WaterAid design philosophy can be expressed as follows:

(i) Unless there are special circumstances, select a 15 to 20 year design horizon. Consider a longer life for major structures which are difficult to extend, such as intake works.

(ii) Schemes should be sized to produce the required quantity of water for the final population at the end of the design life of the scheme.

(iii) WaterAid funds schemes to improve drinking water supply and sanitation. It does not normally fund schemes whose primary purpose is irrigation or the watering of livestock. In areas where people traditionally own cattle and other livestock, WaterAid does support the provision of live-stock watering points as part of the drinking water scheme. WaterAid also encourages small domestic vegetable gardens.

(iv) Schemes should be designed to give value for money but where extra capacity can be included without significant extra cost then this can be done (eg choice of the next larger size of pipe when the theoretical pipe diameter needed is in between two standard diameters).

(v) All installations should be "sustainable" and operation and maintenance should be considered fully at the design stage. The design must be such that the community is willing and able to pay for operation and maintenance.

(vi) In most cases the most immediate health benefit will arise from the use of greater quantities of water. Designers should strive to make this possible. It may also be desirable that water quality should be improved. It is acceptable to use a questionable source untreated provided that no new or existing user receives a lower quality of water than before (see Feachem, McGarry and Mara "Water, wastes & health in hot climates" Wiley 1977), but provision should then be made to upgrade quality as soon as practicable. It is suggested that the following check-list be applied to each new scheme:

Have you:

1 Established the reliability of surface water sources by assessing the flow during the dry-season, over a number of years if possible (see B7)?

2 Considered the long-term sustainability of ground- water sources (eg Is ground- water recharged as fast as it is abstracted? Are surface catchments properly protected)?

3 Assessed the likely quality of the water and if in doubt arranged for quality tests, and provided for catchment protection and/or water treatment if necessary?

4 Checked the population estimates before proceeding with the design?

5 Allowed for growth in population over the life of the project and taken into account other factors which may affect the final population figure?

6 Checked whether the "final" population figure is realistic for the particular community?

7 Consulted the community and considered any religious and traditional constraints, including legal ownership of land and water sources?

8 Made provision for overflows and for drainage to prevent standing surface water, particularly at collection points?

9 Made provision for extension where this can easily be done (eg deepening of wells or the provision of extra tap-stands)?

10 Made provision for treatment should it be necessary at a later date?

Reference Books

Water Aid maintain a small specialist Library, and suggestions for additions are always welcome.

The following is a selection from the reference books held, those marked* are recommended for consideration in a field library.

Other useful references will be found in some individual notes.

1. Water Supply

Small Water Supplies - Sandy Cairncross & Richard Feachem
Ross Bulletin 10. 1986
(booklet outlining all aspects of water supply)

Water Supply (3rd edition) - A C Twort, F M Law & F W Crowley
Arnold 1985

Small Community Water Supplies-Technology of Small Water Supply Systems in Developing Countries - Edited by E H Hofkes - Wiley 1986

*Community Water Development - C.Kerr - ITP 1989

Water Supplies for Rural Communities - C & M Ball - ITP 1991

*Hand Drilled Wells, A Manual on Siting, Design, Construction & Maintenance, Bob Blankwaardt - Rwegarulila Water Resources Institute, Dar es Salaam 1984

Community Water Supply - The Handpump Option, Saul Avlosorolf & 6 Others - World Bank 1987 (includes Pump Selection Guide and Handpump Compendium)

Rain Catchment & Water Supply in Rural Africa: A Manual.
Erik Nissen-Petersen - Hodder & Stoughton 1982

*Rainwater Harvesting - The Collection of Rainfall and Run-off in Rural Areas. - ITP 1986 - Arnold Pacey.

*A Handbook of Gravity Flow Water Systems - Thomas D Jordan Jnr. ITP 1984

*Hand Dug Wells and Their Construction - S B Watt & M E Wood - ITP

*Ferrocement Water Tanks and Their Construction - SB Watt - ITP

*Maintenance Systems for Rural Water Supplies - T Bastemeyer & J T Bisscher - IRC

Principles of Laying Water Mains - WAA - 1985
(cartoon illustrated 'man-in-the-trench'
booklet)

Water - pumping devices - a handbook for users and choosers.
P. Fraenkel - ITP 1986

2. <u>Sanitation</u>

Rural Sanitation: Planning and Appraisal. An Oxfam document
A Pacey - IT Publications 1980

Sanitation in Developing Countries, Ed. Arnold Pacey - Wiley - 1978

Handbook for District Sanitation Coordinators - K Basaako & 3 others,
TAG Tech. Note 9 - World Bank 1983
(prepared for Botswana Rural Sanitation Programme)

*Sanitation Without Water - U Winblad and W Kilama
Macmillan Education, 1985

Design of pour-flush latrines - Duncan Mara
TAG Technical Note No.15 - World Bank - Washington DC, 1985

Design of ventilated improved pit latrines - Duncan Mara
TAG Technical Note No. 13 - World Bank, Washington DC, 1984

Principles of Laying Sewers - WAA 1982
(cartoon illustrated 'man-in-trench booklet')

Sewage Treatment in Hot Climates, Duncan Mara - 1978 - Wiley 1980

*Ferrocement Pour Flush Latrines - A Trinidad of C Rubles
Austriaco - IFIC

3. Water & Sanitation

*Surveillance of Drinking water Quality in Rural Areas
B Lloyd & R Halmer - R. Longman Science & Technology 1991

Water Treatment & Sanitation. A Handbook of Simple Methods for Rural Areas in Developing Countries - A T Mann & D Williamson.
ITP 1983

Environmental Health Engineering in the Tropics - An Introductory Text, S Cairncross & R G Feachem - Wiley 1983
(includes health & pollution, water supply, excreta & refuse, vector-borne diseases)

*Rural Water Supplies and Sanitation: A text from Zimbabwe's Blair Research Laboratory - P Morgan - Macmillan 1990

*The Worth of Water: technical briefs on health, water and sanitation, with an introduction by John Pickford - ITP 1991

Surface Water Treatment for Communities in Developing Countries
Schulz Okun - Wiley 1984

Handbook of Water Purification (2nd edition), W Lerch (ed.)
Ellis Horwood 1988

Slow Sand Filtration - Recent Developments in Water Treatment Technology - NJD Graham - Ellis Horwood 1988

Disinfection of Rural and Small Community Water Supplies - A Manual for Design and Operation - WRC/WHO 1989

*Simple Methods for the Treatment of Drinking Water
Gabrielle Herber - Gate/Vieweg

4. Community Health and Health Education

*Community Health and Sanitation - C Kerr (ed.) - ITP 1990

Education for Health - A Manual on Health Education in Primary Health Care - WHO Geneva 1988

Where There is No Doctor - A Village Health Care Handbook
David Werner - TALC 1987

Teaching Health-Care Workers: A Practical Guide
F Abbott and R McMahon - Macmillan Education 1985

Community Health Worker's Manual, E Wood - African Medical & Research Foundation 1982

*Helping Health Workers Learn - D Werner & W Bower
Hesperian Foundation

*The Community Health Worker - WHO

*Facts for Life,UNICEF/WHO/UNESCO

*Puppets for Better Health - Gill Gordon - Macmillan

*The Copy Book: Copyright Free Illustrated for Development
Bob Linney & Bruce Wilson - ITP

*Making the Links - Guidelines for Hygiene Education in Community Water supply and Sanitation - Marieke T Boot - IRC

*Just Stir Gently: The Way to Mix Hygiene Education with Water Supply & Sanitation - M T Boot - IRC

5. Personal Health

Health Handbook for the Tropics - G Hamilton - VSO 1982

Health Manual: A Self Help Guide - Veronica Moss - Lion 1986

HIV/AIDS and Overseas Employment; a guide for employers, including information for staff and for health workers - UK NGO Aids Consortium for the 3rd World - 1989

6. Building/Construction

Field Engineering - An introduction to development work and construction in rural areas. - compiled and edited by Peter Stern and others - ITP 1985

Appropriate Building Materials - a catalogue of potential solutions.
Roland Stutz & Kivan Mukerji - SKAT/ITP/GATE 1988

7. Training

*Training for Transformation - A Handbook for Community Workers
S Timmel et al. - Mambo Press

*Tools for Community Participation - A Manual for Training Trainers in Participatory Techniques - Lyra Srinivasan - Prowess/UNDP

8. Evaluation

*Partners in Evaluation - Marie Therese - Macmillan

9. Development General

*Rural Development:Putting The Last First - R Chambers - Longman

*Indigenous Peoples: A Field Guide for Development - Beauclerk, Norby & Townsend - Oxfam

*Self Help Promotion: A Field Guide For Development
K.C.W. Verhagen - RTI

*Social Survey Methods - A Guide for Development Workers
P Oakley - Oxfam

10. Other

*WaterAid Technical Manual - WaterAid

*People and Water - WaterAid

*A Good Start. Effective Employee Introduction, 2nd Edition
Alan Fowler - Institute of Personnel Management

*Getting to Yes - Negotiating an Agreement Without Giving In.
Fisher, Vry & Patton - Century Business

Safety

Safety in design, construction and operation must never be overlooked but the strict standards of developed countries may not be realistic in many areas and it will be necessary to adapt responsibly to local practice.

Design

Thoughtful detailing in design can protect water sources, minimise contamination in storage and distribution, and reduce the incidence of accidents to operating personnel. Simple measures like providing rope or handrail protection to open tanks, good access facilities to pump wells, and protection to electrical equipment can save lives.

Construction

This will be largely a matter of common sense. The main hazard may well be in excavation. Don't allow local labour to take unnecessary risks, and don't take any yourself. Unless the ground is exceptionally firm, dry and free from fissures, some simple shoring should be insisted on, for vertical-sided excavations more than 1.5 m deep (see T14). Don't forget hazards of foul or explosive gases in deep excavations, often arising from methane or hydrogen sulphide held in the strata and accumulating in unventilated spaces. Never enter a confined excavation more than 2 m deep on your own, or allow other people to do so, and always have someone available with a safety line on the surface. Hard hats, goggles, gloves and safety harness should be indented for when considered necessary.

Setting Out Procedures

CIRIA issued in May 1988 a revised pocket handbook on 'Procedure for Setting Out Buildings and Civil Engineering Works'. This is recommended for general use by WaterAid field personnel.

Inter alia the handbook draws attention to the importance of:

(a) physical checks - rough checks of distance by pacing, levels, angles, falls and verticality (by eye), may highlight gross errors in setting out;

(b) calculation checks - always have a check, if possible independent, on calculations, especially if electrical calculators have been used, so as to minimise the risk of mis-keying;

(c) good records;

(d) "safe" locations for setting out stations, temporary bench marks and off-set pegs (ie avoid locations where pegs and bench marks are likely to be disturbed)

Water Related Diseases

It is intended to produce a supplement or separate publications on Health Education. Meantime, reference can be made to 'The Water Engineer's Guide to Health Education and Sanitation' written by Gretcha Sauer, and held in the Water Aid Library, which contains additional source references.

The following four pages are abstracted from this Guide.

Water Related Diseases

Type	Common Name	Scientific Name	Causative Organism	Vector
WATER	Diarrhoea		viruses bacteria	water,food unwashed hands, flies
	Dysentery		bacillus amoebas	
	Cholera		bacillus; vibrio cholera	
BORNE	Typhoid		bacteria; salmonella	water,food faeces
	Polio	Poliomyelitis	virus	faeces contact with sick people
	Bilharzia	Schistosomiasis	worm	water and snails
	Guinea worm		worm	drinking dirty water

Water Related (continued)

Type	Common Name	Scientific Name	Causative Organism	Vector
WATER CLEANED	Diarrhoea Dysentery	see above		
	Worms	Depends on type of infecting worm	nematodes ascaris (whipworm, tapeworm)	faeces, flies unwashed hands, not wearing shoes, not using latrines
	Impetigo		bacteria	contact with infected people, many people living close together
	Scabies		parasites arthopods	
	Lice			
	Conjunctivitis		bacteria	insufficient washing dust
	Trachoma			insufficient washing
*WC	Bilharzia	see above		
	Skin infections		bacteria	bathing in dirty water

* Water contact

Continued/

Water Related Diseases (Continued)

Type	Common Name	Scientific Name	Causative Organism	Vector
W A T	Malaria		Protozoa; Plasmodium	mosquito
E R	Sleeping sickness	Trypanosomiasis	Protozoa Tryanosomes	Tsetse fly
R E	Bilharzia	Schistosomiasis	worm; Schistosome	water/snail
L A T	River blindness	Onchocerciasis	worm; Onchocera volvuluv	small black fly
E D	Yellow		Zoonosis	mosquito

Barriers against foreign organisms entering the body

A. The bacteria already present in intestines (intestinal flora) will fight new bacteria. This is why babies get diarrhoea often; they do not have a well developed intestinal flora.

B. Diarrhoea is the body's natural response to foreign organisms; it is a cleansing mechanism.

Continued/

C. Hydrochloric acid in the stomach has enough strength to fight the foreign organisms entering our digestive system. Different organisms have different survival capacities against the HC1. The number of germs required to cause the following diseases are:

D. Number of germs necessary to cause disease

Number of germs necessary to cause disease			Transmitted through
Vibrio cholera	Cholera	10^9	Water
Salmonella typhi	Typhoid	10^5	Water
Shigella sp	Dysentery	10^2	Water and food

E. Different routes of transmission (drawings, demonstrations and flannel boards are good for explaining these.)

- i) From contaminated water.
- ii) From dirty collecting and storage containers.
- iii) From flies that land on food/water people, after landing on faeces.

F. Other water-related points:

- i) 50% of our body weight is water.
- ii) water is necessary for digestion.
- iii) water is necessary for us to breathe.
- iv) there are more diarrhoeal diseases in the dry season because there is less water available for washing and for drinking.
- (v) the organisms that cause diarrhoeal diseases come from other people or animals.

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Group 2 - **Basic Data**

Constants

(Metric) HP = 76.2 kg m/sec

(Imperial) HP = 550 ft lb/sec

Mass* $= \dfrac{\text{force (wt)}}{\text{accl. due to gravity}}$ i.e. $\dfrac{\text{lb}}{32.2}$ or $\dfrac{\text{gm}}{981}$

Water weighs 62.4 lbs/ft^3 or 1 kg/litre

Viscosity of water is approx:-

0.017	poises at	0°C
0.013	" "	10°C
0.010	" "	20°C
0.008	" "	30°C

Gravitational constant (g) = 32.2 ft/sec^2

= 981 cm/sec^2

Pi (π) $\doteq$ 3.14

e $\doteq$ 2.72

*** Note**

In earth's gravity, a mass of 0.102 kg has a weight of 1 Newton (N).

Metric/Imperial/US Conversion

(Metric units are generally used in this handbook, but imperial retained where they are traditional and familiar)

Length	1m = 39.37 inches (3.28 ft.) 1km = 1093.623 yards (approx. 5/8 miles)
Area	1 Hectare (10,000 m^2) = 2.4711 Acres
Mass **Weight**	1 kg = 2.2046 lbs 1 tonne (1000 kg) = 0.9842 ton (2205 lbs)

Strictly, Force (or weight) = Mass x Acceleration due to gravity, but in practice mass is often taken as synonymous with weight and the gravitational constant included in formulae as necessary.

Force	1 Newton (N) = 0.2248 lb.f or 0.102 kg.f.
Volume	1 m^3 = 35.3 ft^3
Liquid Measure	1 litre = 1.7598 pints (British) 2.1134 pints (US liquid) 1 gallon (British) = 1.20091 gallons (US liquid) = 4.546 litres
Energy	1 Joule = 1 Nm 1 Joule/sec = 1 Watt

Miscellaneous 1 force-de-cheval (metric horse-power)
= 0.986 HP (British) = 735 Watts

1 calorie (grosse)	=	1000 calories (petite)
	=	3.97 B.Th.U.
1 bar	=	0.9869 atmospheres
	=	14.504 lbf/in^2 ($0.1\ N/mm^2$)
1°C	=	$\frac{5}{9}$ (°F - 32)
1 litre/sec	=	13.20 g.p.m.
1 m^3/sec	=	19.005 mgd
	=	35.31 cusecs

Characteristics

The table gives very approximate guideline data. (See also T1).

The wide variations of material quality do not need stressing. The factor of safety used to determine the safe tensile and crushing strengths will depend on the situation, the assessment of load, and the variability of the material. It is usual to take higher factors (5 or 6) with timber than with man-made materials of good quality.

Laterite

'Laterite' is a term used to describe a range of materials rich in sequioxides of iron or alumina which are widely distributed in Africa and some other tropical countries. The term is derived from the Roman word 'later' meaning 'a brick'. Laterites range from a plastic red clay, which hardens irreversibly on exposure to air, to rock-like materials which can only be broken with a sledge-hammer or in a crusher, and usually occur in large sheets. Lateritic gravels are also found, usually in gently-rolling terrain in relatively thin soil horizons. The strength and characteristics of laterite are very variable.

Laterites are useful as fill material and for low cost roads with light traffic. Crushed laterite and lateritic gravel may be used for low-strength concrete.

Material	Specific Gravity	Ultimate Tensile Strength		Ultimate Crushing Strength		Modules of Elasticity	
		$10^6N/m^2$	T/in^2	$10^6N/m^2$	T/in^2	10^6N	T
Cast Iron	7	90-150	6 to 10	620-770	40 to 50	80	8000
Steel	7.9	390-540	25 to 35			160	16000
Aluminium	2.7	80-140	5 to 9			55	5500
Softwood	0.5 to 0.8	80-150	5 to 10	30-60	2 to 4	6	600
Hardwood	0.8 to 1.2	80-150	5 to 10	60-90	4 to 6	8	800
Limestone	1.9 to 2.4						
Sandstone	1.7 to 2.6						
Granite	2.6 to 2.8						
Common Brick	1.4 to 2.0						
Concrete	1.8 to 2.0						
Sand and Gravel	1.6 to 1.9						

Unit Weights

Item	Unit Wt. (kg)	Load for 4 Tonne Truck
Sand and Gravel	1600 per m^3	2.5 m^3
Common Brick	2.5	1600
Cement (bags)	51	80
CGI sheets 0.6 m x 2.1 m	8.5	470
CI pipe 1" i.d.	2.7 kg per m	1500 m
CI pipe 1½" i.d.	4.4 kg per m	900 m
CI pipe 2" i.d.	6.7 kg per m	600 m
Steel tube to BS6323		
21.3mm o.d	3.2 mm thick	1.43 kg per m
26.9	3.2	1.87
33.7	4.0	2.93
42.4	4.0	3.79
MDPE (12 bar working pressure) Supplied in 25 to 150m coils		
20mm i.d.		0.13 kg per m
25		0.16
32		0.27
50		0.66
(6 bar working pressure) Straight pipes		
90 mm i.d.		1.38 kg per m
125		2.66
180		5.47
PVC (6 bar working pressure)		
3 in i.d.		1.20 kg per m
4 in		1.83
6 in		3.54

Soil Bearing Pressures

As a very rough guide, permissible loading on typical soils may be taken as:

Subsoil	Working Load	
	kN/m^2	T/ft^2
Alluvium, made ground	1	½
Soft clay, wet sand	2	1
Dry clay, loam	4½	2
Firm dry clay	7	3
Compact coarse sands and gravel	9	4
Shale and soft rock	20	9
Hard rock	90+	40+

Water Demand

Sources - IT Technical Note 7 and internal (ref. 3rd meeting of Eng. Advisers).

Water demand varies considerably with social habit, ease of access, and quality of water.

Individual countries may have their own design criteria and local enquiries should be made.

The current WHO recommendation is 45 litres/head/clay and may be set by government as a standard. The information below should be used when it is possible or necessary to consider demand levels in more detail.

Communal Water Points (Wells, Boreholes, Standposts)

The IT Note suggests the following 'average' consumption.

Source distance	Approx. water usage (litres/head/day)
>2,500 m	5
250-2,500 m	15
<250 m	15-35

The WaterAid internal note records that consumption soars if the source is within 100 m., and falls dramatically if the distance exceeds 1 km (or 30 minutes travel return time), so that health benefits related to quantity will not be derived by providing new sources 200 m or more distant if the existing source is within 1 km.

The recommended design criterion for rural situations is to plan for an improved source for each population grouping of about 200 to 250 people. Allow 35 litres per person per day (45 litres per person if it is possible to design for future improvements in standard of living, but reducing to a minimum of 20 litres per day in difficult situations) if the household is within 200m of the source; and 15 1/hd/d if the source distance is between 200 m and 1 km.

Gravity supplies will be used (and wasted) more than those depending on hand pumps.

It should be noted that approximately half to three-quarters of the daily demand is likely to be consumed at sunrise and sunset. Ideally the source should be able to supply the day's requirements in a six to eight hour period.

Piped supplies

Type of supply		Approx. water usage (litres/head/day)
Yard or single household tap		75
Schools:	Day	25
	Boarding	45
Hospitals		300 per head
Government Offices		30
Livestock:	Horses	35
	Cattle	40
	Pigs	15
	Sheep	12.5
	100 Chickens	15

To put this into perspective, the water needed for agricultural purposes for irrigation is of the order of 750 litres per kilo of grain grown and 1,500 litres per kilo of rice grown. For small scale manufacturing 100 litres of water are required per kilo of paper made, 4 litres per kilo of bread baked and 100 litres per kilo of steel made.

Water Quality

Source: IT Technical Note No. 7

When considering how to improve a water supply it is necessary to consider the quantity, proximity and quality of the water. Enabling people to have more water, closer to home, will give significant health benefits, but in the long term it is also vital to ensure that the water is of suitable quality.

Water easily collects all kinds of impurities which give it colour, odour, taste and turbidity. These may be either of organic origin, derived from decomposition of plants and animals and wastes, or inorganic origin such as soils, minerals and metals. In inhabited areas water can also be contaminated with pathogens and parasitic organisms.

In scarcely populated areas the chemical characteristics of surface or ground water are not normally harmful, apart from excessive fluoride and nitrate levels, but some other chemicals can cause people to reject or improved water sources. For example iron in ground water causes staining in clothes and it has also been noted that hard water, typical of ground water sources, can lead to a considerable increase in cooking time.

Drinking water should therefore, as far as possible, be colourless, odourless and pleasant to taste, and guidelines as to acceptable chemical quality are given in the tabulation

Groundwater is usually free from disease-causing organisms if taken from below a depth of about 10 metres, but water from shallow wells or surface water in populated areas is very likely to have been polluted and the bacterial quality of the water needs to be checked. WHO recommended a coliform count less than 10 per 100 ml, although in some areas a relaxed standard is accepted - (UNDP work to an MPN of 50 per 100 ml in West African village wells) (see T5 for notes on water sampling and analysis)

WHO also advise that for coliform counts per ml of 10 to 300, the water should be treated before use, and over 300 the source should be regarded as "unacceptable" (but in practice there may be no option - see Design Philosophy, G2)

Guidelines for chemical quality, and examples of different types of water as shown in the table.

C/93

Guidelines for Potable Water Quality

mg/litre	Ca	Cl	F	Fe	Mg	NO_3	Na	SO_4	pH
Guideline values (WHO 1984)	-	250	1.5	0.3	-	10	200	400	6.5-8.5
Maximum	200	600	2.0	1.0	150	100	400	400	6.5-9.2

<u>Examples of Quality from different sources</u>

(There are of course very wide variations in surface and groundwater quality - the examples quoted should not be regarded as 'typical'.)

Rainwater (SE Asia)	2	3	-	0	2	1	-	4	5.6
Surface water (Sudan)	7.2	10	1	0.6	5.9	0.27	19	0.02	7.42
Ground-water	14	5.9	-	0	4.7	-	22	52	-

B6/2

Water Resources

Water Resources is not a problem in places where there is an ample quantity of water of acceptable quality throughout the year, but these are not situations in which WaterAid is most needed. In areas where safe water is scarce, consideration of water resources is implicit in our aim to design sustainable facilities; and we will have in mind that with improved water supply more water will be used, village populations may increase (with improved health or by immigration) and more people will imply more agriculture with increased irrigation needs in dry areas. This is of concern not only where wells and boreholes are used, but also with spring and stream sources, where there are obviously both seasonal and long term flow fluctuations.

Consequently, in preparing a project proposal, check:

1. That there will be ample and sustainable source of safe water at all times.

2. If in doubt, look for long term records of rainfall and stream flow or water table levels.

3. If these are not available, seek <u>reliable</u> local information on which a judgment can be made.

4. Give consideration to competing uses of water, such as primarily for irrigation.

It may sometimes be decided to meet pressing needs by improvement to the water supply even though there is doubt as to long-term sustainability of the source. In this event, make the position clear both to the local community and the appropriate government authority.

Roughness Factors

In the past, various empirical formulae were used for pipe and channel flow, each using an arbitrary roughness factor specific to particular materials and conditions. Thus the popular Hazen Williams formula (see F1), used a coefficient 'C' and the Manning formula for open channel flow (see F3), a constant based on the earlier Kutter roughness coefficient 'K'. Modern flow formulae all use a roughness factor 'k' having a dimension in millimetres, which can be used for pipes running full , or part full, and for open channels, and this is used in the Colebrook White formula which forms the basis of the flowcharts in F1. Take particular care not to confuse 'k' with 'K' and 'C' and coefficients used in other empirical formulae. The recommended 'k' values are:

Material	Clean Water[1]	Dirty (Surface) Water	Sewage[2]
Alkathene Perspex	0.003	-	-
uPVC/AC	0.015-0.003	0.15	0.6
GRP, Clayware	0.06	0.3	0.6
Ductile & Galv. Iron	0.03-0.015	0.3	0.6
CI, Spun Concrete	0.3	0.6	0.6
Cast concrete Brick, Masonry	-	1.5	1.5

Note: (1) These values are for new pipes or channels with well-made joints. Mis-aligned joints, rust, tuberculation, slime etc. result in increased loss at head, and in design it is prudent to use larger 'k'values that those tabulated to allow for deterioration in service.

(2) These values apply for velocities sufficient prevent deposition of sand etc., ie, greater than 1.2 m/sec (see B9). For lower velocities a 'k' value of 1.5 - 3 should be assumed, if there is risk of sand or grit in the water.

Transport Velocities

Rising Mains

For clean water the rate of flow and hence velocity for the available head or pressure in rising (force) mains can be calculated using Hazen Williams', or Colebrook-White formula.(see F1) For dirty water, use Colebrook-White but choose a high 'k' value (see B8).

It is important that the velocity in the rising main is sufficient to prevent deposition and accumulation of sand or grit deposits (even with clean or treated water this is a wise precaution). Recommended self-cleansing or pick-up velocities are given below:

	Settling Velocity (m/sec)	Pipe Dia.(mm)	150	300	600
Coarse sand (up to 2.5 mm)	0.4	Pick up velocity (m/sec)	0.6	0.6	0.6
Grit (2.5 to 5.0 mm)	1.5	" " "	1.2	1.5	1.8

Open Channels

In open channels or streams, lower velocities can be accepted than in rising mains, as sand, etc. can be transported by bed movement and need not be fully suspended.

As a rough guide, the following transport velocities are appropriate in these situations:

Fine sand	(0.4 mm)	0.15 m/s
Medium sand	(1.1 mm)	0.22
Coarse sand	(2.5 mm)	0.30
Gravel	(2.5-25mm)	0.75
Shingle	(25-75 mm)	1.20

(These are 'mean' velocities, i.e. Quantity/Cross Section of flow.)

Labour Requirements for Common Tasks

- The following are very approximate and must be adapted for use in each location.

Description	Unit	Output per man/day
A. Temperate Zones		
Clearing bush or scrub	m^2	180
Clearing undergrowth and small trees	m^2	60
Digging loose soils to depth less than 1 m and load into barrow	m^3	0.8 - 1.8
Spreading soil in 150 mm layers	m^3	8 - 16
Levelling and trimming soil slopes	m^2	48
B. Nepal		
Excavation (shallow)	m^3	1.4
Excavation in rock	m^3	0.3 - 0.4
Back filling	m^3	3
Plain concrete	m^3	0.14
Cement plastering (1cm)	m^2	2
Ferrocement (5cm)	m^2	0.3
Barbed wire fence	m	6
Jointing HDPE pipes	Item	10
Jointing GI pipes	Item	7

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Group 3 - Formulae

Clean Water Flow in Pipelines

General

The most accurate formula for general application over a wide range of conditions is Colebrook-White. This is not however convenient for simple calculations, and is usually presented in chart form. Three simplified charts are attached, for values of the roughness coefficient 'k' corresponding to very smooth; fairly smooth; and average, and are for clean water only. (See B8.) If extensive pipeline design is undertaken, the full series of charts should be obtained from QAG.

A simple formula suitable for clean water in pipes flowing full which gives sufficiently accurate results for most applications is Hazen Williams.

	Metric	**Imperial**
	$V = 0.3555\ C\ d^{0.63}\ i^{0.54}$	$= 0.115\ C\ d^{0.6}\ i^{0.54}$
where	V = Velocity in m/sec	V = ft/sec
	d = Diameter (internal) in m.	d = ins
	i = Hydraulic gradient = Head/Length	
	C = Roughness Coefficient (see over)	

Continued/

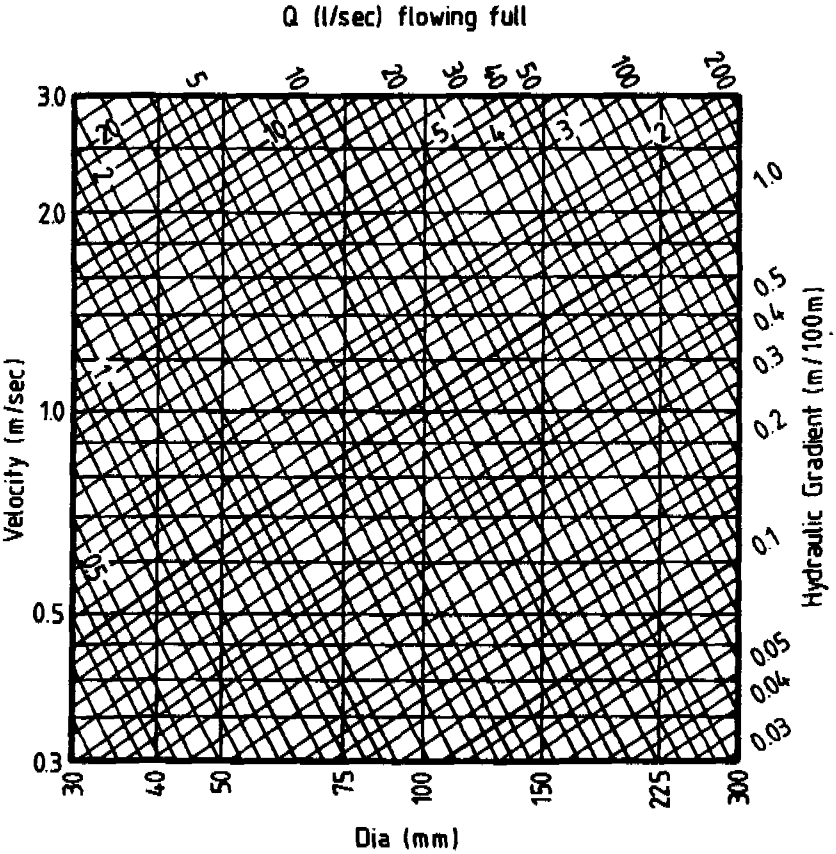
Values for 'C' for use in the Hazen Williams formula (this varies with material and size)

Pipe Material	Nominal Diameter 100 mm (4") or less	300 mm (12")	600 mm (24")
C.I. - New	125	130	135
- Ordinary	95	105	115
- Old	70	80	90
- Very rough	55	65	75
Ductile Iron		As CI +5	
Steel		As CI - 5	
Lined with concrete	All	120 - 140	
Lined with bitumen	sizes	140 - 150	
uPVC/GRP/MDPE/HDPE		140	
Asbestos cement		140	
Clay		110	
Spun concrete		120	
Cast concrete		100	

The formula is most accurate for pipes larger than 100 mm, for velocities over 1 m/sec., and for values of C over 100.

Note Remember to use the <u>actual</u> internal diameter of the pipe in a calculation - it may differ significantly from the notional size.

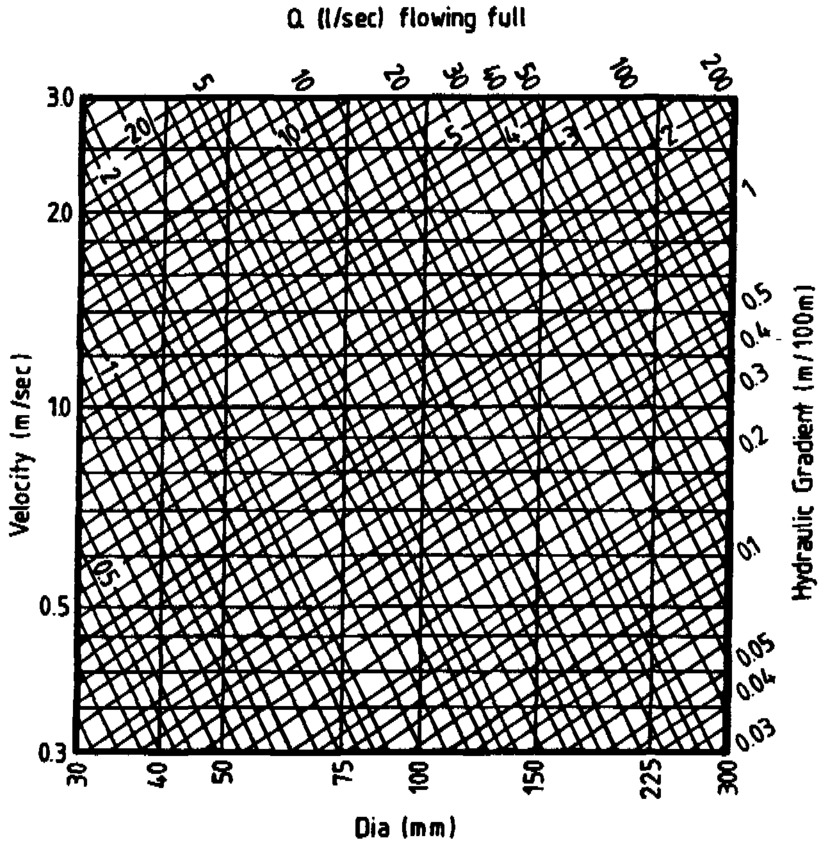
Continued/



k = 0.003 mm

Pipe Flow Chart

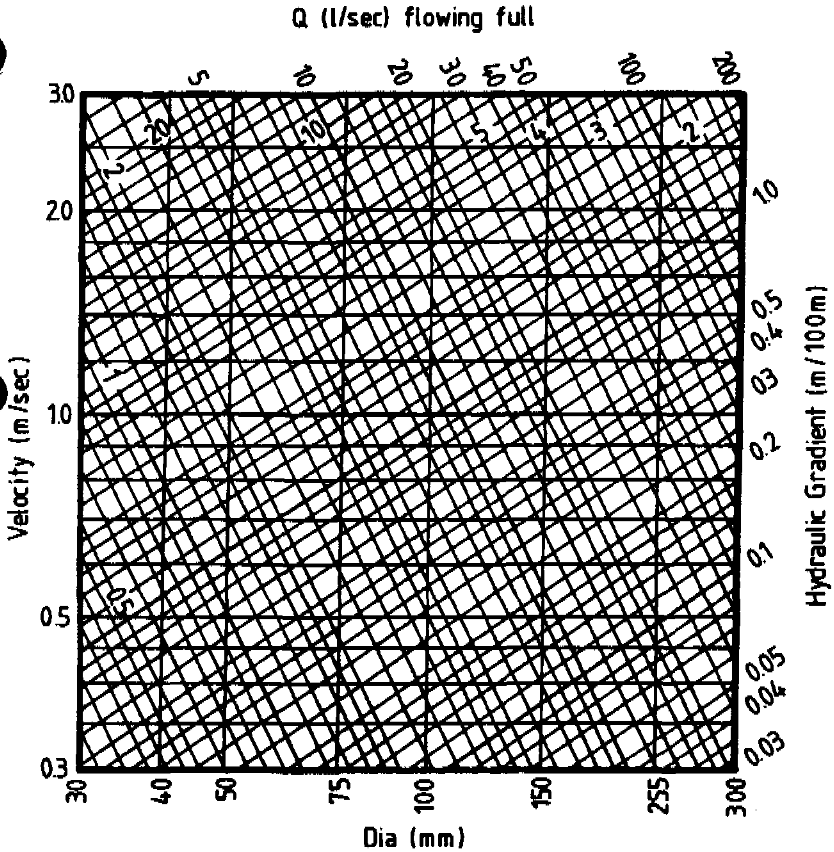
Fig F1/1



k = 0.015 mm

Pipe Flow Chart

Fig F1/2



k = 0.03mm

Pipe Flow Chart

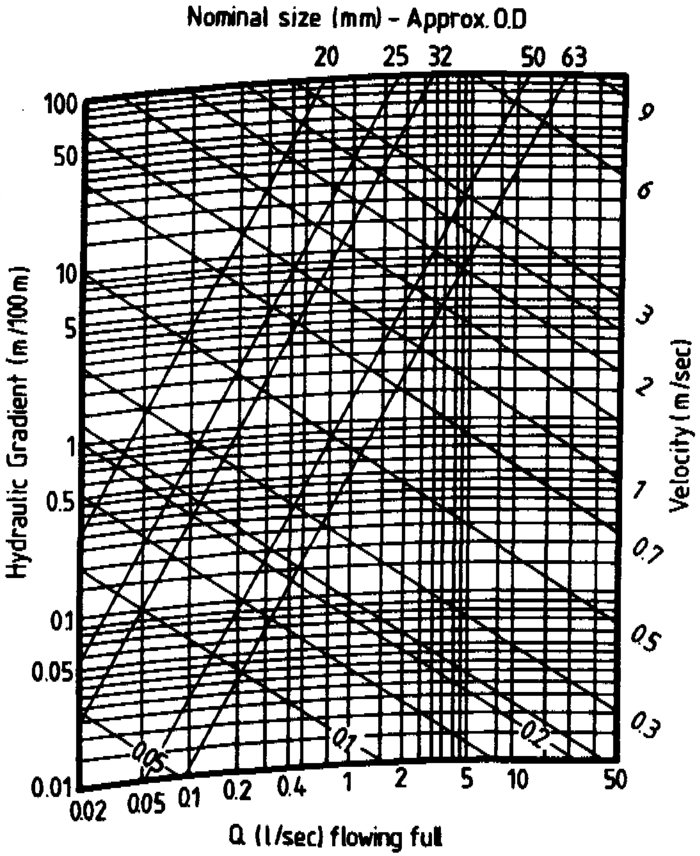
Fig F1/3

Service Pipes

The flow chart in Fig. F1/2 may be used for galvanised pipe and Fig. F1/1 for new plastic pipe. Alternatively, the chart in Fig. F1/4 can be used for MDPE pipes Class B to BS:1972.

Pressure losses in tapping the service pipe to the main, in stopcocks, ball valves and bibcocks may be much more significant. Average values of head loss (m.) at fittings are:

Dia	Fitting	Head Loss (m) Flow (litres/min)		
		7.5	15	25
13 mm	Ferrule	0.3	0.7	2.4
	Tap (open)	0.7	1.7	4.9
	Ball valve (open)	1.7	4.7	-
19 mm	Ferrule	0.15	0.4	1.1
	Tap (open)	0.3	0.7	2.4
	Ball valve (open)	0.7	1.8	4.0



Flow Chart for MDPE
Pipe to Water Industry
Specification 4-32-02

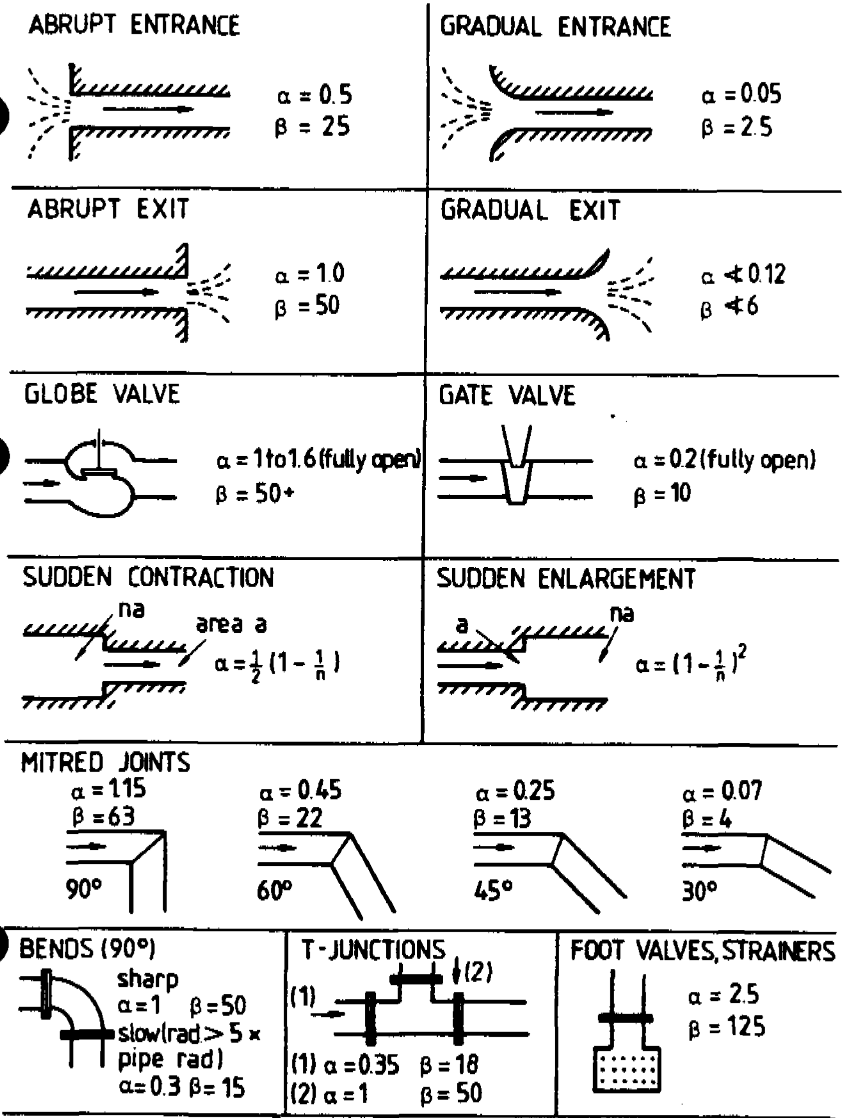
Fig F1/4

Secondary Losses in Pipes

These may be important on short runs of pipe. They may be stated in terms of the kinetic head,($V^2/2g$); or an equivalent pipe length (which will vary accordingly to the pipe material or roughness). Fig. F2/1 shows some commonly used values.

For gate valves 1/4 closed is approx. 1
1/2 " " " 6
3/4 " " " 24

Venturi meters normally have an of about 0.3 depending on the throat/pipe diameter ratio.



Expressed as $\Delta h = \alpha \frac{V^2}{2g}$ or Equivalent pipe length $l = \beta$ diameters, for pipes of average roughness (i.e. roughness coefficient $k \leq 0{\cdot}03$ mm)

Energy Losses in Pipe Fittings

Fig F2/1

Open Channel Flow

For uniform turbulent flow, Manning's formula gives an approximate value $V = cm^{0.67} i^{0.5}$

where m = hydraulic mean depth (water cross-section divided by wetted perimeter)

i = hydraulic gradient x

$c = \frac{1}{K}$ (metric units)

$= \frac{1.486}{K}$ (imp. unit)

K = Kutter's roughness coefficient*
= 0.01 smooth cement
= 0.12 concrete, wood
= 0.015 brickwork
= 0.02 - 0.03 earth

The velocity distribution depends on channel configuration but for a typical stream the actual velocity at 0.6 depth is usually very close to the mean velocity. The surface velocity is about 1.15 the mean, and the velocity near the bed about 0.7 the mean.

x This is the slope of the free water surface and has no relevance to the pipe gradient in pressure systems.

* This is not synonymous with the roughness coefficient used in the Colebrook-White formula - see B8.

Kinetic (velocity) head

The kinetic head in a stream or channel is $\frac{v^2}{2g}$

where v is the mean velocity in the stream.

Orifice Discharge

$$Q = C_d \, a \, V$$

C_d = Discharge coefficient
a = Area of orifice
V = Velocity = $\sqrt{2gh}$ where h is the head over the orifice centre.

For water, approximate values of C_d are

0.6 for sharp-edged circular orifices
0.95 for bell-mouthed circular orifices

Triangular (sharp edged) Weir Discharge (free discharge)

$$Q = 0.315 \tan \frac{\Theta}{2} \sqrt{2g} \, h^{2.5}$$

0 is notch angle

h = head over apex

For 90° notch, Q (l/sec) = $0.014h^{2.5}$
where h is in cms.

or Q (cusecs) = $2.53h^{2.5}$
when h is in ft.

Rectangular (sharp-edged) Weir Discharge (free discharge)

$$Q = 0.67\, C_d\, b \sqrt{2g}\, h^{1.5}$$

b = width

h = head over sill

$$C_d = 0.623 \; \frac{(b - 0.2h)}{b}$$

(If only sill is sharp-edged, $C_d = 0.623$)

Rectangular (broad-crested) Weir Discharge (free discharge)

$$Q = 0.385\; C_d\, b \sqrt{2g\, h^{1.5}}$$

and C_d is close to unity.

Submerged Weirs

The above formulae are not significantly affected if the submergence is less than 60% of the upstream head.

(NB When measuring h do not forget to allow for the kinetic head of the approach velocity. Remember to use consistent units within each formula.)

Bending Moments, Shear and Deflections

As a reminder, basic formulae for common situations are tabulated overleaf.

In all cases :

w	=	Uniform load per unit length (total distributed load is wL)
W	=	Point load
L	=	Length of beam
a	=	Greater distance from support
b	=	Lesser distance from support
E	=	Modulus of Elasticity
I	=	Moment of Inertia

= The sum at the mass of each element of cross section x the square of the distance of that element from the centre of gravity

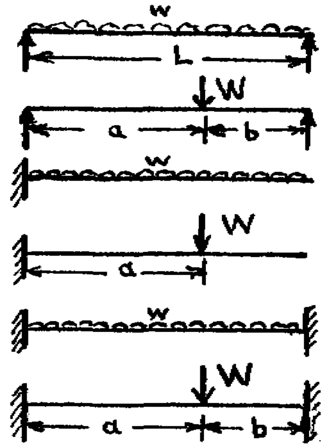
= $0.084\ bd^3$ for solid rectangular sections
= $0.063\ D^3$ for circular sections of D diameter

(Values of I for standard steel sections are given in manufacturers catalogues)

The moment, shear or deflection due to the self-weight of the beam must be added to that due to the imposed load.

C/93

Condition	Load	Max.BM	End Reaction	Max.Deflection
Simply supported	Uniform	$\frac{wL^2}{8}$	$\frac{wL}{2}$	$\frac{5wL^4}{384\ EI}$
"	Point	$\frac{Wab}{L}$	$\frac{Wa}{L}$	$\frac{Wab(L+b)\sqrt{3a(L+b)}}{27EIL}$
Cantilever	Uniform	$\frac{wL^2}{2}$	wL	$\frac{wL^4}{EI}$
"	Point	Wa	W	$\frac{Wa^2(3L-a)}{6EI}$
Fixed ends	Uniform	$\frac{wL^2}{12}$	$\frac{wL}{2}$	$\frac{wL^3}{384\ EI}$
"	Point	$\frac{Wa^2b}{L^2}$	$\frac{Wa^2(L+2b)}{L^3}$	$\frac{2Wa^3b^2}{3EI\ (L+2a^2)}$



F5/2

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Group 4 - Technical Notes

Pipe Materials

General

Apart from size and strength, the choice of pipe material depends on cost, suitability for intended use, durability and availability.

Tables 2 and 3 set out some limitations of commonly available pipes. Asbestos Cement pipes are included, as they may still be met in some areas, but following recognition of the danger in handling this material it should be avoided if possible, and is not advisable for potable water supply.

Plastic Pipes

As Tables 2 and 3 show, there is a very wide, and increasing, variety of plastic pipes designed for different purposes - plumbing, rainwater goods, building drainage, service ducts, water supply, sewerage etc. Advantages are light weight and resistance to corrosion. All are usually classed as 'flexible', although small pipes in some plastic materials are semi-rigid. The availability in size of the more common types is shown on Table 3. Composite pipes such as GRP and reinforced plastic mortar are available in size up to 2m dia.

In general terms, uPVC pipes are cheap, more rigid than most others, more temperature sensitive, and more easily damaged. MDPE balances strength and toughness and is preferred for distribution and service pipes. MDPE pipes below 63mm O.D. are usually designed for a 12 bar test pressure; larger diameters for 10 or 6 bar. MDPE pipes up to 90mm O.D. are available in 50, 100 or 150m coils, larger pipes in 4 or 6m lengths - consider transport problems.

Table 1 - Commonly Available Plastic Pipes

	Usual Max. Dia.(mm)
uPVC (BS:3505 or 3506)	600
Low Density Polyethylene (LDPE)	300
Medium Density Polyethylene (MDPE)	500
High Density Polyethylene (HDPE)	1200
Polypropylene	450
ABS	300
Nylon	25

Relevant characteristics of plastic pipes are:

Hydraulics All plastic pipes have good friction characteristics when clean, as compared with iron, steel, concrete or A.C.; when scaled or silted, the friction coefficient is largely independent of pipe material.

Temperatures All plastics are temperature sensitive to varying degree. (See Table 3.) uPVC tensile strength falls with increasing temperature, the decline accelerating at about 60°C, and rigidity falls sharply over 70°C. (Conversely, these pipes are very brittle at low temperatures.)

Expansion Most plastic pipes have high coefficients of expansion which need care in design. (See Table 3.) For example, typically, PVC pipe expands 1.6 mm per 3 m length for each 10°C rise in temperature.

Handling Semi-rigid pipes like uPVC are easily damaged in handling, especially at low temperatures, and quite light scratches may lead to subsequent stress failures.

Storage In storage, plastic pipes should be supported at frequent intervals (e.g. 10 cm wide supports at not more than 1 m spacing), and not stacked so high (say 4 or 5 layers) as to engender permanent distortion. They should be protected from sunlight.

Installation See T2 (Pipe Laying)

Colour Coding Pigments are used for identification and to protect against U.V. degradation. In UK, blue is used for clean water, yellow for gas, but black pipes are better for pipes above ground and exposed to sunlight.

Table 2 - Recommended Uses

Material	Use			Type	
	Sewage	Potable Water	Pressure	Rigid	Flexible
Clay	Yes	Occasionally	-	Yes	-
Concrete	(1)	Occasionally	-	Yes	-
Asbestos Cement	(1)	No	Yes	Yes	-
Ductile Iron	Yes	Yes	Yes	Yes	-
Steel	(2)	(3)	Yes	Yes	-
uPVC	Yes	Yes	Yes	(4)	Yes
Polypropylene	Yes	Yes	Yes	-	Yes
Glass Fibre (GRP)	Yes	Yes	-	Yes	
Polyethylene	Yes	Yes	Yes	-	Yes
Polyurethane	Yes	Yes	Yes	-	Yes
Nylon	Yes	Yes	Yes	-	Yes

1) Not suitable for septic sewage.
2) Short life unless protected by suitable lining and coating.
3) Requires protecting externally (e.g. galvanising). Usually internal lining not required if under pressure and air excluded, but this is difficult to ensure and internal protection is highly desirable except for very temporary work.
4) Can be classed as semi-rigid in the smaller diameters.

Table 3 - Properties of Pipe Materials

Material	Density (gm/cc) (x 10^{-6})	Coefficient of lin.exp.	Softening Temp. (°C)	Elongation at break (%)	Tensile Strength (MN/m^3)
Clay	2.3	5	-	-	-
Concrete	2.3	11	-	-	-
Asbestos Cement	2.0	10	-	-	25
Ductile Iron	7.2	12	-	7	400
Steel	7.9	12.5	-	20	500
uPVC	1.4	up to 60	70	70	50
Polypropylene	0.9	" " 120	110	300	6
GRP	2.0	" " 40	-	-	250
Polyethylene:					
LDPE	0.91	" " 280	80	500	5
MDPE	0.93	" " 150	110	500	9
HDPE	0.94	" " 200	90	500	9
Nylon	1.1	" " 150	130	-	50
Pitch Fibre	1.2	-	-	-	25

Notes (1) These properties are generally the values at 20°C.

(2) There are wide ranges for each material; the figures quoted are indicative, to give a comparison between materials. For accurate values refer where possible to the manufacturer.

Pipe Laying and Jointing

Most pipework for Water Aid projects will be small diameter, flexible pipes, which are best laid in shallow trench. The depth will rarely be greater than that needed to avoid exposure by erosion or damage by cultivation or grass fires, and in these circumstances the strength of commercially available pipes will usually be adequate if laid with a suitable surround (see Installation below), but see note T15 on thrust blocks for pressure pipes. See also T11 (pipeline design)

Handling and Storage

Failure of rigid and semi-rigid pipes can originate from rough handling to and on site as well as over-loading, and care in transit, in store and in laying is rewarding. Slings should be used in handling and pipes stored on even surfaces. Flexible and semi-rigid pipes need support to the whole length of the barrel - see more detailed notes under 'Pipe Materials'.

Installation

It is vital to ensure that large stones, rock or timber do not cause local stress to pipes under load, and all except small plastic pipes in trench are best laid with a granular or selected soil surround (sandy gravel passing 30mm sieve is ideal). Above ground supports must be adequate to avoid sag, provision made for expansion, and protection given from direct sunlight. (See also separate technical note on Pipe Supports T3.) Some plastics - particularly polypropylene - have been subject to vermin attack, but uPVC and HDPE appear free from this problem.

Pipes under Roads

Additional loads will be imposed where pipes cross vehicle tracks, and in this and similar situations, thought needs to be given to the structural strength at the pipe. For most situations, provide not less than 0.75 m cover over the pipe and surround the pipe with selected material (sandy gravel is ideal) containing no material larger than 30 mm. This is particularly important with plastic pipes, which can be damaged by large, sharp stones. Careful consolidation and reinstatement is necessary to avoid 'wheel thump'.

Pipe Failures

The most common types of failure after laying are:

- poor jointing (test before putting pipes into service)
- beam fractures due to uneven support
- bearing fractures due to hard spots on pipe bed
- longitudinal fractures due to excessive vertical load
- shear fractures due to settlement where pipe enters a fixed structure
- socket failures due to unsuitable joint material (a resilient material is preferred)
- stress fractures of flexible pipes due to large, sharp stones in backfill
- unbalanced force at changes of direction etc of pressure pipes.

Joints

For small pipes, push fit or compression joints or solvent welding are suitable. Solvent welding of larger pipes (over 50mm diameter) requires careful technique in accordance with manufacturers' instructions, and should be avoided if possible.

Jointing MDPE Pipes

The following reflects WaterAid experience in the field: The preferred options are butt or fusion welding if large quantities are used, and push fit or mechanised joints for smaller quantities.

Butt Welding

Butt weld properly executed is as strong as the original pipe. There are two ways of executing these joints namely:-

(i) The hand held heating plate where a disc of approx 125mm diameter and 15mm thick on the end of a handle is heated in a naked flame to 205 degrees centigrade. This is achieved by marking the plate with a thermal crayon which changes colour at the right temperature. A teflon bag is then placed over the plate to prevent the pipe sticking and the pipe ends are pressed onto the plate until melt occurs when they are removed and pushed together to form the joint. This method is suitable for jointing coils of small diameter pipe in the bush.

(ii) A butt welding machine which is designed to clamp the pipe. A cutting plate shaves the ends of the pipes to give a good fit, then an electrically heated teflon coated heating plate is used to heat the pipe ends to the correct temperature, and the pipe ends are forced together by hydraulic pressure to form the joint. For pipe sizes of 50mm diameter and above and especially where the use of 5.8m lengths is concerned this is the preferred method.

These machines are not complex, are easy to use, and if properly maintained will give a long and satisfactory service.

The major disadvantage is that in order to weld in situ it might be necessary to extend excavations to allow for the installation, operation and removal of the machine.

The machine is based on a 125mm chassis (liners can be used for 90mm, 63mm and 50mm pipes) complete with trimmer and heater plates and a hydraulic hand pump. Cost (1993) is around £3000 plus transport. A small 2.8kVA petrol driven generator is also required to power the welding machine (budget cost of £750) The whole of this equipment can be supplied as a package from Fusion Group plc.

Fusion Welding

When first introduced it was not reliable and more costly than other comparable systems. It is however now a standard for the British Gas industry and a Water Standard is in the course of being written. As a result of its increased use and quality control combined with automated production the cost of fusion fittings has considerably reduced and it is now comparable with butt welding.

The fittings have sealed in the sockets the necessary heating wires which have an electric current passed through them to generate the heat required to fuse the fitting to the pipe.

Operationally the pipe end is cleaned to remove dirt, grease and plastic impurities and the fitting is then clamped onto the pipe. The fitting has two terminals which are connected to a controller, current is then passed through the built in wires for a preset period of time fusing the fitting to the pipe, the joint is then left to cool and the clamp removed. The more modern fittings have a set resistance which is measured by the controller and this automatically sets the correct time for the fusion process.

The main advantage is that no additional excavation is required and a series of fittings can be clamped onto pipe and the control box moved to the next as soon as the fusion process is complete. Its disadvantage is that once the joint is made the only method of removal is to physically cut it off the pipe and use a new fitting to remake the joint.

The cost of the control box is in the region of £1000 (1993). A small petrol driven generator is also required, and a series of clamps to hold the fittings firmly onto the pipe during the fusion operation. The budget cost for control box, generator and clamps is around £2000 (1993 prices).

<u>Push Fit</u>

This type of joint is very simple and only requires the end of the pipe to be chamfered and then simply pushed into the socket of the fitting. It has a standard "O" ring to hold against pressure and a clamp ring to hold the fitting firmly on the pipe which can be released with a simple tool allowing the fitting to be reused. The chamfer and extractor tools are simple and inexpensive.

Its advantage is simplicity but its major disadvantage is cost.

<u>Mechanical</u>

This type of joint has been widely used by WaterAid especially in Sierra Leone where it was specified as a cheaper alternative to the Push Fit. The types used have been made of plastic and have the same life span as the pipes. The fitting contains sealing rings and clamp rings to prevent the fitting parting under pressure. The only tools required are a set of stilson wrenches.

Its advantage is that it is easy to remove the fitting and it can be reused although perhaps with new sealing rings.

Pipe Supports

Where practicable, pipes are best laid in shallow trench for protection. If pipes are laid above ground they need support. Points to watch are:

1. Vulnerability to damage from people, animals, falling trees, grass fires, etc.

2. Erosion or other damage by seasonal floods and land slips.

3. Sensitivity of design to line and level.

4. Restraint at bends, junctions, etc. (See separate note on thrust blocks, T15.)

5. Provision for expansion and contraction, especially with plastic pipes. (Long straight steel pipelines may be laid in zig-zags).

6. Accessibility for inspection and repair.

Conventional supports are brick or concrete, or fabricated steel when pipelines are supported on structures.

Points to watch are:

Loading Primary vertical load is not a problem with small pipelines and longitudinal thrust from expansion or side thrust due to water pressure at changes of direction may be more significant. External loading can arise if the pipe can be sat or walked on.

Location Rigid pipes usually need support behind each joint, sometimes intermediately also with small dia. pipes. Flexible pipes need enough support to avoid excessive sag under load (check the weight of the full pipe.

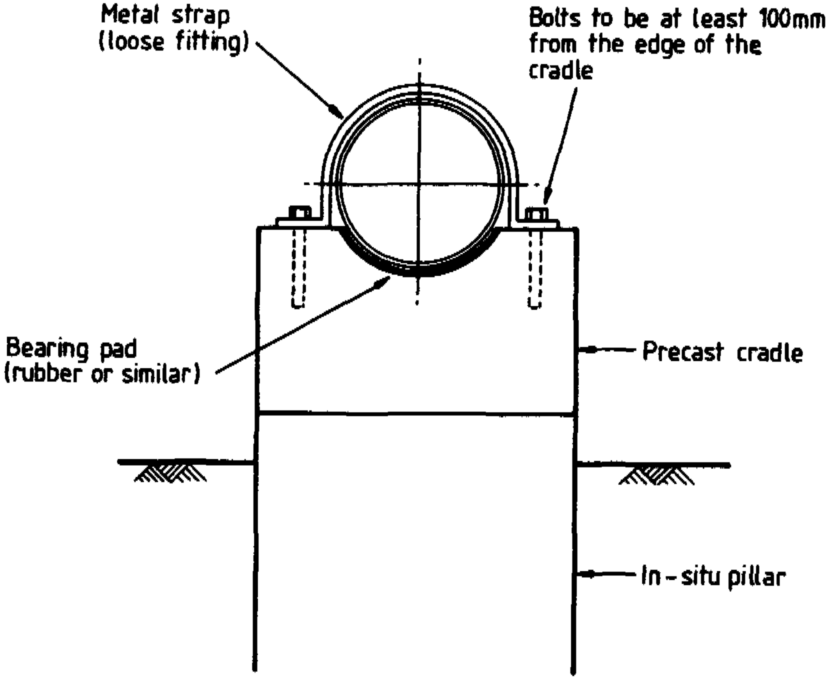
Fixing If pipe level is critical, support design should allow for local adjustment, especially in bad ground. Avoid rigid fixing but allow the pipe to slide longitudinally, with firm restraint at all changes of direction, and at intervals to avoid creep (especially in steep gradients). Fig.T3/1 shows a typical design, but note that:

(a) in some countries timber cradles may be an acceptable alternative if durability can be assured;

(b) metal straps may be open to theft; one solution is to weld the bolts.

Service Pipes If plastic pipe (MDPE or similar) is used adequate support must be given, preferably by clipping to a flat surface. Support spacing for MDPE pipes should not exceed 0.4 m for 1" nominal size pipes, or 0.5 m for 2" pipes when horizontal, or double these distances when vertical.

River Crossings Rigid pipes may be self-supporting over short spans - but guard against their use as a bridge! Flexible pipes can be threaded through a steel pipe 'bridge'or suspended, supported at frequent intervals to avoid flexing and protected against sunlight.



Pipe Support

Fig T3/1

Stream Gauging

If practicable, simple or compound weirs are usually the best way of gauging streams. Construct on a reasonably straight stretch and use a combination of triangular and rectangular weirs if there is a wide variation in flow. See F4 for Weir Characteristics.

Approximate methods of gauging flow will usually rely on measuring the velocity. Again select a straight stretch with constant cross-sectional area. A surface float, such as a bottle, travels at about 1.15 x the mean velocity of the vertical plane in which the float travels. See F3 for Open Channel Flow. A weighted canister or drogue, supported by a small surface float and positioned to be at 0.6 of the average stream depth, will travel at the average stream velocity.

If fluorescent dyes or similar colouring matter are available, the average stream velocity can be readily, if approximately, measured by observation. This entails quick mixing at the entry point and a consistent cross-sectional area over the measured length.

Observations at varying rates of flow will enable a stage discharge curve (i.e. a graph of discharge against water level) to be constructed. This will help to eliminate rogue observations and provide a ready reference for quantity at any observed depths.

Water Sampling and Analysis

This note is not comprehensive. A full description of suitable methods and equipment will be found in L G Hutton's book on 'Field Testing of Water in Developing Countries', available in WaterAid's library, to which reference should be made if the need for extensive tests is foreseen. A paper by Simon Trace reviewing water quality standards and testing in Nepal is also useful.

Sampling Frequently, analysis will be carried out in a laboratory, but the analysis will only be as good as the sample, and care must be taken to ensure that the sample is representative of the bulk of the water (if in doubt, take several from different points or at different times); is not contaminated in sampling; and is protected so far as possible from change before it reaches the laboratory.

For chemical analysis a large (say 1 litre) sample is necessary. The bottle(s) and stopper must be scrupulously clean, and washed out with the water to be sampled before filling. Stopper (with glass stopper preferably) - do not leave an air space. Label carefully with date/time/origin/and name, and get to the analytical laboratory as quickly as possible, keeping the sample cool and shaded in transit.

For bacteriological analysis even more care is necessary, and some experience desirable. A 250ml sample is adequate, but a clean sterile bottle with glass stopper is necessary. Again, rinse with water under test before filling. Be careful not to touch the contact surfaces of the stopper with your fingers. Keep the sample shaded and as cool as possible and analyse within 3hrs of sampling. Label as for chemical analysis. If sampling from a tap, flame sterilise the tap orifice (with plastic taps use a strong chlorine solution) and then run some water before taking the sample.

Field Tests The most common field tests are:-

(a) Conductivity
(b) Turbidity
(c) Chlorine residual
(d) Odour

Field test kits are also available for most physical and chemical characteristics of interest, and for bacteriological analysis, and the manufacturers' instructions on them should be carefully followed.

(a) **Conductivity** This gives a rapid method of estimating total dissolved salts in water, and is valuable in making a quick first assessment of the quality of ground water. Light-weight battery powered conductivity meters are available; if not temperature compensated, a thermometer will be necessary. Conductivity is expressed as micro-siemens per cm (mu/cm) - previously called micromho (muho). A reading in excess of 1500 mu/cm suggests poor quality, and indicates a total dissolved solids in the range 750-900 mg/1 at 25°C.

(b) **Turbidity** There are no accurate simple field test methods, but a rough indication can be obtained by fixing a small interior mirror to a graduated rod, and lowering in full daylight until it cannot be seen. The depth of immersion corresponds roughly to the silica scale of turbidity as follows:

Depth cm	**Turbidity (silica scale)**	**Filterability**
2	1000	Sand filters clog quickly
8	130	
10-15	100-65	Filtration possible but difficult
30-45	30-18	
80	10	Suitable for sand filtration

(c) **Chlorine Residual** All field testing depends on the depth of colour developed by adding a reagent, and is best measured by using a suitable test kit. If this is not available, but DPD reagent (Diethyl-para-phenylene diamine) can be obtained, as foil-wrapped tablets or in liquid form, add 3-5 drops of reagent to a 5ml sample in a clean glass bottle. The table below gives a rough and ready relationship:

Colour	**Residual Chlorine) (mg/1)**	**Odour**
Light yellow	0.1	Slight
Yellow	0.2-0.5	Obvious
Deep yellow	0.7-1	Strong
Brown	1	Very strong

(d) **Odour** As indicated above, smell can be used to give a very rough indication of chlorine residual.

Other odours may indicate pollution and require investigation. A rough guide as to acceptable quality is to measure the dilutions required with odourless (e.g. distilled) water before the odour disappears. Dilutions of 2 or less indicate acceptable quality; 3 to 4 are marginal; and 5 or more generally unacceptable (but may be the best available).

Water Treatment

Many surface waters need treating before potable use. Untreated water is only suitable for domestic use if it comes from an unpolluted source (e.g. a stream or lake upstream of inhabited areas) or if the user can be trusted to use simple disinfection methods for water used for drinking or food preparation. (But see comment in B6)

It is not possible to deal adequately with all aspects of water treatment in a field handbook. There are many text-books available. A good, simple and practical account is given by Smethurst in his 'Basic Water Treatment' (Thomas Telford Ltd., 1979).

It may however be useful to note the usual sequence of operations which apply to both small and large treatment works:

Coarse screen (100 mm spacings)
o
Pump if necessary
Store if necessary
Fine screen (6 mm)
o
If necessary, add chemical coagulants(1) (often lime and aluminium sulphate) and mix gently for 15 mins.
o
Settle in sedimentation basin for 2-4 hours
o
Filter through clean sand.
'Rapid' filters remove fine particles.
'Slow' filters (see D12) also improve bacterial quality.
o
Chlorinate if necessary (i.e. if rapid filtration used, not always after slow filtration)
o
Store (not less than 30 min. retention
o
Distribute

With 'clean' water from wells, boreholes or protected springs, treatment may not be necessary, although chlorination may be a wise precaution.

It is possible that the alkalinity from new concrete will effectively sterilise water stored in concrete tanks, but this is unreliable and should not be depended upon.

(1) Chemical coagulants may be very expensive or unobtainable. Ground-up seed suspensions of the plant species Moringa oleifern and Moringa stenopetala have been shown to be an effective alternative. Details are held on file by WaterAid, and reference should be made to QAG if this alternative is proposed. If no coagulant is available, increase the sedimentation period.

Iron Removal

High Iron and Manganese content is undesirable, see B6. If unavoidable they can be reduced by chemical treatment, using a mixture of sodium carbonate and sodium phosphate, followed by settling and filtration. A simpler approach, less effective, but probably adequate in most situations, is to precipitate by aeration; in the simplest form, water in shallow storage tanks, open to the air and sunlight, can be agitated to aerate and then settle before us. A better method is to aerate in a ventilated packed tower, using two 150mm layers of 25mm stone, and then filtering through coarse sand. Dissolved air flotation is another possible method, but more sophisticated and probably not appropriate in most WaterAid situations.

Piling

Source - ICE Works Construction Guide - 'Pile Driving'.

Construction may involve both sheet piling, and simple timber piling, for support to intakes and similar application. The above source reference will be found a useful guide.

Some points of note are:

1. The driving efficiency is related to the ratio between the weight of the hammer and of the pile.

2. The Hiley formula is a simple and popular method of calculating the driving resistance.

   It is: $$R = \frac{Whn}{S+0.5C}$$

   where R = the driving resistance, related to the working load by an appropriate factor of safety
   - W = the weight of the hammer
   - h = the fall of the hammer
   - S = the set per blow
   - C = the total elastic compression of the pile, dolly and ground
   - n = the efficiency of the blow

[The same units should be used for R & W (e.g. Tonnes); and for h, S and C (e.g. mm)]

For <u>timber</u> piles, driven with a drop hammer, n varies from about 0.5 when the weight of the hammer is equal to the weight of the pile, to 0.2 when the pile is six times the weight of the hammer.

For <u>steel</u> piles driven with a drop hammer,n will be between 0.55 and 0.23 for the same ratios.

The value of C is made up of the temporary compression of the pile head and dolly, that of the pile itself, and that of the ground under the pile.

For timber piles, C (mm) will vary from $2 + \frac{L}{3}$

(where L is the length of the pile in metres) for easy driving, to $10 + L$ for hard driving, with $8 + \frac{2L}{3}$ as an average condition.

Comparable values for steel piles range from $2 + \frac{L}{4}$ through $6 + \frac{L}{2}$ to $8 + \frac{3L}{4}$.

3. Sets of less than 2 mm should be avoided for continuous driving - the stress in the pile is too large.

4. Similarly, hammer drops should be less than 1½ m.

5. Guide frames are of course necessary with all types of pile.

6. Hard driving will damage pile heads; 'helmets' or a 'dolly' can be used as protection, or extra length added so that the damaged portion can be cut-off; heads of timber piles can be protected by fitting a steel ring to prevent splitting.

Timber Struts, Columns and Compression Members

The steps in design are:

1. Calculate the maximum axial compressive force or load (P) that the member is required to carry.

2. Decide on the allowable compressive stree (f). Typical values for timber, parallel to the grain are:

   Softwood - 30 to 60 N/mm^2 (or MN/m^2)

   Hardwood - 60 to 90 N/mm^2

   (See B1 and B2 for definition of N.)

3. Hence calculate the minimum cross-section area (A) required - $A = \frac{P}{f}$

   and choose an appropriate size of member.

4. Calculate the radius of gyration (r) of the selected member - $r = \sqrt{\frac{I}{A}}$

   For rectangular sections of breadth 'b' and depth (the smaller dimension) 'd'

   $I = \frac{bd^3}{12}$ and $A = bd$, so $r = 0.289d$

   For circular sections of diameter D, $r = 0.25D$

5. Calculate the effective length (Le). This depends on the end fixing and varies from 0.7 x the actual length (L) for fixed ends, to 2L when the ends are not restrained. Most struts are pinned at both ends (i.e. restrained in position but not in angular direction) and for this condition Le = L, and this is usually a safe assumption.

6. Calculate the slenderness ratio (S) which is Le/r <u>and must not exceed 180.</u> If necessary, choose a larger section.

Note Use consistent units throughout, e.g. kg and mm; or T and ins.

Concrete

Introduction

All engineers are aware of the ideal requirements for producing good concrete: suitable materials well proportioned, thoroughly mixed and compacted and adequately cured. In many developing countries these conditions cannot be easily realised, and the following notes are intended to guide on the points to watch in more difficult circumstances. Obviously no risks should be taken with concrete which is used for structural purposes, where orthodox design and construction methods should be followed.

Materials

Concrete consists of coarse aggregate in a cement/sand matrix and the strength of the concrete cannot be greater than the lowest strength of either component.

(a) Coarse Aggregate

Any reasonably clean, strong, non-reactive graded material, whether natural or man-made, is usable; thus brick or broken tiles can make adequate concrete if they are inherently strong enough and do not deteriorate on immersion in water. Most natural gravels, if clean, are suitable, since they are a residue of a natural selection process. Crushed rock is also suitable, if it is not friable or subject to lamination.

(b) Fine Aggregates

These should ideally be clean and well graded. Materials of near single size produce harsh concrete, difficult to work and liable to be porous. High organic or silt content is very undesirable. A simple test for grading and for silt is to mix the sand with several volumes of water in a jar, and allow to settle for two hours; the grading between coarse and fine particles can easily be seen and the silt which settles on the top should not be greater than 20% by volume. Very silty sand should be washed. Some salt (sodium chloride) can be tolerated for unreinforced concrete, but high sulphate content is most undesirable - in desert countries, sulphates can migrate and crystallise on the surface and the sand should be taken from a lower layer. Beach sands, including coral and shell sands, can be used, but are often saline and must be taken from well above high water; they are usually poorly graded. See note below on a method of testing the suitability of sand.

(c) Laterites See Note B3 - Laterite.

(d) Cement

Even if cement is taken from a reliable source it may deteriorate in storage. It is hydroscopic and unless held in air-tight containers will gradually hydrate: typically, concrete made with cement 12 months old will be less than half as strong as that made with fresh cement. Cement containing soft lumps is suspect, and hard lumps should be viewed with alarm and rejected, except as a form of coarse aggregate; hydrated cement cannot be re-used, and crushing hard lumps to incorporate in the mix only adds an inert material. See note below on a suitable field test for cement quality.

(e) Water

If water is suitable for drinking by animals it is probably adequate for concrete. Quite heavy salt concentrations can be tolerated (reasonable concrete can be made from clean sea-water, but there is risk of reinforcement corrosion and sea water should not be used for reinforced concrete); high silt or organic content is damaging. Water containing a high sulphate concentration or contaminated with metal salts, for example from mine wastes, can seriously affect concrete strength.

Cement Mortar Test

When in doubt as to the quality of sand, cement or water, guidance can be obtained from a simple field test. Mix a 2:1 cement mortar to a stiff consistency and cure a 12mm thick pat on a polythene sheet. In 24 hours it should be reasonably (biscuit) hard and should not be friable. If the result is unsatisfactory, each ingredient can be tested at a time, e.g. if testing for cement quality, use clean sand and clean water, and so on.

Similarly, in the absence of a laboratory to crush cubes the quality of concrete can be judged by a surface scratch test using a shovel or pick to determine the hardness of the concrete after three or four days - hardness is closely related to strength, but soft surface laitance can be ignored.

Mixing

It is, of course, important that the ingredients should be in the right and consistent proportions. This cannot be obtained by such elementary methods as 'Use 40 shovelfuls to one bag of cement.'

Insist, where possible, on volumetric batch mixing, and standardise on a 1:2:4 mix unless weak concrete for fill or similar use is adequate. Minimise water - aim for a 5 to 7cm slump from a 12" truncated cone pile - remember that stiff, dry concrete is difficult to compact.

Placing

Good compaction is essential for strength, durability and water-tightness. Hand tamping will be usual and to be effective concrete should be placed in layers of not more than 45cm.

Curing

Loss of water from the concrete in the first 24 hours after placing is very harmful and the concrete should be covered, or at least shaded, for at least this period. With large volumes of concrete the heat of hydration may drive off some of the contained water and the aggregates should, if feasible, be kept in the shade and washed with water before mixing. Weak concrete is less susceptible to this difficulty than strong concrete. Drying conditions on the surface from exposure to sun or strong winds will also lead to evaporation and loss of strength.

Strength

Given adequate materials, mixing and curing, the expected strength of different mixes with ordinary Portland cement is:

Total Aggregate to Cement	Compression Strength after 28 days (N/mm^2)
9	7.5
8	10
7	15
6	20
5	25

Joints

Great care is needed in jointing new concrete to old (ie past the initial set). The old concrete must be clean, dust-free, and scabbled to remove laitance and roughen the surface. A 5mm layer of 1:1 cement mortar may be placed before pouring the new concrete.

Temperature

Concrete should be maintained at 5°C or above while curing. The effect of higher ambient temperatures is to reduce workability (the slump decreases by about 50% for a rise in temperature of 20°C) and to accelerate strength development, although the 28 day strength, which approaches the 'ultimate' if the temperature is maintained above 10°C, is not much affected by higher temperatures. The more rapid hydration of the cement at high temperatures increases the curing problem (and may necessitate special measures when casting large volumes of concrete to avoid excessive temperatures developing).

Reinforcement

Unconventional sources of steel reinforcement, such as strapping from packing cases, old wire ropes, etc., may be utilised. Protection of the steel from corrosion using adequate cover is more important than bond and, if practicable, the steel may be painted for this purpose. Substitute materials are normally used as a binder, rather than for tension strength. There is a good deal of literature on the use of bamboo for reinforcement, if this is available in a particular area - refer to QAG for details.

Fibrous materials are useful, but note that asbestos fibres present a health risk, and glass fibres must be of special quality as conventional glass is attacked by the alkali in the cement. Chopped polypropylene string is probably the most suitable material likely to be available.

Corrosion

See separate note (T10) on corrosion of concrete and protective measures.

Formwork

See T16.

Ferrocement is like reinforced concrete but

(a) thickness rarely exceeds 25mm;

(b) has more reinforcement (4 to 8%) in the form of wire mesh expanded metal, or closely-spaced small wires distributed uniformly in both directions;

(c) is made with a rich Portland cement mortar (sand/cement ratio 1.5 to 2.5, water/cement ratio 0.35 to 0.5, all by weight), <u>without</u> coarse aggregate (use clean sand $\ngtr$ 2mm and uniform grading).

The mortar is applied by hand or trowel to both sides of the mesh reinforcement, ensuring cover of at least 1.5mm. Plaster in 2 stages with a 2-week interval if required. Cure as for concrete.

Ferrocement can be used for small tanks and slabs, to any shape without formwork. It has a high tensile strength-to-weight ratio, and good cracking behaviour. Galvanised wire may give problems due to reaction with the alkaline cement.

Ferrocement can be used for small tanks and slabs, to any shape without formwork. It has a high tensile strength-to-weight ratio, and good cracking behaviour. Galvanised wire may give problems due to reaction with the alkaline cement.

Ferro-cement has been adapted for the construction of simple water tanks using wire-reinforced mortar. These are commonly referred to as 'Ferro-cement Water Tanks' and a design note (D5) under this heading is included in Group 5; they differ from conventional ferro-cement in that wire is used mainly for stress distribution, and is often less than would be needed to carry the full tensile loads.

Corrosion of Concrete

The most common forms of attack on Portland cement concrete are from acids or sulphates. Acidic conditions may occur naturally in peats and other soils with high organic content, and protective measures are required in the pH is less than 4.5. Many industrial wastes, especially from agriculture of mines, are acidic. Sulphates are often found in groundwater and if the concentration is in excess of about 1000 mg/l SO_4, protection is necessary.

Concrete is also attacked by septic sewage. In the complete absence of oxygen (e.g. in aqua privy vaults) corrosion is not severe, but hydrogen sulphide is released into the atmosphere and on mixing with air will oxidise to sulphurous and sulphuric acids. Very acidic conditions may then result with severe corrosion of the walls of structures or sewers just above the surface of the sewage.

In general terms the better the quality of the concrete the higher the resistance to all forms of attack. The following table shows some simple protective measures.

Method	**Degree of Protection**
Externally	
Sacrificial layer	Longer life.
Sulphate-resisting cement (if avail.)	Protects against sulphates but not against acids.
External coating	Bitumen and coal tar are satisfactory if free from pinholes (use two coats).
Plastic film wrap	Effective if not damaged.

Method	**Degree of Protection**
Internally	
Sacrificial layer	Lengthens life.
Calcarious aggregate (if avail.)	Lengthens life in acidic conditions
Bitumen or coal tar coating	Not very effective.

Another form of attack on reinforced concrete is corrosion of the reinforcement which then expands and cracks or spalls and concrete. The most serious corrosive agents are chlorides and carbon dioxide, both of which break down the protective oxide layer on steel reinforcement. Carbon dioxide may form in peat or other soils with a high organic content, and chlorides are of course present in sea-water and often in highly mineralised groundwater.

This form of attack is most severe in areas of concrete which are alternatively wet and dry. The best protection is ample (not less than 40mm) of good dense concrete cover to the reinforcement.

Water Pipelines - Design

These notes reflect field experience:

1. Most water pipelines function as pressure pipes. They do not need to be of constant diameter throughout, although normal economic design would seek to keep a generally uniform velocity.

2. Air-locks in pipelines can be very troublesome. Avoid humps if at all possible by careful choice of route; if humps unavoidable, provide an air release valve or cock or a stand-pipe at each high point, and a drain valve at each valley to scour sediment - but bear in mind misappropriation of water from these valves! Ideally, provide hatch-boxes or removable pipe sections at intervals, to allow cleaning tools to be inserted.

3. When screwed couplings are used (as with galvanised steel pipes) provide screwed unions at key points and at intervals of say 300 m to enable pipes to be removed without difficulty.

4. With flanged pipes, it is a fallacy that valves etc. can be easily removed and reinstated unless there is a little longitudinal 'flexibility' - it is easy to remove a 90° bend for this purpose.

5. In many countries there are no standards for flanges, or flange materials or screwed couplings, so specify carefully:

   Flange thickness and diameter.
   Pitch circle diameter, number and size of holes.
   Flange joint material, and whether full face or within bolt circle.
   Diameter and length of flange bolts.
   Type of screw thread and number of threads per unit length.

   Plastic flanges may buckle between boltholes and need metal back-up rings, with longer bolts. Holes in plastic flanges are sometimes made with a hot poker, but may be oversized and poorly located.

6. Fill pipelines slowly, to allow air to escape, and when in operation, open or close valves slowly to minimise surge pressures.

7. See B8 for recommended minimum velocities.

8. Ease of access to key points is important for maintenance and control; measures should be taken to minimise accidental or deliberate damage to the pipeline.

9. Provide permanent markers (eg concrete) at key points, junctions and changes of direction to allow pipelines to be located.

10. Pipes in gravity schemes will often need to cross streams or rivers. If these are shallow it is preferable to lay the pipe under the stream bed, but ensure that it is well below scour level, or protected with boulders etc.

    With fast flowing water and deep channels it may be necessary to cross above the stream. In these circumstances:

    a) If an adequate permanent bridge structure is available, use it to carry the pipeline laid on it or slung under the structure.

    b) Allow for the weight of water as well as of the pipes and support at frequent intervals to minimise deflection, especially with plastic pipes. (See T3) If joints are unavoidable use bolted joints if possible.

    c) Ensure that the pipe is protected from accidental or wilful damage and from direct sunlight. In long crossings, allow for the expansion. (See T1)

    d) Provide isolating sluice valves close to the crossing on either side.

    Should there be no suitable structure, the alternatives are to construct a special pipe bridge, or, if the gap is not too wide or piers can be built in the stream, to use rigid pipes to span from bank to bank. If a length of rigid over-sized pipe is available, the pipeline can be laid inside. Steps must always be taken to avoid the pipe being used as a bridge or for play, and a protective fan of steel spikes at either end is often used. The pipe must of course be well above possible flood level.

11. Break pressure tanks - High pressure in the distribution network may result in high leakage at joints, fittings and taps, and residual head at standpipes should not exceed 10m, (See D6) Pressure

reduction valves are expensive and difficult to maintain, and a simple break-pressure chamber is preferable. This uses a float-operated valve in a open chamber, similar to a W.C cistern provided with a drain/washout and an overflow. This can also be used as regulating reservoir. In some circumstances, a simple vent pipe will serve the purpose, but the outflow pipe needs to have more capacity than the in flow, to ensure that there is no outflow from the vent.

12. Nepal practice is to keep the design velocity to 0.7 and 3m/sec; to provide washouts at 1km intervals; and to allow a 'design length' of 1.15 times the survey length.

13. Regulating reservoirs can be used to reduce pipe sizes, and avoid interruption in supply when the source yield is less than peak demand. In Nepal, they are sized at 0.37 daily demand, for complete regulation, down to 0.1 d.d. to regulate flows to twice the daily demand. In Uganda, 3 to 4 1/hd has been found useful.

Site Roads

Road design is not likely to fall into WaterAid activity, but occasionally it may be necessary to construct short lengths of roads suitable for light traffic to serve treatment, storage or other sites.

Usually it will be possible to get local advice on suitable forms of construction. The following brief note is intended only to cover emergency situations where this is not available.

The key points are:

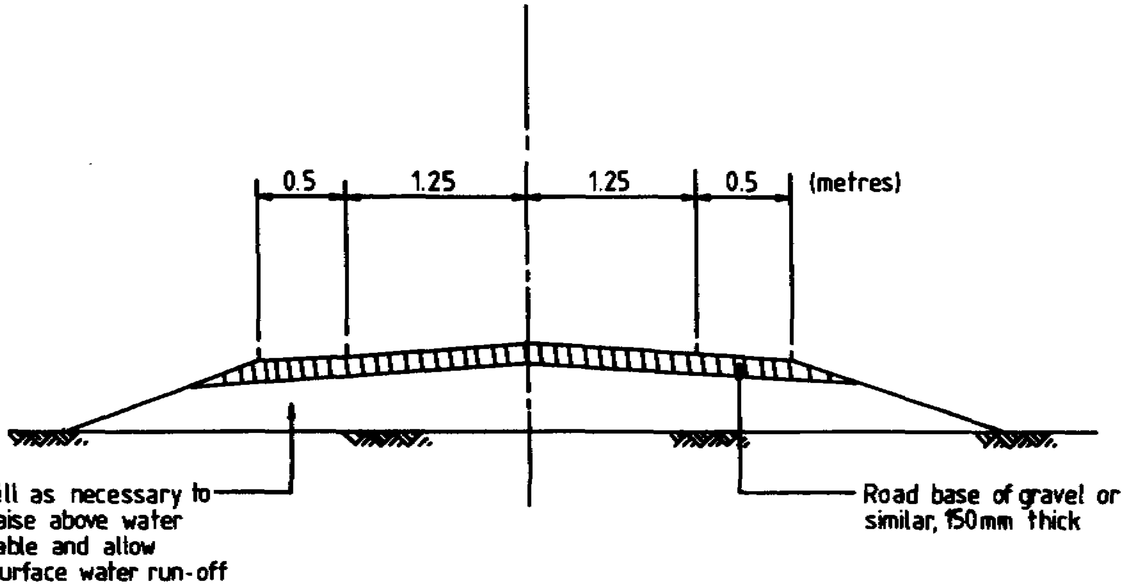
(a) The road material must spread the wheel load to limit the pressure on the subsoil to within an acceptable limit.

(b) The surface must be shaped and maintained so as to shed water on either side, and to avoid pot-holes or undulations which escalate the wheel loading.

(c) The subsoil must be kept as dry as feasible by good side drainage.

With these precautions, many naturally occurring subsoils will be adequate for light traffic. If not, maximum use must be made of local materials, usually some form of gravel, or sandy gravel, or crushed stone with content of fine material to assist in binding. See Fig.T12/1 for a typical cross-section of a simple road of this type.

Suitable material for the road base should not contain more than 25% of The material (passing No. 200 sieve) or particles larger than about 40mm. The material should have a Liquid Limit less than about 30, and a Plasticity Index less than about 15. Most laterite materials (see B3) are suitable. (The Liquid Limit (LL) is the minimum moisture content at which the soil will flow under its own weight; the Plastic Limit (PL) is the minimum moisture content at which the soil can be rolled into a thread 0.125 in. diameter without breaking; and the Plasticity Index (PI) is the difference between LL and PL. A soils laboratory is needed to determine these values, but typically a sandy loam has an LL of 25 and a PI of 10; and clays have LL between 55 and 75, and PI between 30 and 40.)



Cross Section on Single Lane Road

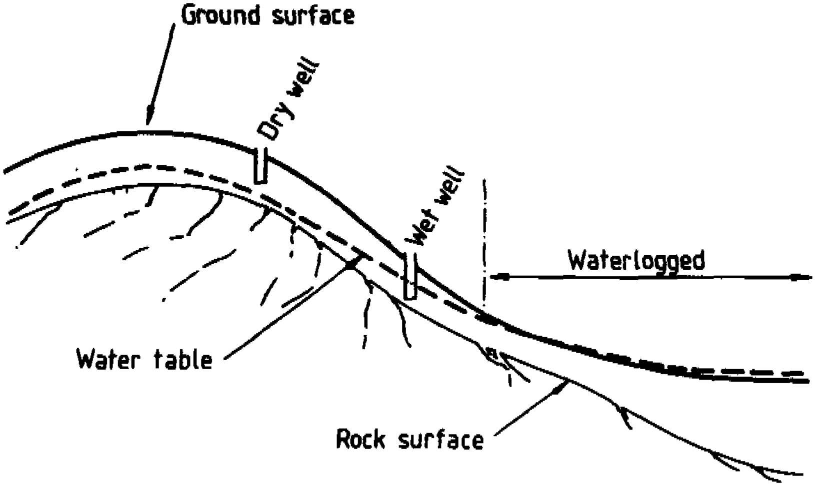
Fig T12/1

A. General

Groundwater does not flow in underground streams (except karstic [1] areas). It is present in pores and fractures in the soils and rocks and moves excruciatingly slowly under gravity towards points of discharge - river beds, etc. At these points the flow may be concentrated in zones of higher permeability (fractures in rock, natural pipes in weathered material) producing an illusion of a linear stream discharging as a spring. Where permeabilities remain the same throughout the system there is a continuous line of seepage, e.g. along dambo[2] or vlei[3] floors or around the edge of wetlands. Either way a point of discharge defines the inter-section of the 'water table' with the surface, often due to an underlying impermeable (clay) layer.

The 'water table' tends to follow the contours of the landscape, only it is more subdued, being closest to the surface near valleys and deepest on the top of ridges (Fig.T13/1). If there are any wells/boreholes in an area, by measuring the rest water level and combining this with known points of discharge, it may be possible to 'contour' the water table and use this to predict water levels in a new well.

(1) Bedded limestone with solution cavities.
(2) & (3) African terms for flat-floored valleys where the water table is close to the surface.



Water Table Configuration Fig T13/1

B. Well-Siting

A good dug well has

i) shallow water table
ii) permeable strata
iii) easy digging

It should be at least 50m from pit latrines and cattle pens and protected from waterlogging, surface run off and soil erosion.

Geological maps will establish whether it is a 'hard rock' or 'soft rock' area. Soft or sedimentary rocks are relatively permeable, particularly sandstones and bedded limestones. However, much of Africa is underlain by hard crystalline rocks such as granite and gneiss which are virtually impermeable unless weathered or fractured. The weathered zone ranges from 0 to 50m thick.

o Fractures found in association with fault zones, often easily identified in aerial photographs as linear features exploited by streams or marked by vegetation changes. Linear drainage patterns, controlled by faulting, may also be obvious on topographical maps.

  If possible choose a site where two drainage patterns intersect (Fig.T13/2a)

o Fracturing and deeper weathering often occur adjacent to vertical dykes - usually composed of dolerite - a fine to medium grained, greyish black, crystalline rock, more often seen weathered into large rounded boulders with reddish brown iron-stained surfaces. It produces a dark red clayey soil. Dolerite dykes may sometimes from ridges. In aerial photography they show up as linear features and often attract denser tree cover (Fig. T13/2b)

o Weathering is often deeper around the base of inselbergs (bare granite outcrops) where the extra surface run-off infiltrates (Fig.T13/2c).

- o Areas of seasonal waterlogging show up as darker patches in aerial photographs. On the ground the change in vegetation may be quite subtle and difficult to spot. The presence of low grey anthills may indicate a water table close to the surface. Wells should be sited upslope from the edge of the waterlogged area.

- o Site upslope of springs and seepages to intercept the most permeable zone. (Fig.T13/2d)

- o Site upstream of rock bars across valleys (they may act a subsurface dams).

- o Site downstream of earth dam walls, close to the foot to intercept leakage.

- o Where there are changes of slope and no springs, choose a site at the base of the steepest section (Fig.T13/2e).

- o In river valleys tall acacia or manpanil trees often grow on hidden sandbars - potentially high yielding sites.

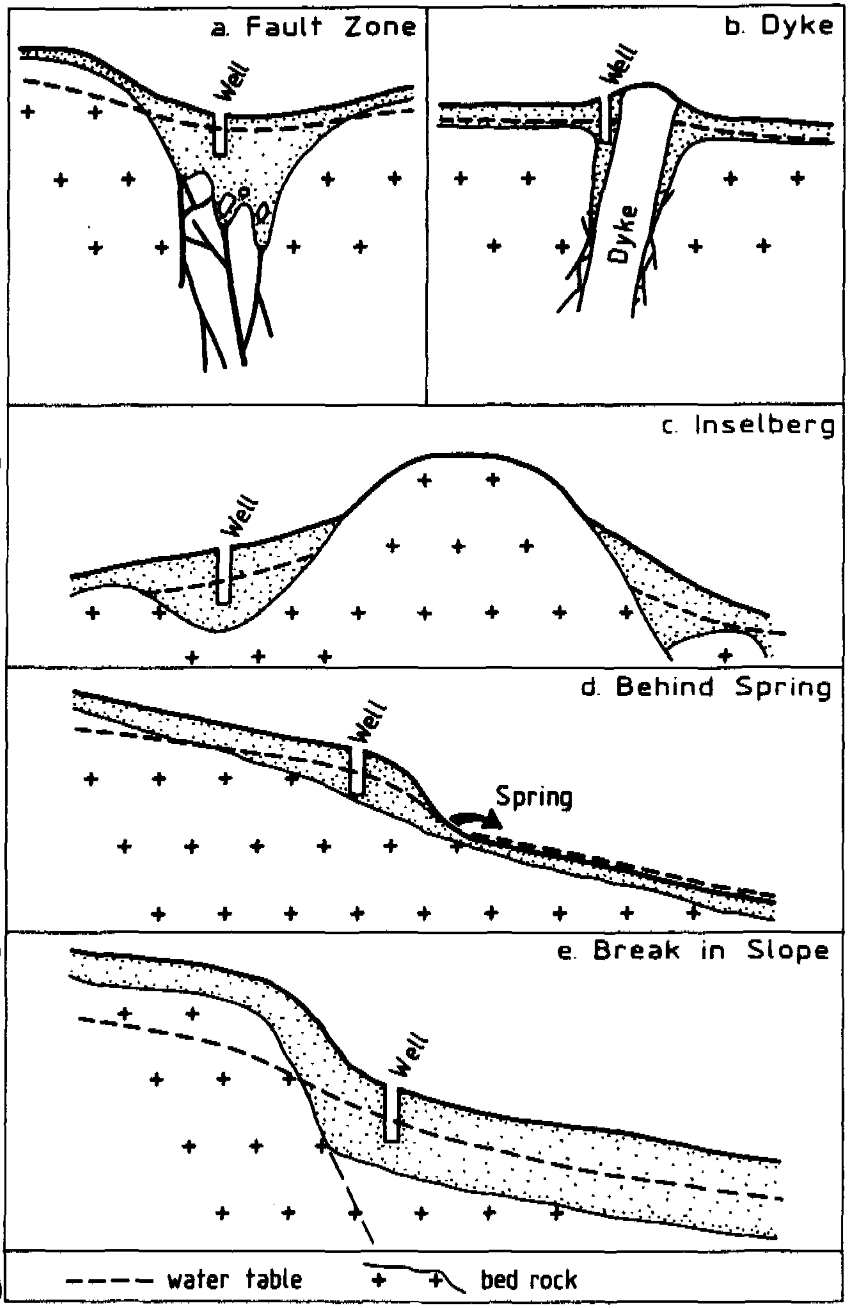
- o Look for large trees known locally to be water-seeking, eg fig trees.

- o Large high anthills are often a sign of deep weathering. Check what burrowing animals have brought to the surface - if minerals look fresh, the weathered zone is shallow. Feldspar is the best indicator as it weathers it becomes milky and starts to separate along cleavage plains, later it turns to clay.

- o Geophysics may be used to confirm the depth of the weathered zone. Resistivity and electromagnetic techniques are the most useful but they will rarely pick out the water table in hard rock areas. Get local specialist advice on this.

C. Boreholes or Tube Wells

These can be constructed using simple hand held drilling equipment e.g. Vonder rig. This is possible in areas of deeply weathered bedrock or unconsolidated sediments.



Well Siting

Fig T13/2

If the ground is firm, auger the hole first and then install casing. Casings are usually made of steel or plastic; PVC is preferred being cheap and inert in corrosive groundwaters. Use a centraliser if a gravel pack is to emplaced in the annular space (Fig.T13/3). Where the ground is collapsing it will be necessary to auger inside the casing. If the casing does not fall under its own weight it may have to be driven with sledge hammers and rotated with chain flanges; therefore use steel casing. It is possible to complete the well with a smaller diameter plastic casing and jack out the drilling casing if a gravel pack is needed. In this case add the gravel pack gradually as the temporary casing is withdrawn to avoid a sand lock. (Fig.T13/4).

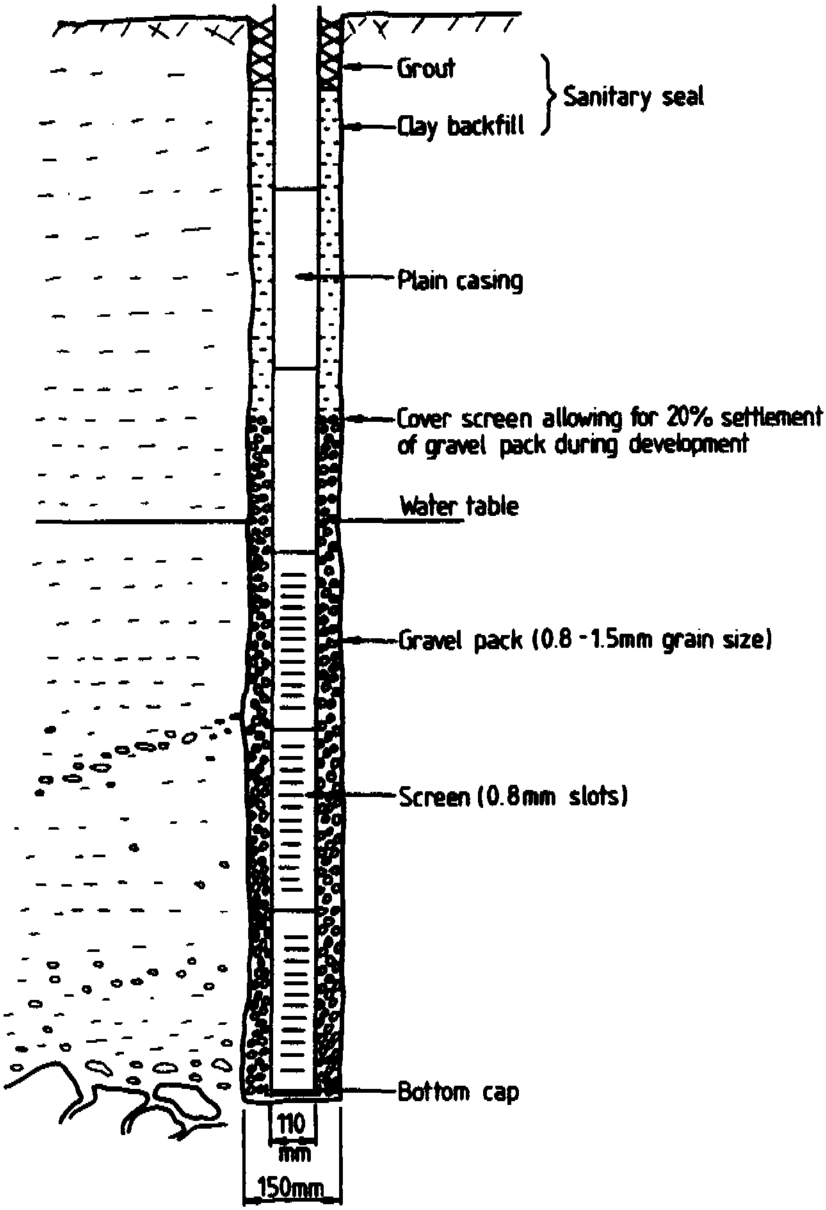
The top of the casing should be sealed with grout (see Fig.T13/3) the bottom of the casing should be screened to allow water to enter and keep aquifer particles out. The well should be 'developed' to pull all the fines into the well and remove them before the well is fitted with a permanent pump (this also applies to gravel packed wells). This minimises siltation and the damage caused by 'pumping sand'. The simplest method of development is 'rawhiding' - over pump the well, stop and allow the water level to recover and repeat until the water is clear.

Tube wells can be completed with a pump which could be handpump or bucket pump.

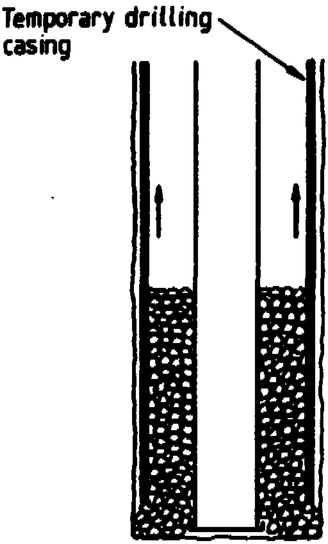
D. Screens and Gravel Packs

Many types of screen are available commercially. The most efficient is continuous slotted wire wound screen with an open area of 80% (e.g. Johnson's); followed by slotted louvre screens, vertically slotted screens and perforated screens with the least open area. In order not to impede the inflow of water a minimum open area of 8% is recommended for handpumped wells.

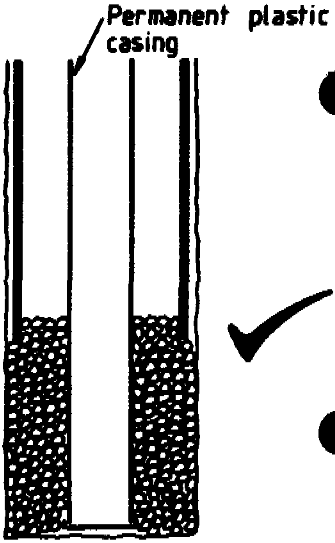
The screen's aperture size depends on the size of the particles surrounding it. This can be increased by adding an artificial gravel pack and is necessary in silts and fine sands. (Fig.T13/4) 'Gravel packs' can be uniform or graded within narrow limits. The mean diameter of the particles should be 4 or 5 times that of particles in the aquifer. A minimum annular space of 50mm should exist before a 'gravel pack' can be emplaced. Some commercial screens come with a prebonded gravel pack or wrapped with various configurations of mesh. This is more expensive than a loose pack.



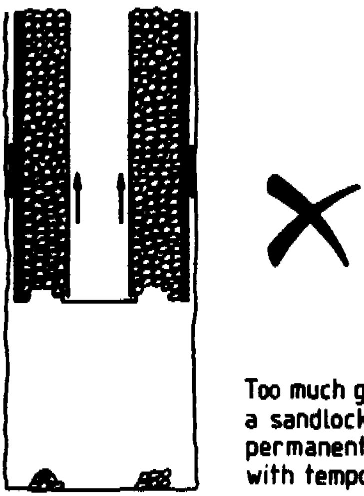
Simple Tube Well Design Fig T13/3



1. Emplace 1 - 1.5 m of gravel pack. Jack or pull out casing.



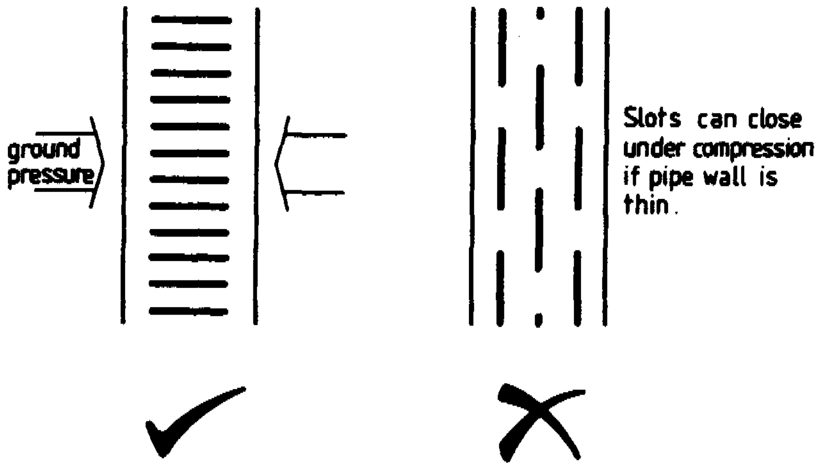
2. Emplace more gravel and repeat. Do not allow gravel to fall below temporary casing if ground is collapsing.



Too much gravel causes a sandlock pulling out permanent plastic casing with temporary drilling casing.

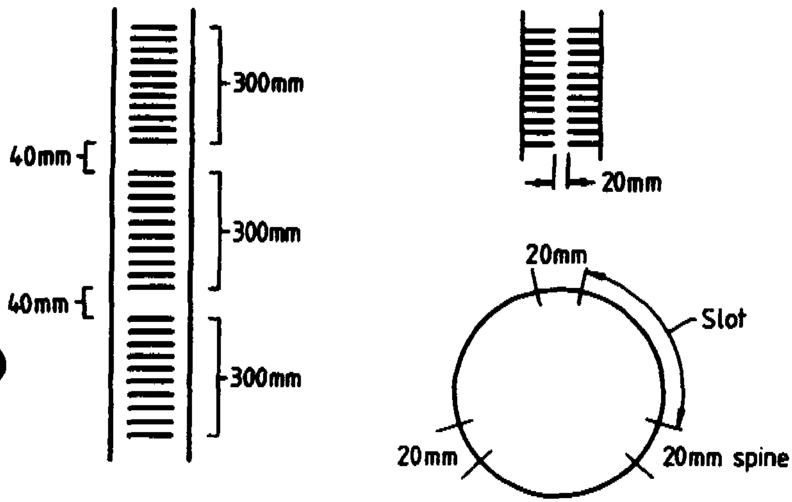
Placing Gravel Pack

Fig T13/4



Slots for Casings

Fig T13/5



Slot Spacing

Fig T13/6

A typical well design for use in weathered overburden would consist of an augered hole (150-200mm dia.), installed with PVC casing and slotted pipe (110-125mm dia. with slot size of 0.8-1mm), surrounded by a gravel pack (grain size between 0.8 and 1.5mm dia. or 1 and 1.5mm dia., depending on slot size).

Use at least 3m (preferably 10m) of screen. Less screens = greater entrance velocities = turbulent flow = greater drawdown, i.e. decreased well efficiency, and possible encrustation problems.

Local screens can be made on site from the same material used for casing. PVC pipe can be slotted if labour is available using a hacksaw (blade 1mm or less). Use Class 10 PVC.

Pipe slotted transversely is stronger than pipe slotted longitudinally (lateral compressive forces are greater than vertical forces in a shallow tube well). (Fig T13/5).

For 110mm diameter pipe:

Cut three rows of slots, each slot 1cm apart in blocks 30cm. Leave a 4cm gap before starting the next block. Leave a vertical spine of about 2cms between adjacent rows. (Fig.T13/6)

For pipe diameters > 125mm consider four rows of slots.

For steel pipes, drilled holes or torch slots can be used to produce a 'poor screen', which can be improved by wrapping with 1mm mesh.

E - Hand Dug Wells

WaterAid has contributed to programmes of hand-dug wells in Ghana, The Gambia, Sierra Leone, Uganda and Nepal. In Zimbabwe, the Blair Laboratory with support from WaterAid is responsible for a major programme of assistance to house-holders who wish to upgrade their family wells.

Hand-dug wells can be used in a wider variety of soils than hand-drilled tube wells, although they are unsuitable for hard rock or running sands. They can be deepened after construction and buckets can be used should the pump break down. they are thus more reliable. However they take longer to construct and are more expensive. Of all the technologies which WaterAid uses, they are potentially the most hazardous. (See Safety, G4)

Design All programmes use a similar basic design (see Fig. T13/7). The common features are:

- The well itself with a 70 to 150mm fixed, impermeable lining of concrete, brick etc, to prevent collapse or contamination. The finished internal diameter is normally 1.3m for ease of digging.

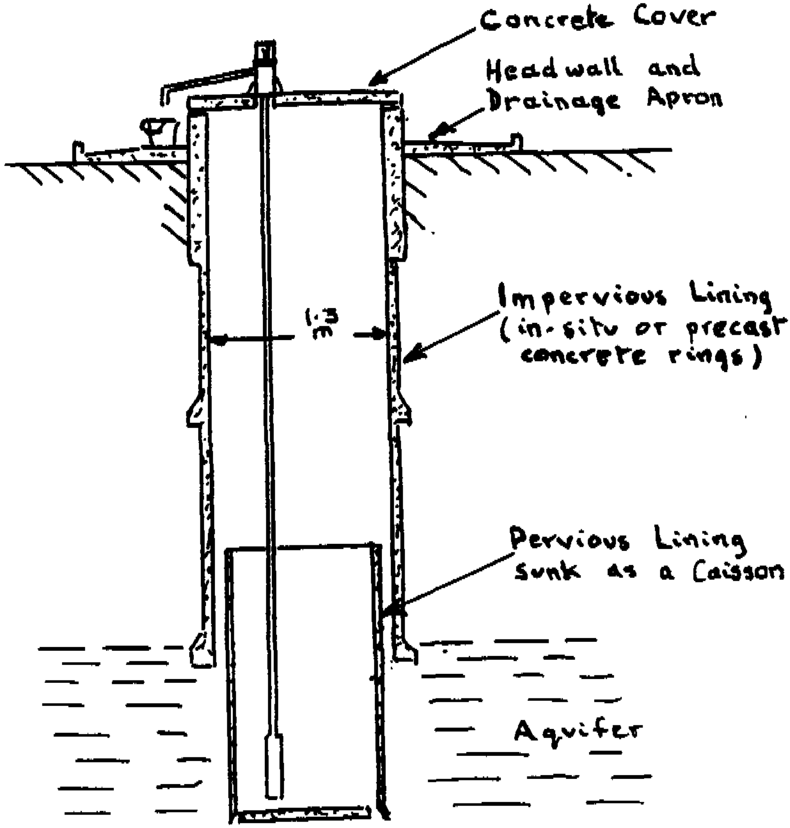
- (Smaller diameter (normally 1m) caisson rings sunk into the aquifer, possibly with holes or made from porous concrete to allow water to enter the well. The top-most caisson ring will extend well above the base of the fixed outer lining.

- The head works

    - An apron to collect spillage and prevent pollution by surface water
    - Provision for drainage
    - Provision for withdrawing water
    - Safety provisions to prevent people and animals falling down the well.

Total depths range from about 10m to some as deep a 20m deep in Ghana. Wells are dug into the water table to that depth which produces a sufficient yield for the intended number of users, normally 250-300, that number which can reasonably use a hand-pump. Each programme has developed its own guidelines on how far this should be, for example the rule of thumb in The Gambia was 3m. (It is important that this relates to the lowest water table in the dry season, and provision made for sinking deeper should the water table drop in the future).

Well Digging: Wells can be dug by the users, by skilled project staff or by a combination of the two. With the exception of The Gambia where there is a tradition of paid well-diggers, wells dug by the users; this keeps the costs down and is the users' major contribution, but use a plumb line to keep the well vertical, and watch the safety aspect. In most programmes communities dig their well with only a few supervising visits from the project staff until the water table has been reached. Lining is normally carried out by skilled project staff, although in Ghana local masons living in the communities lay concrete lining blocks.



Hand-dug Well Fig. T13/7

Well Digging and Lining: The principle well digging and lining methods include:

- Digging throughout inside large diameter pre-cast concrete caisson rings. (Fig.T13/8).
- Digging and lining with concrete in-situ, in short lifts as digging proceeds.
- Digging unsupported to the water table and lining in one lift to the surface using:
    - Curved concrete blocks
    - In-situ concrete
    - Caisson rings
    - Locally burnt bricks
- Digging using temporary corrugated steel or timber board shuttering and lining as above; or backfilling an open pit after building the well lining. (Do **not** backfill around a small diameter rising main.)

Digging and lining in-situ in short lifts will deal with most ground conditions and is safe in that only short lengths of well are unsupported at any one time, but is time consuming and expensive.

Digging inside caisson rings is quicker since concrete takes place at the surface and the rings can be stored ready for use. It is safe in that the ground is always supported. However, the rings are heavy so that substantial lifting equipment is required. Some skill is also needed to ensure that the rings are sunk vertically. In some soils, the rings must be tied together so that they do not part company.

Soils in Ghana and Uganda are such that it may be safe to dig to the water table without supporting the sides of the well. The wells are then lined with the cheapest appropriate material. Where it can be practised safely, this method is the quickest and cheapest.

Dewatering: It will be necessary to dewater as well digging penetrates below the water table. (Dig in the dry season!). Hand operated diaphragm pumps may be adequate. If power operated pumps are necessary, do **not** site the prime mover in or near the well, because of CO danger. Eductors are useful (see T19).

Well Deepening: One of the advantages of hand- dug wells over boreholes is that as if the water table drops the well can be deepened to maintain the supply of water. This can be facilitated by the use of smaller diameter caisson rings which can move relative to the fixed, permanent lining.

Head-Works: Head-works are similar with the greatest variation in the arrangements for drainage of waste water. In countries such as Uganda with fairly impervious surface soils it is difficult to arrange for proper drainage. In Ghana all waste water is led to a small pump about 10m from the well and is drunk by cattle.

Water Lifting Devices: Most wells are fitted with hand-pumps (see T18 on choice of pump). If using a pump, there is little possibility of contamination in use. Some communities in the Upper East region of Ghana cannot afford to maintain a pump. They buy single collapsible rubber bucket which is kept by the well on a post and is the only bucket allowed down the well.

Cover Slab: If a hand or mechanical pump is fitted, the well should be covered with a concrete slab to prevent surface contamination. For wells up to 1½m dia. a 150mm thick slab reinforced with 8mm reinforcement bar at 150mm centres in both directions will be adequate; the hole will of course be sized to suit the pump.

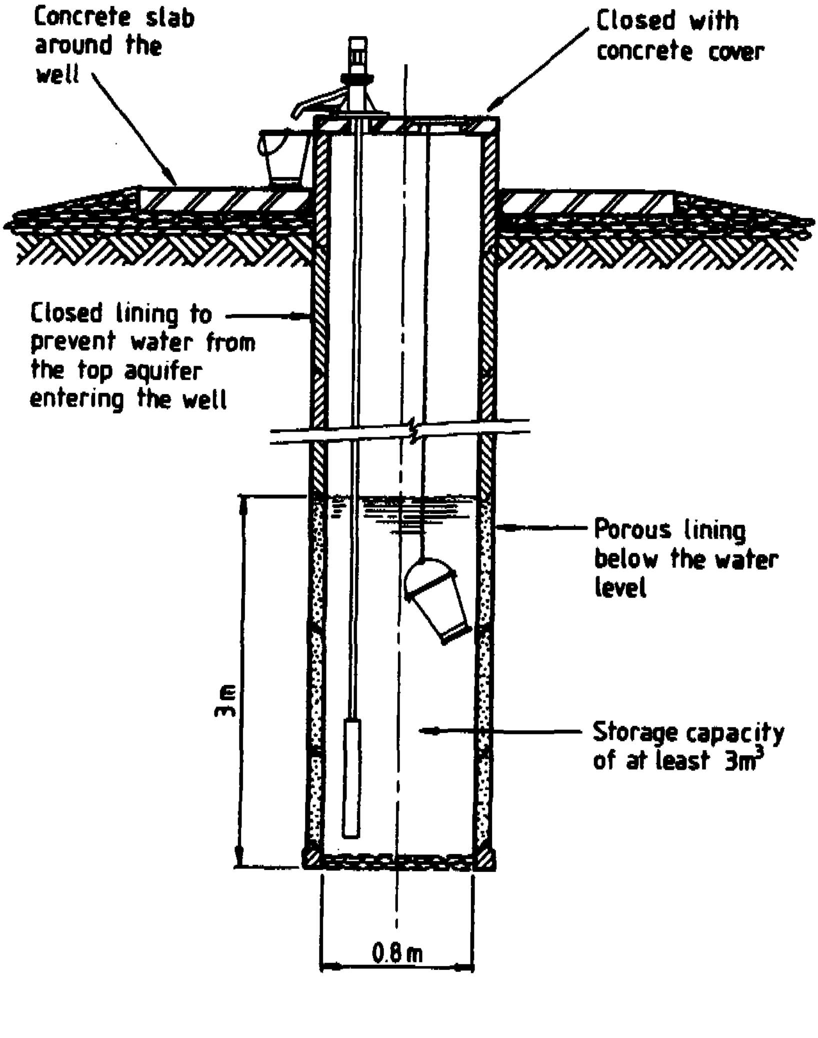
The slab can be cast on the ground, with a ring of bricks if timber formwork is not available; it can be cast in three sections to make it easier to handle.

Yield: Where well storage is negligible and the yield is constant, the rate of drawdown is greatest immediately after pumping starts and falls off exponentially approaching an asymptote and steady state condition. when pumping stops, the recovery curve should be a mirror image. (Fig.T13/9). Therefore:

1. Recovery will appear slow after pumping for a long time.

2 For the same pumping period the drawdown is directly proportional to the yield. This holds true until the main aquifer is dewatered.

3. The radius of the cone influence expands with time, not with the rate of pumping. The rate at which it expands depends on the transmissivity (permeability x thickness of aquifer).



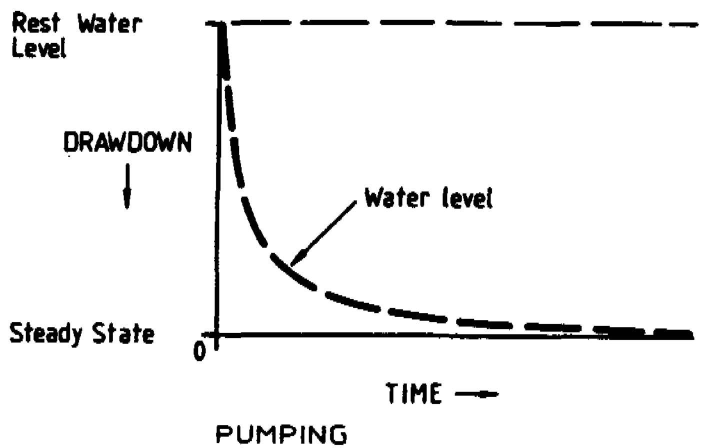
Well with Caisson Rings Fig T13/8

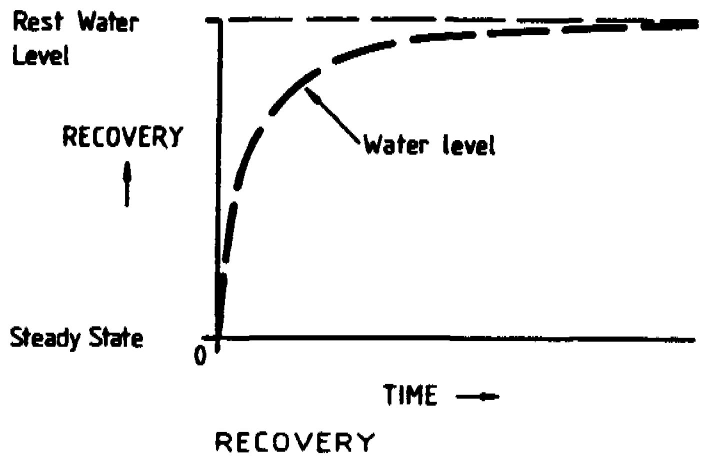
A clayey aquifer will have low transmissivity and a narrow deep cone of influence; a gravel aquifer will have high transmissivity and a wide shallow cone of influence. Therefore the distance between wells and latrines is more critical for sand or gravel aquifers.

4. The water table can maintain steeper slopes where the transmissivity is low. Therefore water will be closer to the surface on topographical highs compared to an aquifer with high transmissivity; as a rule of thumb, look for a recovery rate of 1m/hr.

F Geophysics

Geophysical methods are often used in large scale initial surveys. They require specialist input and the cost is relatively high - if the groundwater is close to the surface, hand-dug wells are better and cheaper. Basically they help to locate rock surfaces rather than water table level.





Well Drawdown and Recovery

Fig T13/9

Shallow Excavations

Uncontrolled excavation is dangerous. The following notes summarise good UK practise. It will be a matter of judgment as to how far to relax this to conform to local practise.

Source - CIRIA Report 97: Trenching Practices
CIRIA Report 113: Control of Groundwater for Temporary Works

This note gives guidance on excavation with vertical or battered sides for depths up to about 3 m. The Reports cited above give more detailed information and advice on excavations of up to 6 m depth. Still deeper excavations should always be designed and supervised by competent and experienced engineers.

1. Ground Types

For this purpose ground types can be classified as shown in Table 1.

2. Safe Slopes for Temporary Excavations

These depend on many factors, including the type and condition of ground, the presence of surface or groundwater, surcharge loading, and the time the excavation is left open. Slopes indicated in the following table offer a rough guide. They assume that the excavation is not open for more than 14 days, and that there is no surcharge and no hazard to adjacent structures. Local conditions, such as fissuring or running sand, are important and should be taken into account. (See Table 2).

3. Supports for Vertical-sided Excavation

For trenches, etc., less than 1.2 m deep, support is only required as necessary to keep the excavations open. For trenches between 1.2 and 3 m deep, timber sheeting should be used except in unfractured rock. Close sheeting should always be used for gravels, sand, silt, soft clay and highly compressible peat. Hit and miss sheeting can be used for firm clay and for peat of low compressibility. Sheeting should be toed in at the formation level and walings spaced at 1 to 1.5 m centres. Examples of suitable waling and strut, assuming good quality softwood, are given in Table 3.

Walings must be supported by hangers or puncheons, and struts by lip blocks. Sheeting should be wedged tight against the walings after placing the struts.

4. Groundwater Control

Surface or groundwater can give unstable conditions, except in unfractured rock, and control in excavation is essential. Methods available fall into four basic groups:

i) those that stop surface water from entering the excavation, e.g. cut-off ditches, low height embankments.

ii) those that allow water to flow into the excavation and be pumped out from sumps and ditches

iii) those where the soil is pre-drained by lowering the groundwater level by wells or well points

iv) those that stop the groundwater entering the excavation by some form of cut-off, such as sheet piling

The pros and cons of the more usual methods are summarised in Table 4.

Table 1

Characteristics of Ground Types

Type	Designation	Particle Size	Appearance
Granule	Cobbles/Boulders Gravel Sand	60mm 2-60mm 0.06-2mm	Particles visible Sand feels gritty
Cohesive	Silt	0.002-0.06mm	Water separates when sample shaken
	Clay	Below 0.002m	Can be moulded on the fingers. Obvious organic content.
Mixed Soils	-	-	Characterised by dominant particle size.
Fill	-	-	Relate to main soil type.
Rock	-	-	Stonger than above soil types.

Table 2

Ground Types	Safe Temporary Slope (Degrees from horizontal) Dry	Wet
Boulder/Cobble	35-40	30-35
Gravel	30-40	10-30
Sand	30-35	10-30
Silt	20-40	5-20
Soft Clay	30-45	10-20
Firm Clay	35-45	20-25
Fibrous Peat	35-40	20-25
Non-fibrous Peat	10-20	5-10
Mixed soil) Consolidated Fill)	According to characteristic content	
Rock	According to degree of jointing, bedding, fracture.	

Table 3

Minimum sizes for Walings and Struts

Strut Spacing (m)	Waling Spacing (m)	Waling Section (mm)	Strut Section (mm) for Trench Widths of : 1m	1.5m	2m
1.8	1	225 x 75	150 x 75	150 x 100	150 x150
2.5	0.9	200 x 100	150 x 75	150 x 100	150 x 150
3.0	0.9	225 x 150	150 x 75	150 x 100	150 x 150

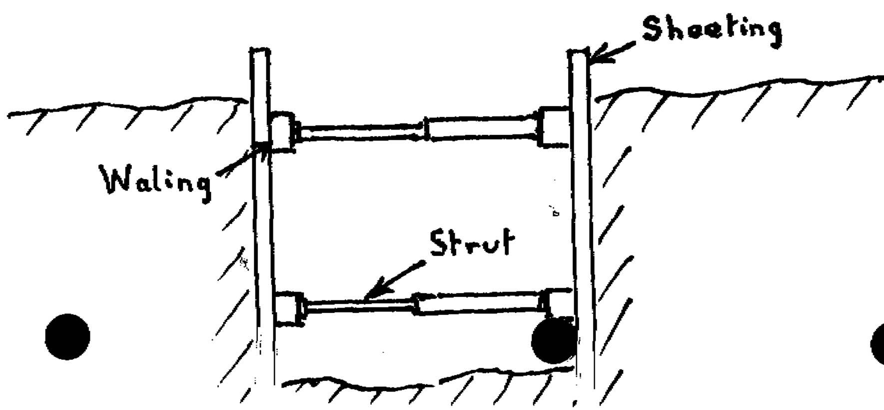


Table 4

Groundwater Control Methods and Open Excavations

Method	Suitable Soils	Advantages	Disadvantages
Surface Water Control	All (use polythene sheeting on permeable soils	Simple	May obstruct access
Internal pumping	All	Simple pumping equipment	May encourage formation instability. Fines lost on sandy soils
Well points	Permeable	Quick and easy to install/move	Needs specialist equipment/experience
Shallow Wells	Permeable	Simple	Costly
Sheet Piles	All except boulders, rocks	Simple	Needs material and driving gear. May be expensive.

5. Permeability

The general relationship for ground permeability is $Q = k A \frac{h}{L}$

where Q = quantity of water flow
k = coefficient of permeability
A = ground cross-section area
$\frac{h}{L}$ = hydraulic gradient

Approximate values of k are set out in Table 5.

Pumping out tests from a well observing the steady state water level in radial observation boreholes can be used to determine the coefficient permeability in situ.

The approximate radius of influence of the cones of depression on a dewatering well in various soils is shown in Table 6. The quantity of water from the well can be roughly calculated from the formula

$$Q = \frac{k\,(H^2 - h^2)}{\log_e \frac{R}{r}}$$

When Q = Flow (m^3/s)
k = Permeability (m/s)
H = Depth of water when not pumping(m)
h = Depth of water when pumping (m)
R = Radius of influence
r = Radius of well

6. Surface Water Control Methods

The figure attached shows typical details. (Fig.T14.)

C/93

Table 5

Coefficients of Permeability

Soil Type	Degree	k(m/s x 10^{-6})
Clean gravel	High	1000
Coarse sand	Medium	10-1000
Fine sand	Low	0.1-10
Silt, sandy clay	Very low	0.001-0.1
Clay	Impervious	0.001

T14/8

Table 6

Cones of Depression in Homogeneous Strata

Drawdown (m)	Radius of Influence (m) (fine sand)	(sand)	(gravel)
1	9	30	95
2	19	60	190
3	28	90	285
4	38	120	379
5	47	150	474

7. Well points

Well points are essentially a series of shallow boreholes with 0.5-1 m long screens on suction tubes of about 50 mm dia. connected to a common suction pipe. They are normally installed by jetting and in fine or sandy soils a sand filter pack round the screen is desirable. Experience in laying out and installing well points is desirable, but details of equipment and installation can be obtained from wellpoint system manufacturers.

8. Pumps for DeWatering Excavations

Suitable pumps for dewatering excavations include:

(a)	Air Lift	Air is fed into a length of tubing. Efficiency varies according to several factors, but is generally low. However, the method may be convenient for shallow lifts of short duration.
(b)	Diaphragm Pumps	Hand-operated pumps of 30 and 100 mm dia. have outputs of about 0.3 and 4 l/sec. respectively. Standard motor driven diaphragm pumps are typically of 75 or 100 mm dia. with outputs of between 6 and 10 l/sec. They will handle some detritus in the water.
(c)	Centrifugal Pumps	All types of centrifugal pumps, including submersible, can be used, but many are not suitable for water containing silt or sand. Typical outputs at a working head of about 6 m range from 7 l/sec for 50 mm (3 in.) pumps to 40 l/sec for 150 mm (6 in.) pumps.
(d)	Eductors	- See T19

9. Delivery Pipes

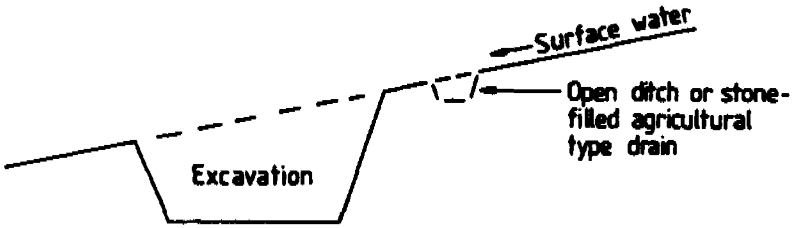
Delivery pipes from dewatering pumps are frequently of rubber or canvas. The friction characteristics of rubber hose result in head losses approximately as follows:

(a) 50mm dia. hose

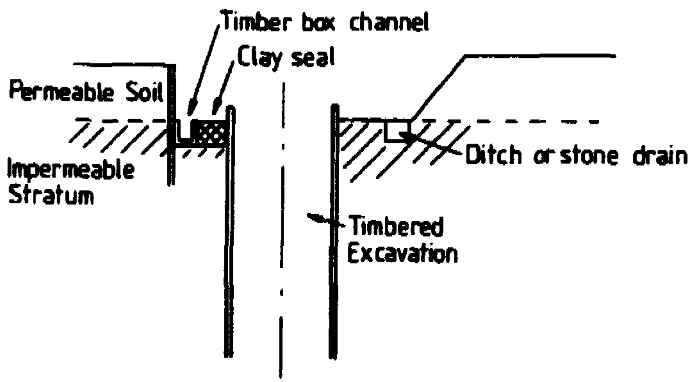
Loss - 10 m per 100 m at 4 l/sec.
- 30 m per 100 m at 7 l/sec.

(b) 100mm dia. hose

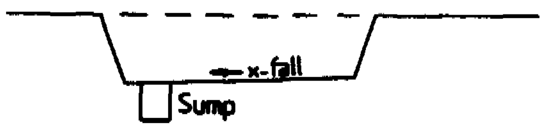
Loss - 8 m per 100 m at 20 l/sec.
- 35 m per 100 m at 40 l/sec.



(a) Cut-off Drain



(b) Alternative forms of 'Garland' drain for Timbered Excavation



(c) Sump Drainage

Note:

In impermeable stratum or if water table high, sump will need to be pumped dry. If water table is below formation in permeable stratum extend sump into permeable layer for gravity drainage.

Surface Water Control Methods

Fig T14

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Loss - 10 m per 100 m at 4 l/sec.
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(b) <u>100mm dia. hose</u>

Loss - 8 m per 100 m at 20 l/sec.
- 35 m per 100 m at 40 l/sec.

Thrust Blocks

In pressure pipelines, unbalanced forces occur at changes of diameter and direction, and at valves, junctions and stop ends. These may distort the pipework or open up the joints. With large pipes (say over 250mm diameter) and high pressures (say over 1 bar) the thrust restraint is a major design feature and should be treated as such. These notes are intended for guidance on small, low-pressure, pipelines.

Calculation

The main unbalanced force is due to the internal pressure:

When P = the internal pressure (kN/m^2)
A = the pipe cross-section area (m^2)
θ = the angle of change of direction

then i) At bends, the force 'F' equals $2 PA \sin \frac{\theta}{2}$

ii) At stop ends, valves and T junctions $F = PA$

iii) At tapers $F = P(A_1 - A_2)$

Methods of Restraint

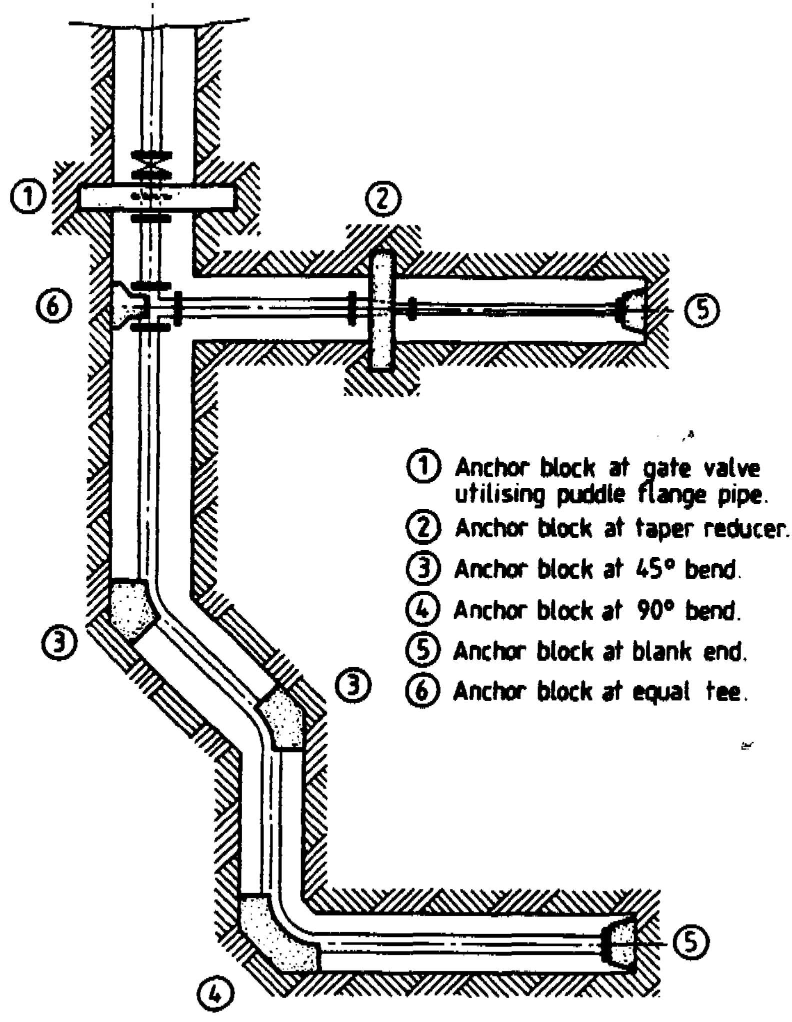
Pipelines above ground need to be firmly strapped to or supported by adjacent fixed structures or adequately sized brick, concrete or steel columns, driven piles etc.

With buried pipelines the passive restraint of the soil, and the friction of the ground round the pipes <u>may</u> be sufficient, but if in any doubt, use concrete thrust blocks as shown in Fig.T15, to increase the bearing area and transmit forces to undisturbed ground.

Joint Restraint

Even if the friction and passive support is judged adequate, there will be some movement of the joints before the full resistance is developed (depending on the nature of the ground). Some method of joint restraint may then be necessary.

Steel pipes are normally welded. Butt-welded or fused joints in plastic pipes should also be adequate for low pressures, but when flexible rubber ring type joints are used, special restraining joint assemblies can be obtained from manufacturers; if not available, use generously sized thrust blocks or other positive restraint.



Typical Arrangement of Concrete Anchor Blocks used in conjunction with P.V.C. pipework incorporating rubber ring mechanical joints when buried.

Fig T15

Shuttering (Formwork)

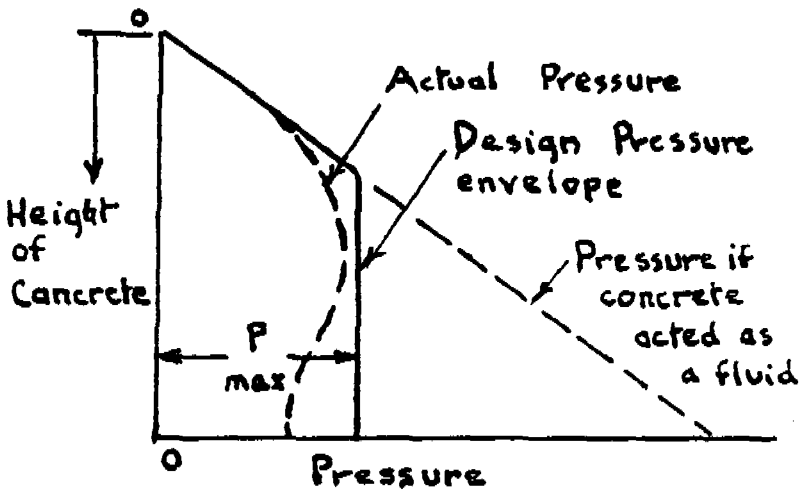
The essentials of shuttering are:
1. It should be strong enough to resist the weight and pressure of the concrete during casting.
2. It should be leak-proof.
3. It should be easy to erect and remove (except (c) below).

Materials
Suitable materials include:

(a) Timber
(b) Sheet metal (plain or corrugated)
(c) Brick or concrete blocks incorporated in the structure as 'permanent' shuttering

Composite materials are common, e.g. plywood or sheet metal facing with a timber framework; a liner of plastic, rubber or even cardboard sheeting, can be used to prevent leaks and give a smoother finish to rough shuttering.

Loading
Many factors affect the pressure on the formwork during casting - the nature of the concrete, the rate and method of placing, the method of compaction, and the floor slope and depth of the cast section. The maximum pressure is often less than the pressure which would be exerted if the concrete behaved as a fluid.



A full discussion of this subject is contained in CIRIA Report 108 (Concrete Pressure on Formwork) 1985, but for field use using normal Portland Cement concrete the approximate loading in Table 1 may suffice.

Access

Tall shutters will create access problems. Best to keep platforms, etc. independent, but if they are attached to the formwork, remember to allow for the weight of the people who will use them!

Striking

The time that should be allowed before formwork can safely be removed depends on a variety of factors including the nature and load on the cast section, the concrete mix, and the temperature, and is fully discussed in CIRIA Report 73 ('Formwork Striking Times - Method of Assessment', 1987). However, safe rules of thumb striking times are contained in BS:811 of which Table 2 is an abstract.

Removal

Shuttering should, if possible, be designed for easy removal and, of course, with an eye for the reuse of the material. With internal circular shuttering, include a small key panel which can be released and removed without difficulty. A release agent applied to the face of the shutter before placing the concrete will avoid the shutter sticking to the concrete with consequent difficulty in removal and damage to the face of the concrete. There are many proprietary materials for this purpose, but oil, a lime wash, a sheet of polythene or even paper, can be quite effective.

Table 1 - Concrete Pressures on Formwork

Concrete Temp. while placing °C	Form Height	Walls (1 plan dimension > 2m) Placing - Rate of Rise m/hr			Columns (Both plan dimensions < 2) Placing-Rate of Rise m/hr		
		1	2	5	2	4	10
5	2	45	50	50	-	-	-
	3	55	65	75	75	75	75
	4	65	70	85	85	100	100
10	2	40	45	50	-	-	-
	3	45	55	70	65	75	75
	4	50	60	75	75	90	100
15	2	35	45	50	-	-	-
	3	40	50	65	60	75	75
	4	45	50	70	65	85	95

Pressure on Formwork in kN/m^2 for good concrete with ordinary Portland cement (P max. in the sketch on T16/1)

Table 2 - Minimum period before striking formwork (good quality concrete made with ordinary Portland cement)

	Surface temp. of concrete 16°C and above	7°C
Vertical formwork to columns, walls and large beams	12h	18 h
Soffit formwork to slabs	4 days	6 days
Soffit formwork to beams and props to slabs	10 days	15 days
Props to beams	14 days	21 days

Support

Formwork can be braced end to end or supported by struts etc. externally, or for wall sections supported by wire or bolt ties running through the concrete. Ties can leave a water path through the wall and may corrode. There are proprietary tie systems which avoid this problem, but these are unlikely to be available and if wire ties are used the wire should be cut back an inch or so from the face and the hole plugged with cement mortar: if metal bolts are used they should be sleeved with plastic or cardboard, allowing them to be withdrawn: plastic or cardboard should be removed for at least an inch from the face, and the hole plugged.

Sanitation

Basic Principles of Latrine Design

The fundamental requirements of latrines are that they:

1. Isolate excreta from the environment
2. Provide privacy and convenience
3. Are affordable

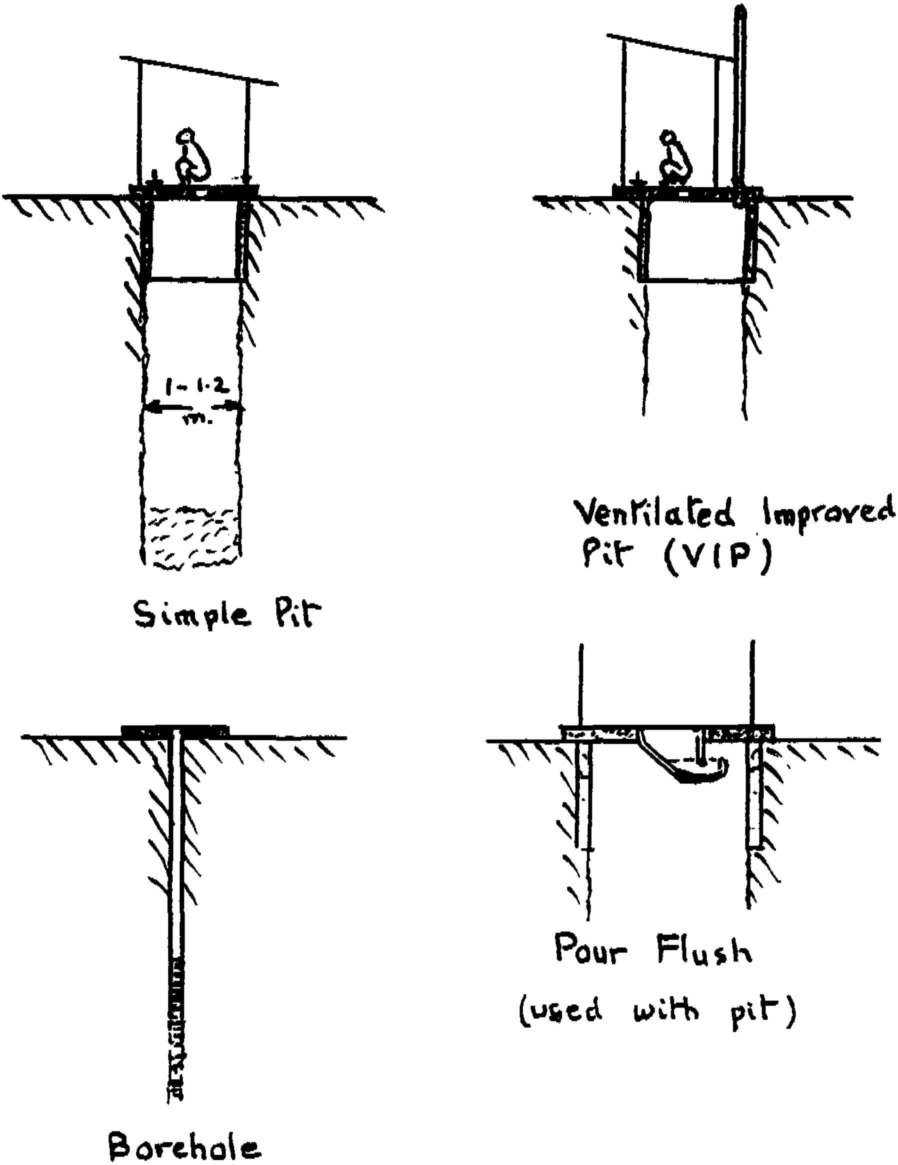
A wide range of designs are available; all require care and attention to detail during construction, use and maintenance. No latrine is ideal for all situations and for all uses. The major options of latrine technologies are sketched in Figure T17/1. Any material can be used. Those locally available may have the shortest life, but will be more easy to replace.

Siting

The main reason for siting latrines well away from kitchen or living quarters is smell nuisance, which can be controlled to some extent by good ventilation and maintenance. The risk of aerial transmission of bacteria and viruses is much less than the risk of poor personal and domestic hygiene.

It is, however, vital that latrines be sited so as to avoid contamination of drinking water sources. Porous soils above ground water level are effective in removing faecal micro-organisms and in breaking down chemical compounds, particularly after the latrine has been in use and some clogging of the soils has taken place. However, bacteria and viruses survive for long periods in water saturated layers and if the water table is close to the bottom of the pit, or if the stratum has large pores, such as gravels or is comprised of fissured rock, then contamination of the water table is very likely. High intensity rainfall aggravates the problem by washing contamination rapidly into the saturated zone. It is advised that:

a) the base of pit latrines be at least 1 metre above the highest recorded or expected groundwater level.



Basic Latrine Types Fig. T17/1

b) the nearest well or borehole be at least 10 metres away if there is 4 metres of fine soil below the base of the pit, and up to 50 metres distant if the pit is close to the groundwater level, or if the stratum is very porous or of fissured rock.

c) if in doubt, ensure that the water supply is tested regularly and especially when the water table is high or after high intensity rainfall.

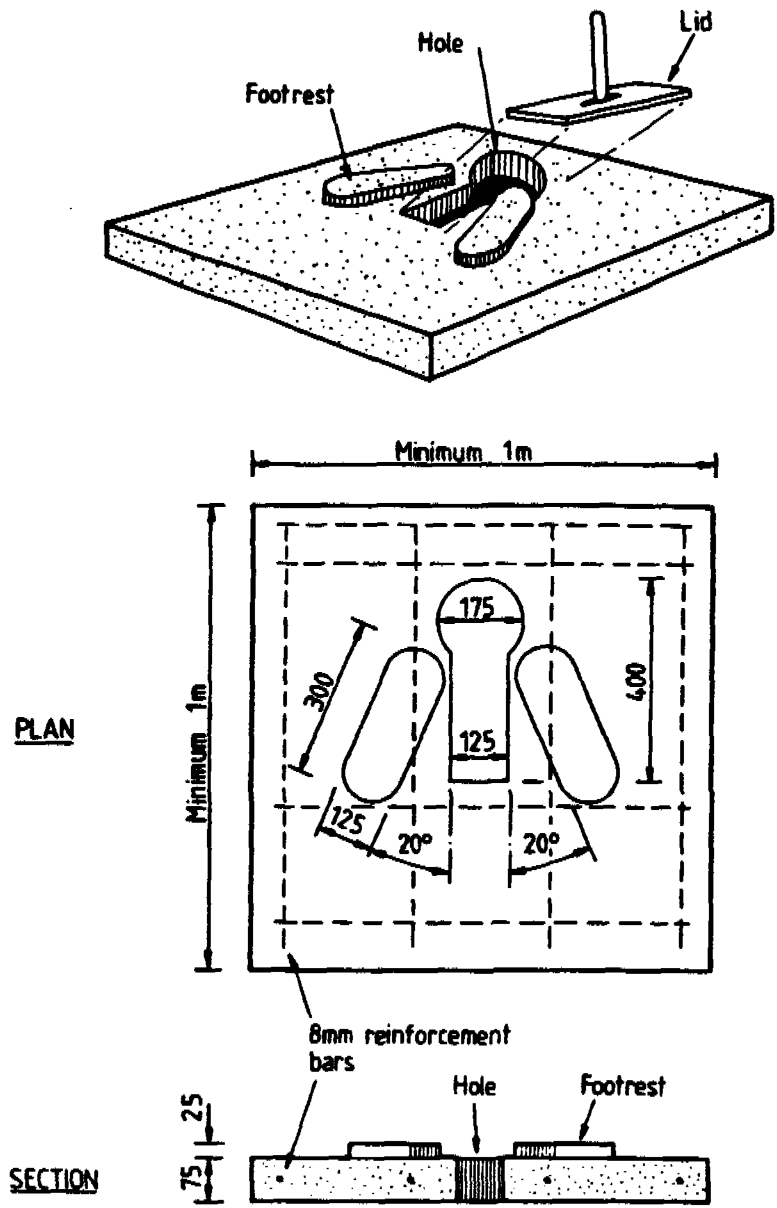
General Guidelines

Pits for latrines should be lined where the soil is unstable. Suitable linings can be made from concrete, bricks, bamboo reinforced cement, timber etc.

The capacity of the pit should be calculated on the basis of 0.06 cu. metres of sludge per person, per year where solids are used for anal cleansing or 0.04 where water is used. Composted sludge can be safely used as a soil conditioner after standing for one year. Where it is locally unacceptable to re-use sludge, full pits can be planted with fruit trees.

Superstructures can be built in any style or design to suit the user, except for VIP latrines, where the provision of plenty of air flow and exclusion of light is essential. Avoid constructing solid, permanent structures over lined pits unless there is a removable cover for compost removal. Slabs are the most critical part of all latrines and should be close-fitting to the walls of the pit to isolate excreta from the environment.

Squatting holes can be made in a variety of shapes to suit the users. the hole should be large enough to prevent fouling, but not so large that children can fall down it. Footrests can be placed on either side, close enough together for children to be able to use it. Typical dimensions are shown in Figure T17/2. Covers for squatting holes can be made of wood or other material, as available, and should be well-fitting to avoid fly nuisance.



Squatting Slab

Fig T17/2

Hygiene

With all types of latrines, cleanliness is essential to avoid odour control and fly nuisance. A floor which is easily cleaned is essential and in dry latrines hand washing facilities should be provided. Figure T17/3 shows a simple Tippy Tap which has been used with success in Uganda, combining convenience with economy.

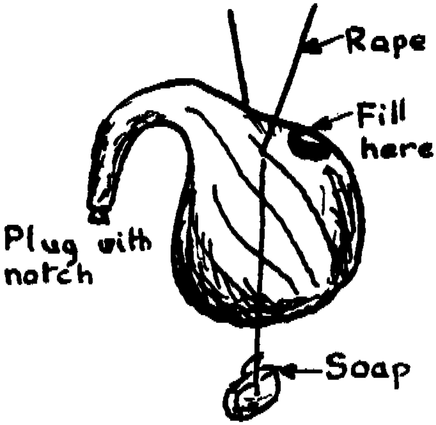
Household Latrine Types

These are illustrated in Figure T17/1

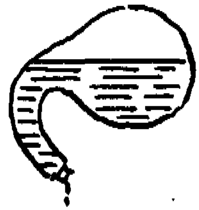
a) Simple Pit Latrines.

These are the cheapest latrines and can usually be made entirely out of locally available materials. They can be smelly and fly ridden, especially if they are too shallow, and should ideally be 3m deep and are usually 1 - 1.2m in diameter for ease of digging. A latrine of this size should last a family of 10 people for up to 7 years. If the water table is high, or if there is hard rock near the surface, it may be possible to mound the soil up to give additional depth.

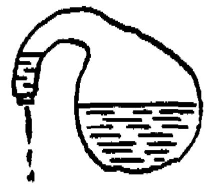
Slabs to cover the pit can be made of timber or thick bamboo and sealed with mud mortar, but such slabs may have a life of less than 3 years and are difficult to clean. A better solution is a simple concrete slab which can be moved to a new pit when the original pit becomes full or unusable. A flat concrete slab spanning a 1.2m diameter pit will need some simple bar or mesh reinforcement, and will need to be 50 to 75mm thick. An alternative is a dome shaped slab (Figure T7/4) unreinforced except for a single 8mm circumferential bar to prevent damage when handling, cast on a mound of earth with a circular former (more easily said than done!); slabs of this size will weigh upwards of 275 kg. A satisfactory solution is plaster the or pave the latrine floor or the ground around the pit - this helps cleanliness but of course does nothing to control flies or odour, and is less durable. A further alternative is the 'sanplat' - a small ($0.6m^3$), light,portable concrete slab sitting on a timber floor, which helps cleanliness but has obvious limitations.



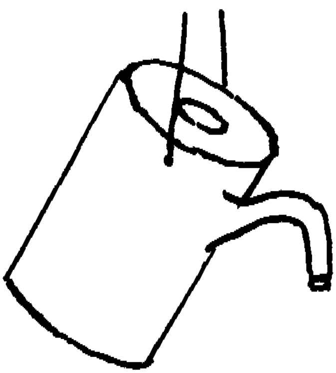
A gourd or similar fruit can be used, or a vessel fabricated from a tin or of perspex, PVC etc.



Fill neck by tipping

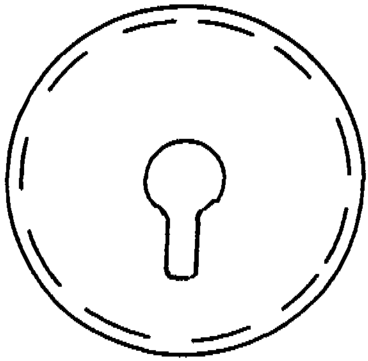


Water retained in neck runs out through notch in plug

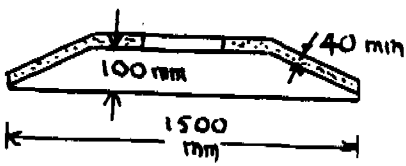


'TIPPY TAP'

Fig. T 17/3



Slab may be un-reinforced but a single 8 mm. bar assists handling



Domed Squatting Slab

Fig. T 17/4

Squatting holes must be fitted with a lid to prevent access by flies. Odour can be controlled by keeping the slab clean and throwing ash or similar material down the squatting hole onto the sludge. A support lining may be necessary, depending on the strata, and can be made of any available local material, with open joints or similar arrangements to allow liquid to soak into the adjacent soil. If the pit is lined, or in good soil, it may be possible, when the pit is becoming full, to leave the sludge to compost for 12 months and then dig it out and reuse the pit. Alternatively a new pit must be used.

Borehole latrines can be quickly constructed with a hand auger and are especially useful where a quick sanitation solution is essential and where people are likely to move around regularly, but the small diameter of the hole means that it is likely to foul, block and fill quickly.

b) Ventilated Improved Pit Latrines

These have been designed to reduce smell by drawing odour away from the squatting slab and to discourage flies and mosquitoes. They are more expensive and must be regarded as more permanent, but are appropriate where people are more prosperous and where the quality of construction can be controlled. Ventilation is provided by a vent pipe with fly proof netting. Wind blowing across the top of the vent pipe causes air to move upwards, but when there is no wind, air in the vent pipe is moved upwards when it is heated by the sun. The interior of the superstructure must be kept relatively dark so that flies do not come up through the squatting hole. Details of the design are therefore important and these will be found in D15 in the Outline Design Section.

c) Pour Flush Latrines

Pour flush (water seal) latrines are appropriate where people cleanse themselves with water after excreting. Construction is more costly and complex than a simple pit latrine and a reliable source of water in needed for flushing purposes. The latrine hut can be sited directly over the pit, or the pit can be offset, which is an advantage in that when the pit is full a new one can be dug near it without removing the super structure. The water seal pan can be moulded out of cement plaster, or plastic, glass fibre or ceramic materials. The smoother the finish and smaller the water seal, the less water is needed for flushing. D14 in the Outline Design Section shows the details of an Offset Pit Pour Flush Latrine.

Handpumps

There is much literature and ongoing research on handpumps.

These brief notes are intended to assist project staff and engineers in the field to assess the type of handpump most suited to their requirements.

In some countries a decision may have already been taken to standardise on a particular type of pump. In these circumstances the notes may prove of help in trying to improve performance or in spotting malfunctions.

1. Type of Pump

The type of pumps commonly used can be classified in accordance with the engineering principle of operation:

a) Suction Pumps

The type of handpump often used in country households before development of piped water supply. Action of the pumping mechanism in the pump head created vacuum, thus drawing up the water. Limited to 7m head lift at sea level and needs priming before operation which may allow polluted water to be introduced.

b) Positive Displacement Pumps - Direct Action

The pump rod operates inside the rising main and incorporates a plunger which is pulled up and pushed down by hand, moving within a cylinder at the bottom. At the same time, a foot valve in the cylinder closes to retain the water. On the upstroke, the plunger flat valve closes, and the bottom front valve opens.

It is effective up to a depth of 13-15m, is easy to use and is mechanically simple and robust. It is only suitable for small flows at maximum depth. The Tara is an example.

c) Positive Displacement Pumps - Reciprocating Action

Essentially similar in engineering concept to the direct action pump but the pump rod is activated by a pump handle improving the mechanical advantage and making it suitable for deeper wells and larger flows. The Afridev, Zimbabwe Bush Pump and India pumps are examples.

d) Progressive Cavity Pumps

A hand turning mechanism at the top of the well rotates the pump rod turning a rotor in the cylinder at the bottom of the rising main, forcing the water upwards. A foot valve may not be required.

The Mono and Moyno pumps are examples but no local manufacture.

e) Diaphragm Pumps

A flexible diaphragm within a cylinder at the bottom of the rising main is inflated by a small foot pump at the surface. The diaphragm distends and forces water through a discharge valve into the rising main. The Vergnet is an example.

f) Solar Pumps (not strictly a hand-pump, but does not depend on an extended power source).

The solar pump is only now being developed fully for commercial use and should be available in 1993. The concept is relatively simple, alternatively using solar rays to heat and gasify a fluid which is then cooled and refluidised. The associated change in volumes is utilised to continually change the volume of oil inside a flexible bag in a fixed container filled with water, developing a negative pressure which lifts the column of water in the rising main.

2 The VLOM Concept

The VLOM or Village Level Operation and Maintenance is an important concept where the breakdown of a pump may mean weeks before skilled assistance is available to carry out repairs. Therefore the design and development of handpumps has been directed to ensuring not only that movable and wearing parts are the most durable but that when replacement of parts becomes necessary they are freely available locally and preferably made locally to avoid the foreign exchange problem (which may be insurmountable at village level). The VLOM concept also requires that the down-the-hole working parts such as the pump rod, plunger and discharge valve and the bottom cylinder and foot valve can be extracted from the well without the use of sophisticated equipment.

Advisers faced with pump selection should put some weight on this concept. A pump which breaks down monthly but can be repaired in a day using local labour is preferable to one breaking down once a year but requiring a month before imported replacement parts and skilled technicians are available to carry out the repairs.

3. Considerations when Choosing Pumps

No subject is likely to produce more strongly held and differing opinions based on personal experiences than village handpumps. Circumstances such as local manufacturing capability and local practice may direct choice to particular types and good locally made pumps may be preferable to better imported products for those reasons.

Depth of water table will affect choice of pump. The World Bank define shallow wells as being up to 12m to steady water level, intermediate between 12m and 25m and deep between 25m and 45m.

a) Shallow Wells

For the shallower depths in this range, open wells with bucket and windlass are an option, as are suction pumps. Both are cheap to install and service but are liable to pollution unless care is taken. The direct action type is very suitable and pollution free but can be tiring to operate at depth, producing less water. Reciprocating action pumps are also used in this range but some designs use a chain mechanism to lift the pump rod, which for shallow wells is not heavy enough to drop quickly enough on the down stroke. (e.g. India Mk II)

b) Intermediate and Deep Wells

Positive displacement reciprocating action pumps are the general rule in this area. Pumps which fit the VLOM criteria are found for intermediate depths but not usually for deep wells.

4. WaterAid Experience

There are a number of designs available, but based on the principle of VLOM and locally produced products where possible the following pumps (positive displacement reciprocating action, except where noted) have been found to perform satisfactorily.

(i) Tara (Direct action)

Suitable for shallow wells, maximum depth 15m, discharge 1200 lph in shallow wells, less at depth. True VLOM.

(ii) Afridev

This pump has been exhaustively developed by agencies such as the World Bank and ODA. The CRL laboratories have continuously researched aspects of the pump and currently are developing GRP pump rods and joints for the uPVC rising main to obviate stress raising characteristics yet allow easy withdrawal. Local manufacture is undertaken in several countries. The pump can produce up to 1320 lph (less at depth) and will operate up to a claimed 45m depth.

(iii) **Zimbabwe Bush Pump**

Developed by Blair Labs and claimed to have similar characteristics to the Aridev but more robust. Currently experimenting with high impact uPVC rising main to overcome corrosion problems.

(iv) India Mark III

Developed from the earlier India Mk II to improve VLOM characteristics. Widely used throughout India and Africa although some critical comments from UNICEF in Uganda. Discharge 720 lph.

The Eductor Set (for Well Dewatering)

The complete Eductor set comprises:-

(i) Stainless steel concentric eductor and strainer

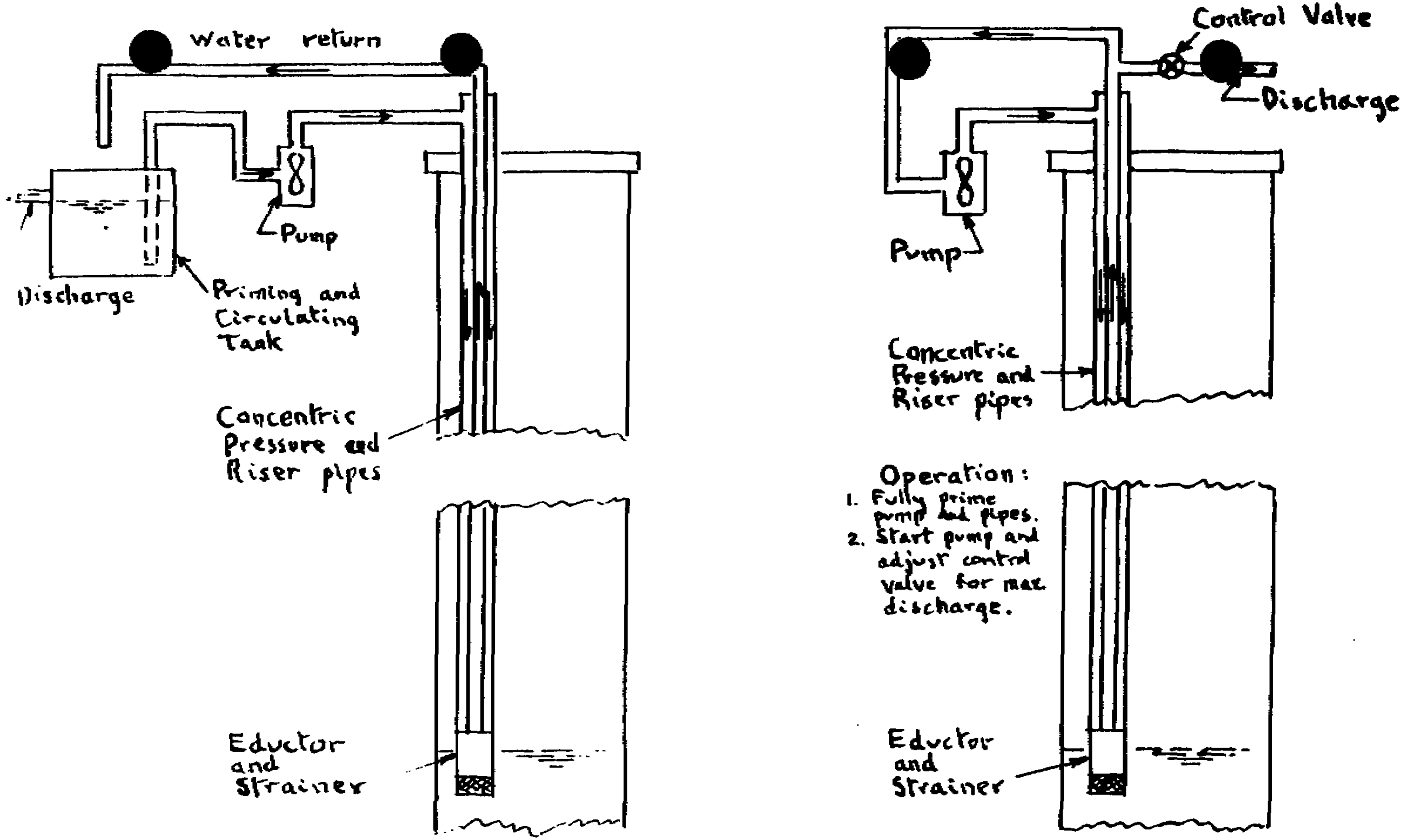
(ii) A contractors pump with hoses

(iii) A well head plate and attachments

(iv) A combined water pressure and riser pipe. Fig T19 are diagramatic layouts.

The Eductor is a hydrodynamic device where water is applied to a venturi sited at the bottom of the well and then returned to the surface. The venturi is designed so that it picks up additional water from the well and this excess can be discharged to a tank or simply to waste. The pump recirculates the water keeping the system in motion. The system is continuous, once primed, and provides a steady unpulsed flow.

The clearances in the Eductor usually exceed 10mm and the unit is fitted with a ball valve so that water is retained in the system after priming. They are useful for suction lifts up to 50m, beyond this efficiency tends to fall away. At best they are less efficient than borehole pumps but are useful for test purposes, or for lifting silt-laden water.



Standard to 20m. depth

Over 20m. depth

EDUCTOR SYSTEMS

Fig T19

INDEX - GROUP 5

Group 5 - Outline Designs

Spring Development and Protection

Sources - Various, including:

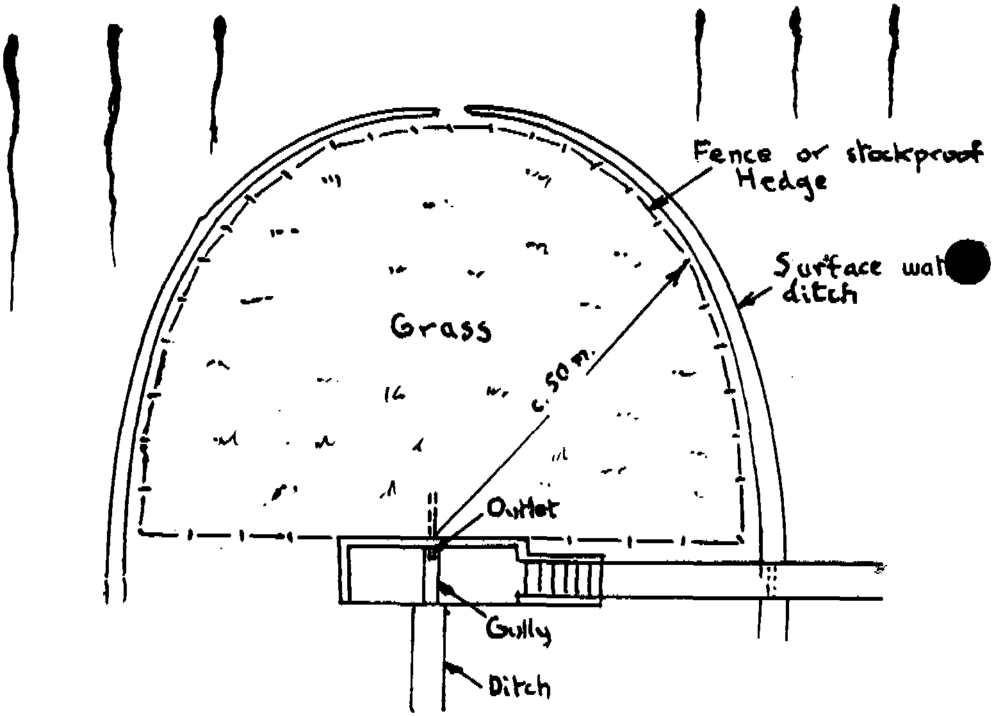
Water for the World - Technical Note RWS ID1
Helvetas Manual 1 - Design of Gravity Water Systems in Sri Lanka
Uganda Spring Protection Manual
Waterlines Technical Briefs Nos. 3 and 34

General

All springs have their own characteristics, so this general advice must be adapted to the circumstances. The primary aims are to protect the catchment area, collect water to a central point and provide collection facilities easy to maintain and to keep clean. A secondary aim may be to provide storage. Obviously it is wise to check the minimum flow in dry season and the year-to-year reliability of the spring, by reference to rainfall and water-table levels, and local knowledge.

Catchment Protection

It is important to protect the water quality by fencing off the immediate catchment area (a minimum of 10 metres radius above the spring is suggested) and by diverting surface water away from the protected area. The protected area should not be used of agriculture or grazing, and is best planted with grass and not trees. It should not be assumed that water, even from a protected spring, is uncontaminated. (Fig.D1/1)



Catchment Protection

Fig. D 1/1

Development

If the spring is not artesian, or has no defined source, collect seepage by a land drainage technique. This will usually mean excavating a shallow trench or trenches through to the eye of the spring. If possible, lay small (30 - 50mm i.d.) perforated or open jointed pipes in the trench surrounded by clean gravel or broken stone, but if necessary rely on coarse gravel or broken stone to collect water (Fig. D1/2). Cover the stone with heavy duty polythene or puddled clay or concrete, and reinstate. Grade the trenches to not less than 1 degree. If there is a steep hillside a short (not more than 3m) adit may be preferred to deep trenches.

Collection Structure

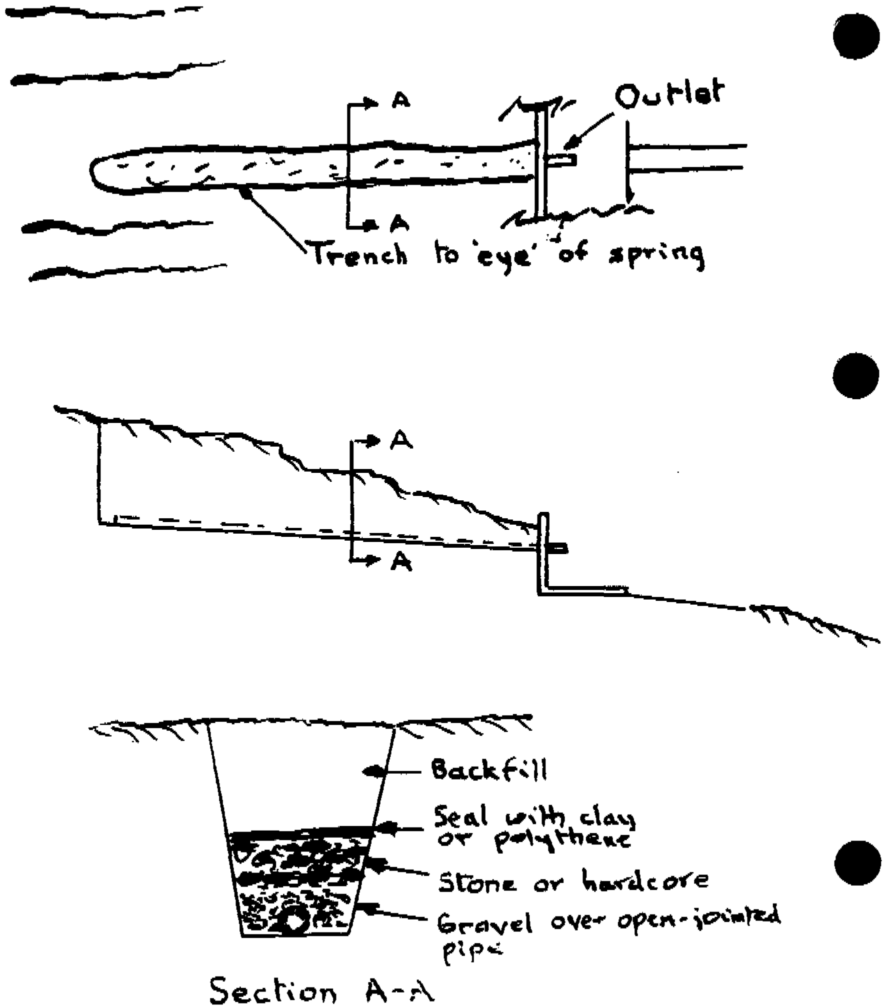
This will have to suit the particular circumstances and might include:

a) a spring box with an open bottom where there is artesian water (Fig D1/3)

b) a spring box with pervious side for steep hillsides (Fig.D1/4)

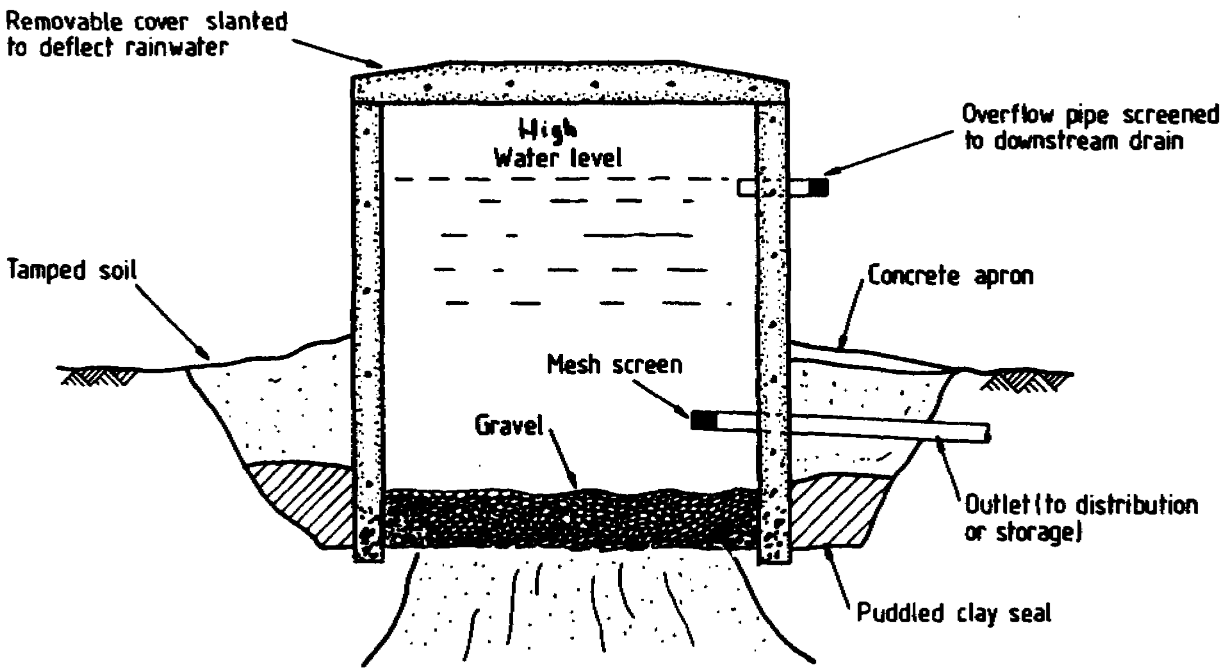
c) more often a protective structure, with or without storage, into which drainage trenches feed (Fig. D1/5). Storage may be combined with a downstream break pressure tank.

In all instances provide an overflow, ensure good access and pave and drain floor below the delivery pipes.



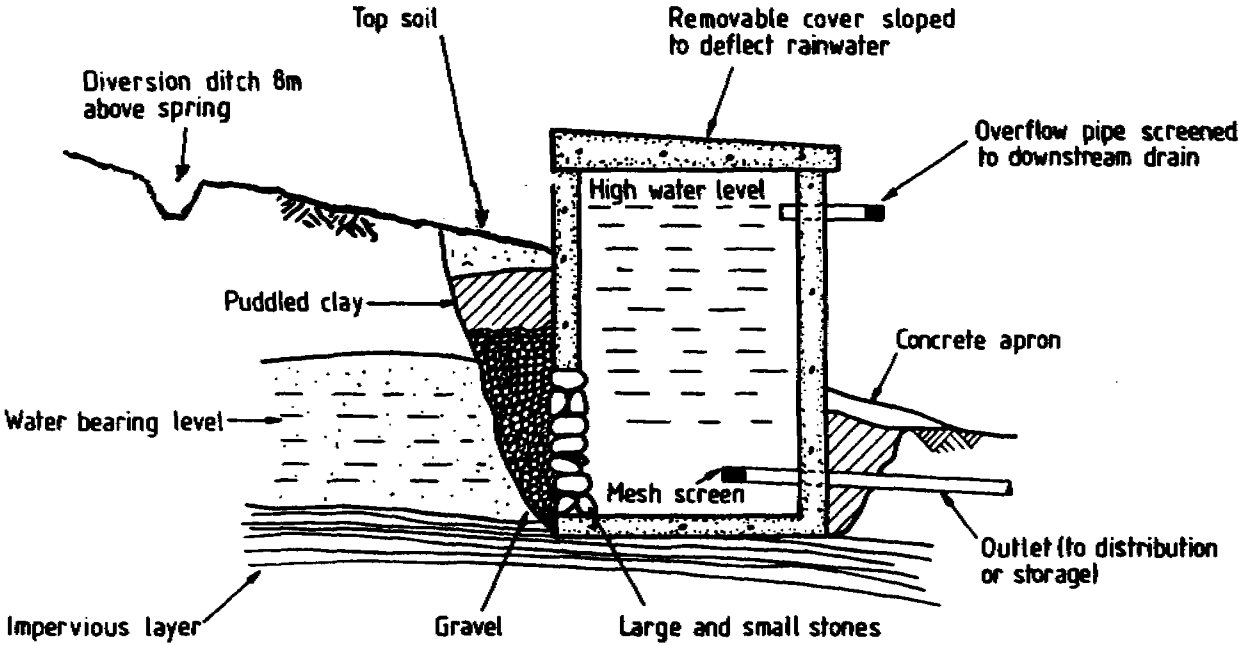
Developing a Seepage

Fig. D 1/2



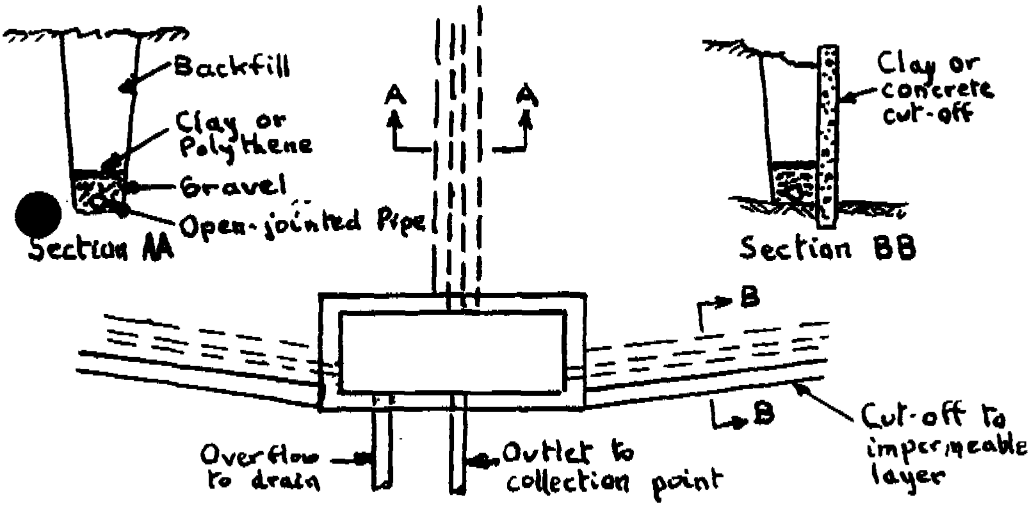
Spring Box with Open Bottom

Fig D1/3



Spring Box with Open Side

Fig D1/4



Note: 1. Overflow not less than 250 mm below ground at collection box.
2. Outlet at or below level of collecting pipes and 250 mm above floor of box.
3. Removable cover to box for cleaning.
4. If possible provide rodding eyes at end of collecting pipes

COLLECTION BOX FOR SEEPAGE AREA

FIG D1/5

Intakes for Ponds

Source - Water for the World Technical Note RWS ID2.

These are ideas for simple intakes from ponds and other bodies of still water. The object is to take water from a clear area not too near the top or bottom and well away from the bank. Sometimes two intakes are helpful to allow a choice to suit varying circumstances.

A. Floating Inlet. (Fig.D2/1.)
Position the inlet 0.3 to 0.5 m below the surface. Use a flexible pipe and anchor both pipe and float. Floats may be in drum or raft form.

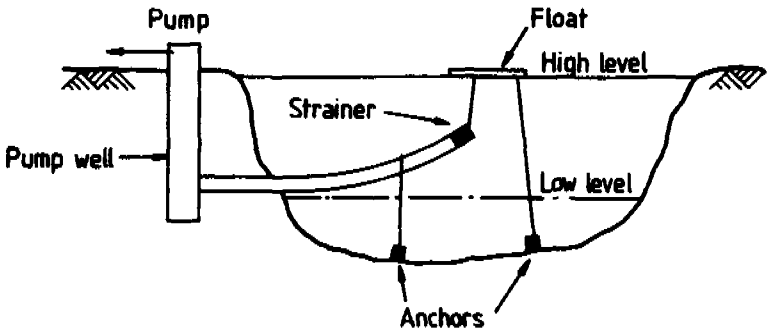
B. Fixed Inlet. (Fig.D2/2.)
Rigid pipes should be used. Supports should hold the inlet at least0.6 0.6m from the bottom (allow for soft sediment). Space supports at joints and at intermediate intervals as necessary to avoid excessive deflection.

C. Strainer. The intake needs to be protected from plants, fish and rubbish. Fig.D2/3 shows a simple strainer. If available, a double walled slotted pipe with annular space filled with small (0.5 to 1 mm for 0.5 mm slots) gravel is ideal. The strainer portion should be removable for cleaning.

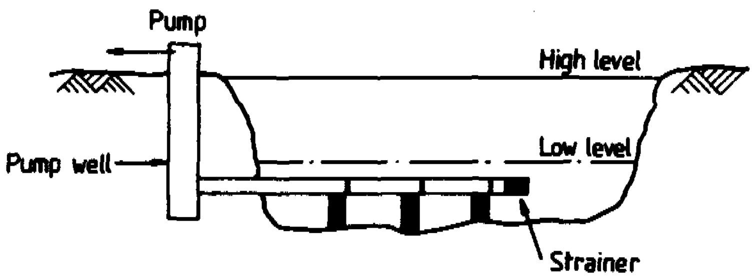
Remember:

1. Pond water is usually heavily contaminated unless in a protected catchment.

2. The strainer must be accessible for cleaning.

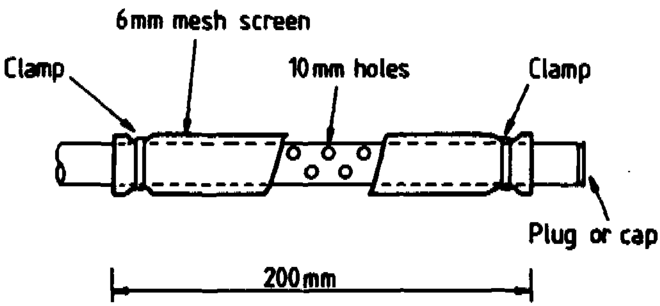


Floating Intake Fig D2/1



Note : Direct coupled pumps can be used if self-priming and suction head is not too great.

Fixed Intake Fig D2/2



Improvised Strainer Fig D2/3

Intakes for Rivers

Source - Water for the World Technical Note RWS ID3.

Techniques depend on stream size, flow variation, bank and bed stability, and nature of ground. Alternatives include:

A. Riverside Well. (Fig.D3/1.)
The well should be sunk to at least 0.5 m below the stream bed and lined with a perforated casing (see Well Design, Note D5). The distance from the bank depends on the porosity of the subsoil; for coarse sand, gravel or other porous soils the well should be at least 15 m from the bank.

B. Infiltration Gallery.
The yield of riverside wells can be increased if necessary by collecting pipes parallel to the river bank discharging into the well (Fig.D3/2). The infiltration pipes should be laid 1 m below the lowest water table, graded to the well, and surrounded with gravel or broken stone. Use perforated or open-jointed pipes. If the stream is seasonal, it may be practicable to lay infiltration pipes under the steam bed at a depth of 0.3 to 0.5 m and filled with gravel, graded from coarse (150 mm) next to the pipe to fine (25 mm) carried up to the stream bed; this will only be successful on stable stretches not subject to accretion or scour. Double-walled, gravel packed, perforated or slotted pipes buried in stable sand bars may also be suitable, and could be connected direct to the pump suction, or discharge into a river-bank wet-well if pumping is intermittent.

C. Gravity Intake.
If the stream bed and bank are stable and the lowest level sufficient, a direct intake can be used, having an intake pipe with strainer (see Intakes for Ponds, D2) protected by concrete or brick wing wells. The intake pipes should be at least 0.5 m above the bed of the stream. Large intakes may be further protected with a bar screen across the wing walls, parallel to or facing downwards from the stream flow. Bars should have at least 100 mm clear spacing. Provide access to clean the screen, and ensure strainers are accessible for cleaning, and preferably removal.

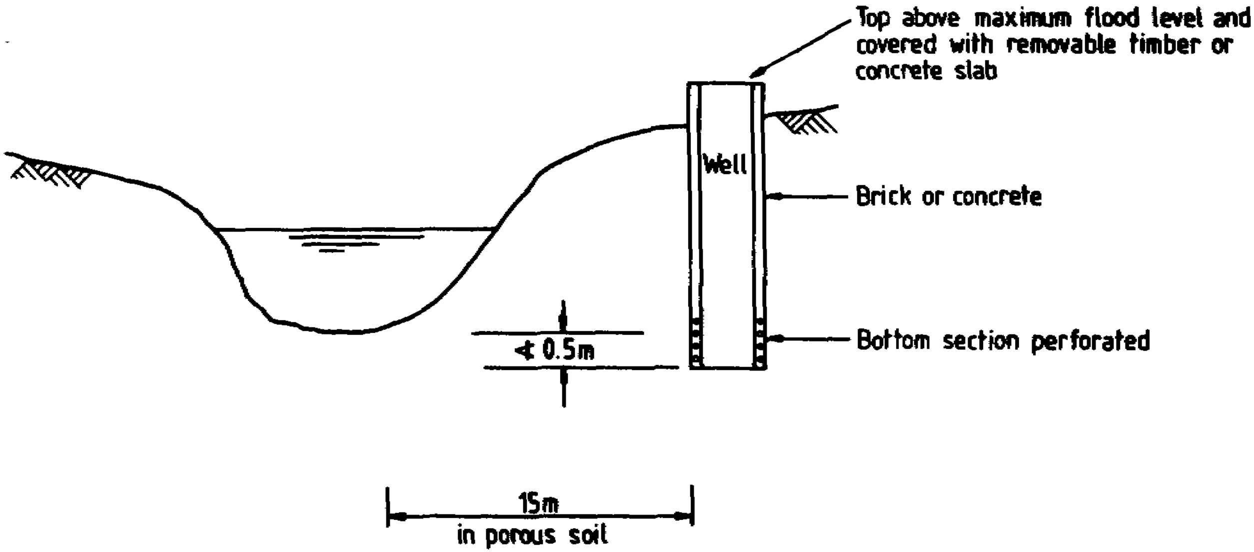
D. Suspended (pumped) intake.

The suction from a pump may be suspended from a simple structure, suitably protected (Fig.D3/3). For small, slow-flowing streams, an intake similar to the fixed inlet for ponds may suffice, but the danger of accumulation of weed etc on the pipe should not be overlooked.

Remember:

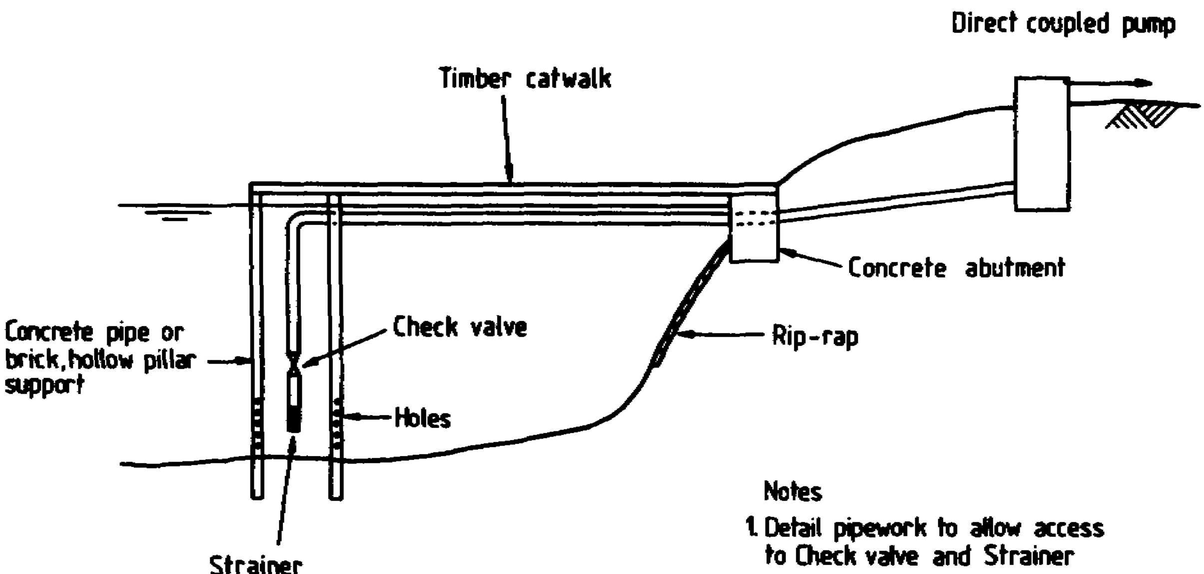
1. River water is often polluted - consider the upstream catchment. Quality as well as quantity may fluctuate widely with seasons, or over long periods of drought.

2. Use self-priming pumps, if possible.



R[illegible]er Bank Wel[illegible]

Fig D[illegible]/1

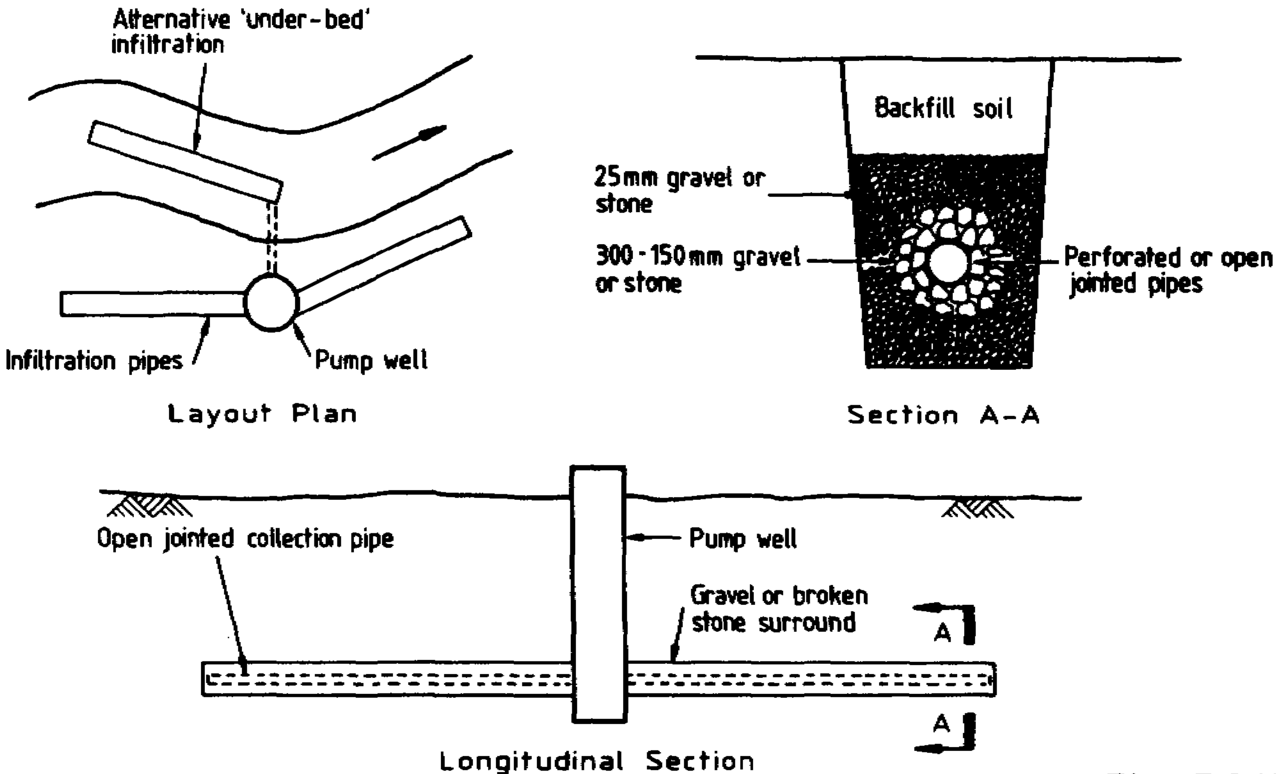


Notes

1. Detail pipework to allow access to Check valve and Strainer
2. Allow for maximum flood level but design structure robustly

Fixed Intake

Fig D3/3



Infiltration Pipes

Fig D3/2

Roof Catchments

Sources - Water for the World Technical Note RWS ID4
BRE Digests 188 and 189 (1976)

Roof catchments can be an effective way of collecting rainwater but require periodic attention if they are to fulfil this function effectively. Adequate storage must be provided to cover dry periods.

Run-off

Corrugated sheet, tiles, slates or other impermeable material are suitable for rainwater collection. There will be a small wetting and evaporation loss which may be of the order of 10% on average, but obviously varies depending on the rainfall pattern.
Thatch or other permeable material is less suitable - there is no evidence of increased health hazard, but the water may be discoloured and of unpleasant taste.

The run-off will be a direct function of the rainfall intensity and the plan area of the roof. 1 m^2 plan area yields one litre of water from 1 mm of rainfall, less evaporation, etc., losses. Wind effects may increase or decrease the run-off - the effective roof area may be as much as + or - 50% of the elevation area variation from the plan area, but in most situations this refinement can be neglected.

The effective yield will be less than the theoretical if the capacity of the gutter and/or down pipes is less than the peak rate of run-off, resulting in uncontrolled spillage. This is likely to be significant in areas where rainfall takes place in short-period, high-intensity storms, unless the gutter and down pipes are designed to take the maximum rate of run-off at the peaks of rainfall.

Gutters

Suitable material includes galvanised metal, PVC and other plastics, asbestos-cement (if sound - it should not be used if there is risk of fibres becoming detached from damaged areas), wood and split bamboo. A simple design of gutter used in Kenya is shown in Fig. D4/1.

Gutters should be laid with a nominal fall of about 8 mm per metre so as to avoid standing water. The distance from the roof drip to the top of the gutter should not exceed 50 mm so as to avoid excessive loss from wind effects, and this limits the gutter length between down pipes to about 6 m.

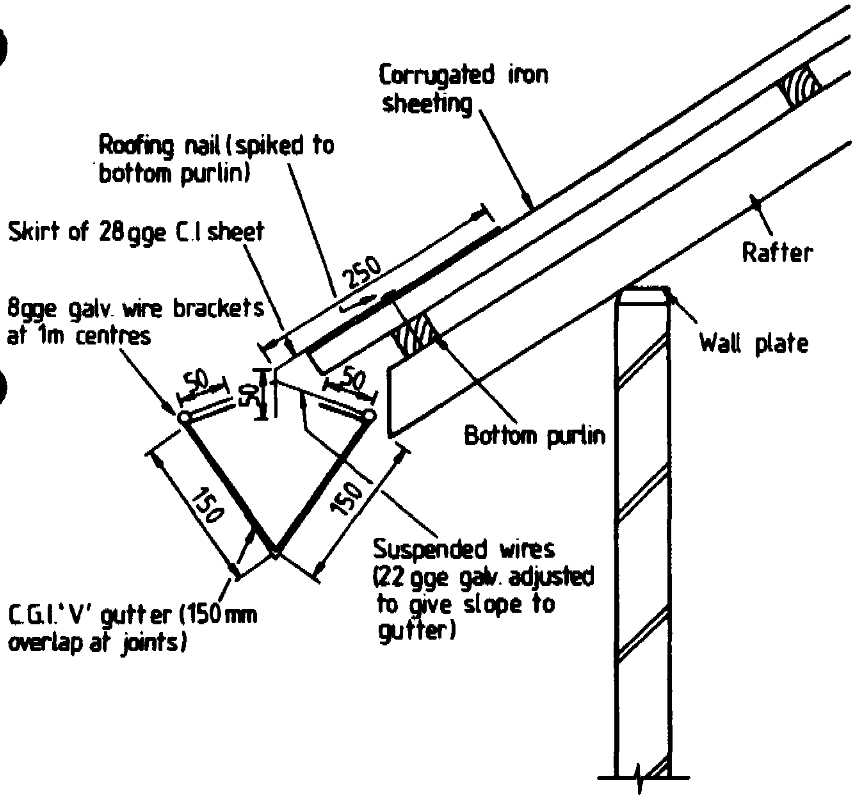
Gutter capacity is a function of the cross-sectional area, the fall, the material, the outlet configuration and, of course, the cleanliness. It is usual to assume level gutters for capacity calculation, in which case the capacity for half-round gutters is as tabulated below.

Diameter (mm)	Capacity (litres/sec)
75	0.4
100	0.8
125	1.5
150	2.3

For other shapes of gutters assuming free discharge the general function is

$$Q = A^{3/2} \times B^{1/2} \times 10^{-4}$$

where Q = capacity in litres/sec
A = cross section area in mm^2
B = width at the water surface in mm



Section Through Typical Wall, Rafter & Corrugated Iron Sheet Showing V Gutter Suspended on 22gge Wires from Skirt Which is is Nailed Above G.I. Sheeting to Bottom Purlin Fig D4/1

Down Pipes

These should be designed to have greater capacity than the gutters so that there is free discharge at entry.

If the head over the entry (that is, the gutter depth when running full, is less than one-third of the down pipe diameter, the entry acts as a weir and the capacity can be calculated by

$$Q = \frac{H^{3/2} \times D}{5000}$$

where Q = litres/sec
H = head over the entry in mm
D = entry diameter in mm

It is assumed that the down pipe is no smaller than the entry, so that the entry condition controls the down pipe capacity.

If the head is greater than one-third of the gutter diameter, the down pipe will act as an orifice and the entry capacity is

$$Q = \frac{D^2 \times H^{1/2}}{15000}$$

In approximate terms, a 50 mm down pipe is required for half-round gutters up to 100 mm diameter, and a 75 mm down pipe is suitable for gutters of between 125 and 150 mm diameter. If possible, sharp bends in the gutter close to the outlet should be avoided. A bend within 2 m of the outlet may induce swirl and reduce the down pipe capacity by about 20%.

It may be convenient to use a box type receiver or hopper at the head of the down pipe. This should be at least as wide as the gutter, but not longer than twice the diameter of the down pipe or, again, swirl may occur with reduced capacity.

Quality

A coarse mesh screen should always be placed in an accessible position over the storage tank to catch leaves and other debris.

If there are long dry periods, accumulation of bird droppings, dust, etc. will result in an initial flush of foul water run-off. Three remedies are suggested:

A. Diversion.
A length of flexible pipe, or swivel elbow, or diverter plate can be used to manually divert the first flush from the storage cistern.

B. A 'foul flush box' can be used to store the initial flow. This must of course be emptied periodically and is not very effective (Fig.D4/2).

C. A charcoal filter system can be used to remove some of the impurities (Fig.D4/3). The filter material needs periodic cleaning and/or replacement.

A combination of these may be economical - e.g. combine A with C to reduce cleaning frequency, or use B as a back-up to A. Unfortunately all methods require attention, which is unlikely to be reliable.

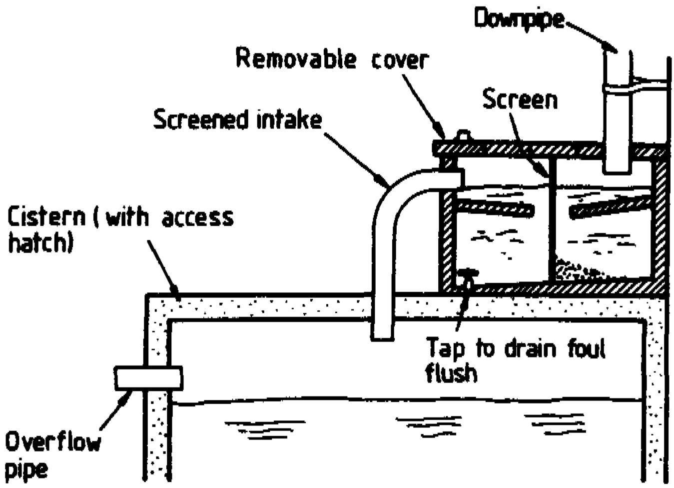
Storage

Rainwater, protected from the incursion of insects, debris, etc, will remain fresh for several months when stored in the dark.

Storage jars and tanks can be constructed above or below ground from a wide range of materials: pottery, concrete blocks, bricks, steel, fibreglass, ferrocement, etc. Ferrocement or wire reinforced cement mortar tanks are a widely applicable low cost option.

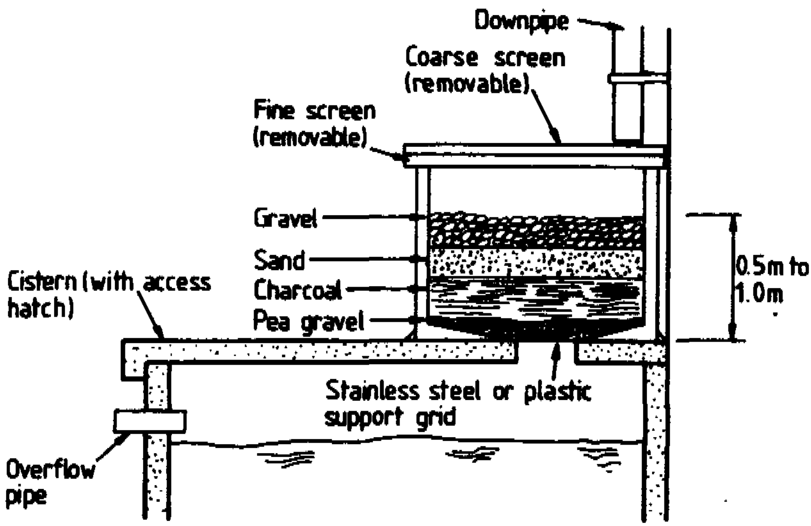
Tank designs up to 150 m^3 are described in 'Ferrocement Water Tanks' by S B Watt, see (D5). Modified designs using stick basket work reinforcement have proved successful for 10 m^3 tanks. Construction manuals are available from WaterAid.

Traditional systems to collect surface run-off in haffirs and valley tanks are not recommended for domestic use without further treatment.



Foul Flush Box

Fig D4/2



Filter System

Fig D4/3

Ferro-Cement Water Tanks

Tanks made from wire reinforced cement mortar are widely used in many parts of the world and are built by hand-trowelling a cement-rich mortar onto a mesh of reinforcement to form cylindrical tanks with thin walls which vary in thickness from 3 - 10cm depending on the size of the tank. The advantages of this form of construction are that it uses locally available skills and materials, is of low cost but high durability, is easy to repair, and is sufficiently light for very small tanks and jars to be moved from a central construction point. The fact that, weightwise, it uses less materials than the equivalent masonry or RCC tank structure is particularly attractive in countries such as Nepal, where construction materials have to be carried over long distances to site on peoples backs.

The design and construction of such tanks is discussed fully in a book "Ferro-cement Water Tanks" by S.P.Watt, copies of which are in the WaterAid library. This note is intended as a reminder of some of the key points and a reflection of WaterAid's own experience in the field, which has been gained mainly in Nepal, Sierra Leone, Tanzania and Uganda. Most of our experience has been on small tanks, to which this note specifically refers. However, larger tanks of up to 150 m^3 capacity can be made without difficulty, using the same technique. Water depths are generally limited to 2m or less and roofing therefore becomes more complicated on the larger tanks. Every field engineer intending to attempt this form of construction should have their own copy of Watt's book.

Basic designs vary between the different WaterAid country programmes. Practice adopted by Nepal, where the technology has been widely used by both government and non-government agencies for many years, is described below, followed by a list of some variations practised elsewhere.

The construction sequence for these small tanks (1 to 20m^3) is as follows:

1. Tanks are provided with a 15cm plain concrete floor (1:2;4 mix).

2. Main vertical reinforcement in the tank's cylindrical wall consists of 8mm diameter high tensils steel bars tied onto starter bars cast into the floor and spaced at around 50cm c/c. This reinforcement is carried over to form radial reinforcement in the roof.

   Two layers of 22 gauge chicken wire mesh (19mm mesh aperture) are tied to the vertical bars to form a cylinder. This is considered to distribute stress and to control cracking, but to have little structural effect. 3.5mm diameter steel fencing wire is wound around the outside of the cylinder, over the chicken wire mesh, at a pitch of between 8 and 14cm c/c to provide the circumferential reinforcement.

3. An internal cylindrical form is used to plaster against. This may be made from tin sheet, bamboo matting, or HDP pipe (used later in the project pipeline) coiled helically against, and tied to, the vertical reinforcing bars.

4. One 12.5mm (0.5") thick layer of 1:2 (cement:sand) plaster, with a water:cement ratio of 0.5:1, is applied to the mesh against the form and left to set for 24 hours. A second similar layer is then applied and the whole kept damp and left to cure for at least a week. The internal form is then stripped and a further two layers of plaster applied from the inside, making the total wall thickness 5cm.

5. A cement/water 'wash' (1:1) is then applied to internal surfaces of the tank which will be in contact with water to give a final seal and a smooth finish.

6. Roofs are constructed using the same techniques as the walls. On the smallest tanks the plastering of the roof and wall may be done simultaneously. On most tanks however it will not be possible to complete a single plaster layer for both in one operation, and the roofs are constructed after the walls are completed. The wall/roof joint does not seem to cause any problem as reinforcement is contiguous.

1. Good quality mortar is essential. Sand must be of uniform grade and both sand and water should be clean. The mix should be stiff but workable.

2. Joints should be avoided in construction, at least in the walls and each layer of mortar should be applied in one continuous operation. Mortar more than 0.5 hours old should not be used.

3. Curing is vital and should extend at least one week after construction work is complete. Tanks should be filled slowly for the first time, or when a tank has been empty for a long time, to give the walls time to take up moisture.

4. Internal coving of the wall/floor joint (the most critical point for cylindrical tanks) helps to reduce cracking at this point.

5. Pipework must enter and exit through the PCC floor and not through the ferro-cement walls.

6. Water depths do not exceed 1.7m for the given wall section.

Noted variations in technique in other WaterAid programmes are:

From Uganda:

(a) Tanks founded in active clay or weak soil should have mesh reinforcement on the base slab.

(b) For the wells, one layer of 22 gauge mesh is adequate above the bottom 90 cms. If 24 gauge mesh is used then 2 layers are necessary for the whole depth, and possibly 3 near the base of large tanks.

(c) The final cement/water wash on internal faces is not necessary.

(d) Pipework can pass through tank walls if above the tap water level.

In Sierra Leone it is advised that all surface tanks above 20 m^3 capacity be built in reinforced concrete designed to CP 110 and BS 5337, with a minimum wall thickness of 200 mm and using block shuttering.

Standpipes and Taps

Sources - Papers by Hugh Speed and WHO Int.Ref. Centre (Tech. paper 14,1979)

The essential needs are a well-supported tap, a free draining bucket stand, and an adequate drain for spillage.

Ideally, residual head at standpipes should be 5 to 10m. Fig D6 shows a typical design developed in Sierra Leone, where standpipes are spaced not more than 150m apart and provided at the rate of 1 tap per 10 households. This can be readily adapted to 2 taps (back to back), extending the platform to both sides.

Points to watch - either prevent the bucket being hung on the tap, or give it support (e.g. a bracket for the bucket over the tap).

- Fix the tap on so tight that it cannot be stolen - or use a collar and padlock.
- in vandal prone areas, bury the standpipe in a concrete column.
- if alternative materials are used for the post, ensure that it is strong and durable.
- the bucket stand shown is in concrete. If not available a simple hard stone slab may be used - but provide adequate drainage to deal with spilt water.
- if necessary, fence around the tapstand.

The WHO paper referenced has graphs of head v. flow for ½" (12mm) to 1½" g.s pipes/taps. Typically, ½" taps will give 800 1/hr at 10m head, and ¾" (18mm) 1500 1/hr at 10m head.

Taps

Taps at tap stands need to be robust, easy to maintain and preferably self-closing. Frequently, conventional bib-cocks are used, because they are available (and often made) locally. They do not comply with any of these criteria especially if locally made!
Alternatives are:

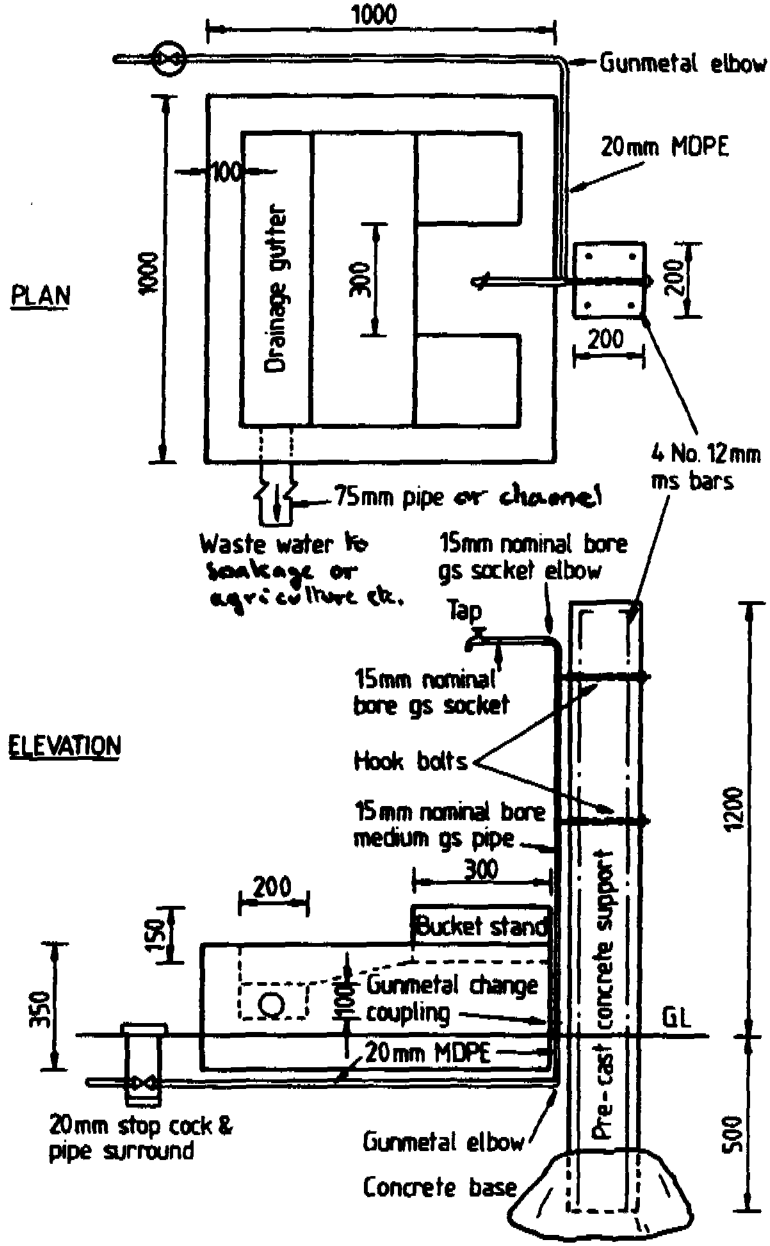
(1) Spring-loaded bib taps

(2) Weight-loaded bib taps

(3) The Talbot 'Taflo' spring loaded tap - superior to (1) and (2) but costs more.

(4) The 'Lane' tap, developed in Nepal - simple, can be made locally, low maintenance, but not self closing and most suited to low pressures.

For a tap stand serving up to 80 users, a tap-flow rate of 0.1 l/sec can be assumed; pipeline branches should be designed in the assumption that <u>all</u> taps on the branch flow simultaneously.



Single Tap Public Standpost Fig D6

Surface Dams, Ponds and Reservoirs

Water supply from small rivers and streams may be interrupted in dry weather, and storage is often used in developed countries to overcome this difficulty. One of the simplest means of storage is to create a reservoir or lake by building a dam across the stream, but in developing countries it will rarely be possible to provide storage capacity for more than a few days' supply, and consequently designs should be usually based on minimum flow in dry weather.

Small dams may however be necessary to divert water, or to provide a simple stilling pond and offtake. They can also be used to 'hold' water to recharge and aquifer.

Dam design is a job for a specialist, and advice <u>must</u> be sought for any dam exceeding 2m height, and should be obtained where possible for smaller dams.

For small dams the essentials are:

1. An impervious core of puddled clay, concrete or asphalt.

2. Protection to the upstream face, preferably with stone rip-rap or precast blocks or bricks, laid on a graded filter layer to avoid damage on draw-down.

3. An adequate overflow to take the <u>maximum</u> expected flood flow over a concrete weir and channel.

4. An adequate 'cut-off' underneath the dam to prevent seepage. A trench taken to impervious strata and back-filled with clay or concrete is a convenient solution in many instances.

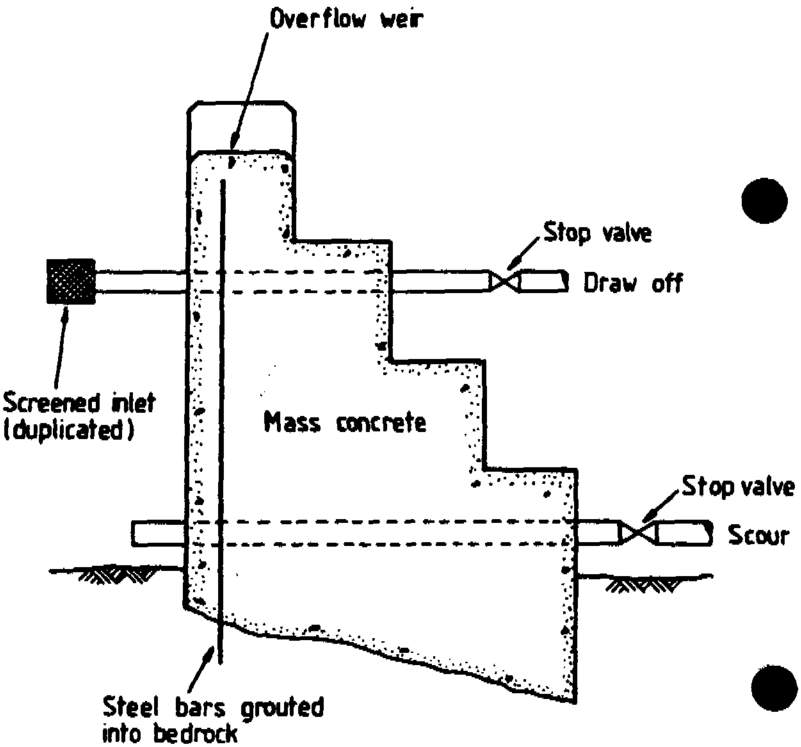
The dam must obviously be stable when full - the 'middle third' rule is safe.

Where concrete is available, a mass concrete dam may be the best solution - Fig.D7 shows a design developed in Sierra Leone. Shuttering can be avoided by using brick or block work.

Sand and sub-surface dams are the subject of Notes D8 and D9.

Ponds and Surface Reservoirs

It is difficult, if not impossible, to prevent pollution of small ponds, whether natural or artificial. If used for domestic water supply it is preferable to draw water from just below the surface, using a floating intake fitted with a strainer (see D2), and it is unlikely that the water will be safe without some treatment.



Small Gravity Dam

Fig D7

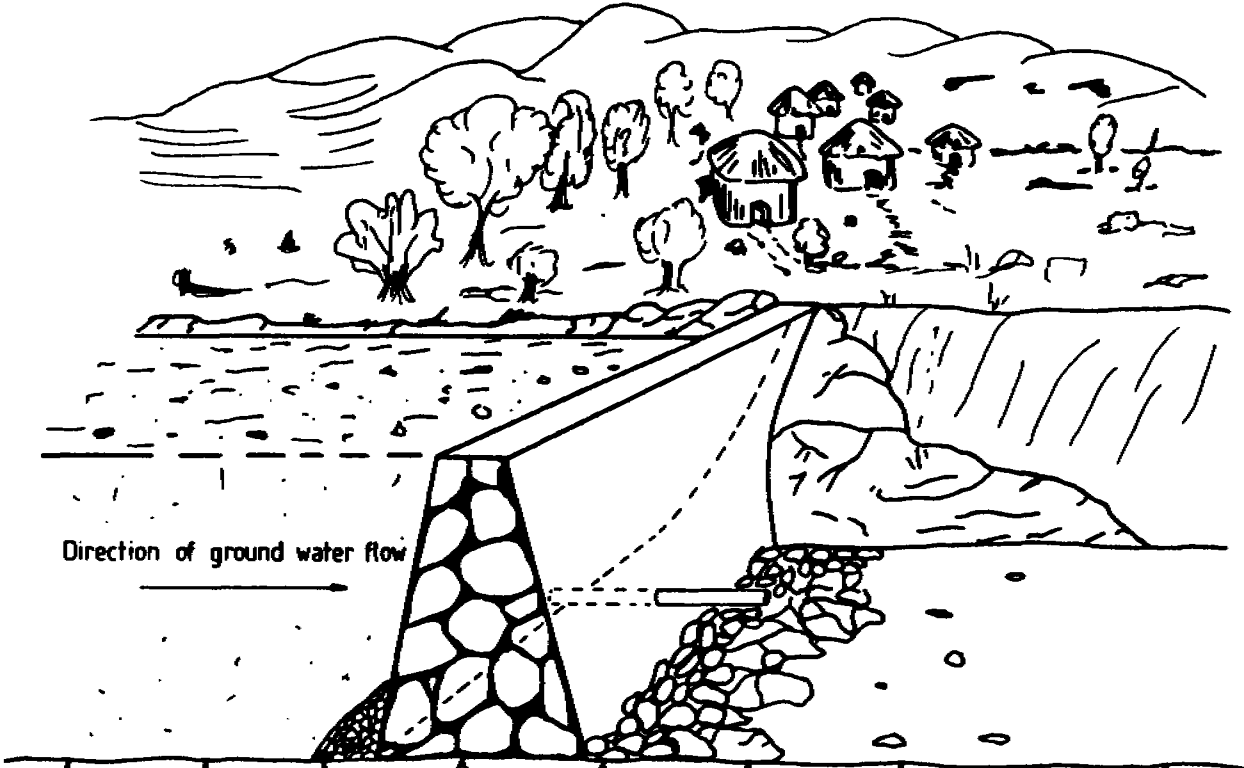
Sand Dams

Sand dams can provide a simple and inexpensive way of storing water in the beds of intermittent streams. The objective is to accumulate coarse sediments behind a shallow weir which is raised in successive steps. This reduces evaporation and overcomes some other problems found with shallow water reservoirs, and reduces the load on the dam (nevertheless, dam heights of more than 2 to 3m must not be attempted without advice from an engineer experienced in dam design).

Some of the essentials for success are an adequate transportation of sand or gravel, and a suitable impervious foundation for the dam not too far below the bed of the stream. The implications of reduced downstream flow should be considered, and the passage of flood flows must not be obstructed.

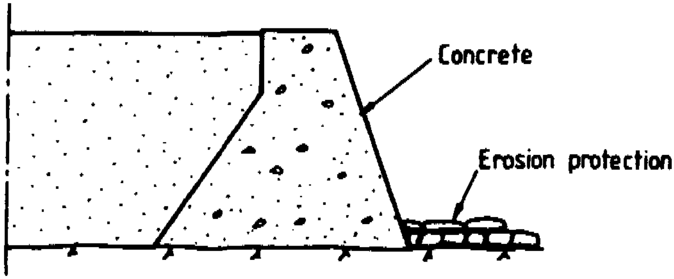
Fig. D8/1 shows the general principle; abstraction from the sand reservoir can alternatively be by well or borehole. The dam is raised in stages so as to maintain sufficient velocity when the stream flows to prevent fine material silting behind the dam. Alternative designs for the dam include concrete, stone masonry, or gabions with clay or plastic film face or core (Fig. D8/2). The dam need not be watertight - some downstream seepage may be beneficial if the loss of water can be tolerated.

Simple design instructions are given by Nissen-Petersen (Rain catchment and water supply in rural Africa - Hodder and Stoughton, UK, 1982) and more extensive aspects are discussed by Wipplinger (Sand storage dams in S W Africa - Die Siviele Ingenieur in Suid-Africa, 1974, pp135-136).

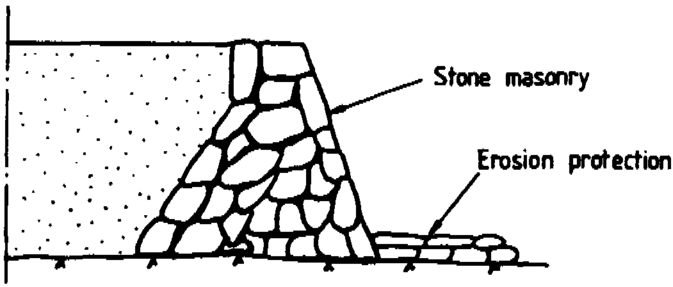


General Principle of a Sand Dam

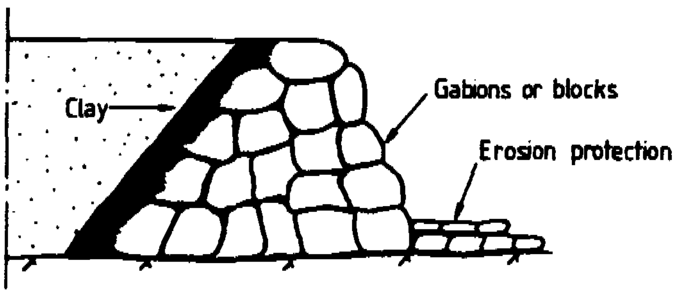
Fig D8/1



a. Concrete sand dam



b. Stone masonry sand dam



c. Gabion sand dam with clay cover

Alternative Types of Sand Dam

Fig D8/2

Groundwater (Sub-surface) Dams

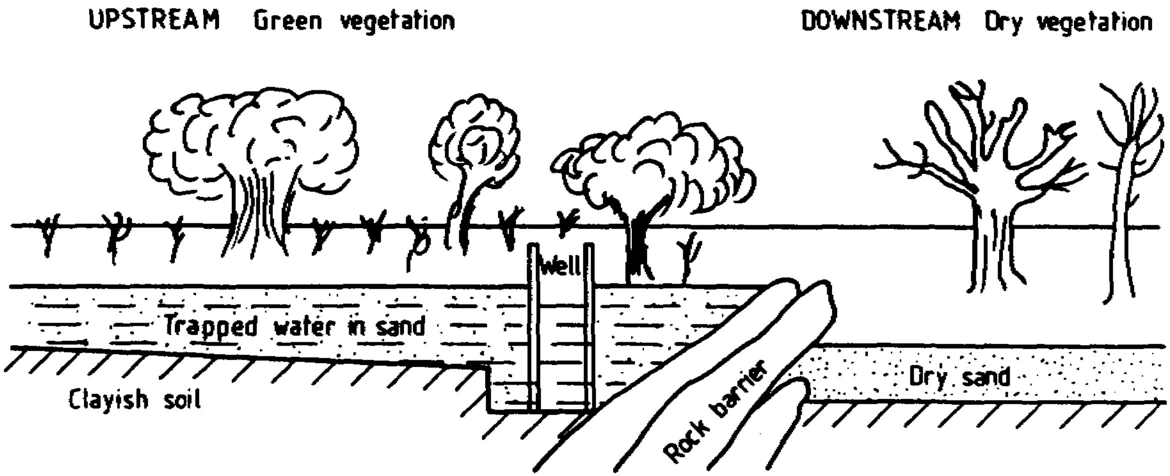
In many river beds, outcrops of impervious bedrock form natural barriers which store water in upstream alluvial deposits (Fig. D9). In suitable hydrogeolic situations, artificial sub-surface barriers can be constructed to interrupt the groundwater flow in the dry season for a similar purpose.

Adequate exploration to determine the depth of the water table, and the existence of a suitable impervious strata beneath a layer of coarse sediment is obviously necessary. This note serves only to outline possible forms of dam.

Assuming trench excavation by hand labour, in battered excavation without support, the maximum depth should not exceed 4 to 5 m. Complete watertightness is not essential, but leakage is wasteful, and alternative forms of barrier that might be considered are clay, concrete, masonry supporting plastic sheet, rendered brick or blockwork, sheet PVC or galvanised iron, or even plastic sheeting on a wooden board structure. Obviously, sheet trenching or piling driven from the surface is suitable, if the equipment is available - or even injected cement or bentonite grout.

Control of groundwater during excavation will be a problem - if possible, minimise this by construction in the dry season. If the ground is suitable (e.g. fissured rock, or coarse gravel), pumping from inside the excavation is suitable; for fine sands, local dewatering from boreholes or wells outside of the trench may be necessary. Similarly, if there is a surface stream even in the dry season, it will need to be diverted away from the excavation or perhaps carried over in a timber flume. In either case, watch out for flash floods.

A more detailed discussion of the subject is contained in a research report by Nilsson (Ground-water dams for rural water supply in developing countries - 1984) held in WaterAid library.



Natural Sub-Surface Dam

Fig D9

Basic Water Treatment

Source - Water for the World Technical Notes RWS 3D1 and RWS 3D4.

For isolated situations that cannot be served by a community water supply, simple techniques can be used to provide safe water. The need is to remove turbidity and sterilise, and the preferred method is to pass through a sand filter, chlorinate and store.

A. <u>Filtration</u> Fig.D10/1 shows a simple filter. If possible, provide for a continuous flow, with a small overflow, so as to keep the sand wet. The sand will of course need to be replaced (or taken out, washed, and returned) periodically.

B. <u>Chlorination</u> Although the sand filter, if kept wet, will remove most bacteria, and storage of filtered water for 5 or 6 days will effect further improvement, it is better not to rely on this if chlorination is feasible. (If not, boil water before use for drinking, etc.)

Chlorine may be available in liquid form (sodium hypochlorite, available as household bleach) or solid form (calcium hypochlorite powder or tablets). Both lose strength on exposure to air and the following table applies to fresh, full-strength ingredients. The aim is to make a 1% solution for use. (see Table).

The 1% solution should be added to the raw water at the rate of 3 drops per litre, or 30 ml (about 2 tablespoonfuls) per 145 litres.

The aim is to achieve a freely available chlorine residual of 0.4 mg/l after a 30-minute contact period, which should give a slight, but not excessive, chlorine taste and odour.

Some simple, cheap expedients for applying chlorine solution for small community water supplies are described below.

<u>Pot Chlorinators</u> These are suitable without sand filtration for clear water from contaminated shallow well sources. The pot is simply suspended underwater. Fig.D10/2 shows the design; a pot containing 1.5 kg of chlorinated lime will effectively chlorinate a well supplying 1000-1500 l/day for about one week.

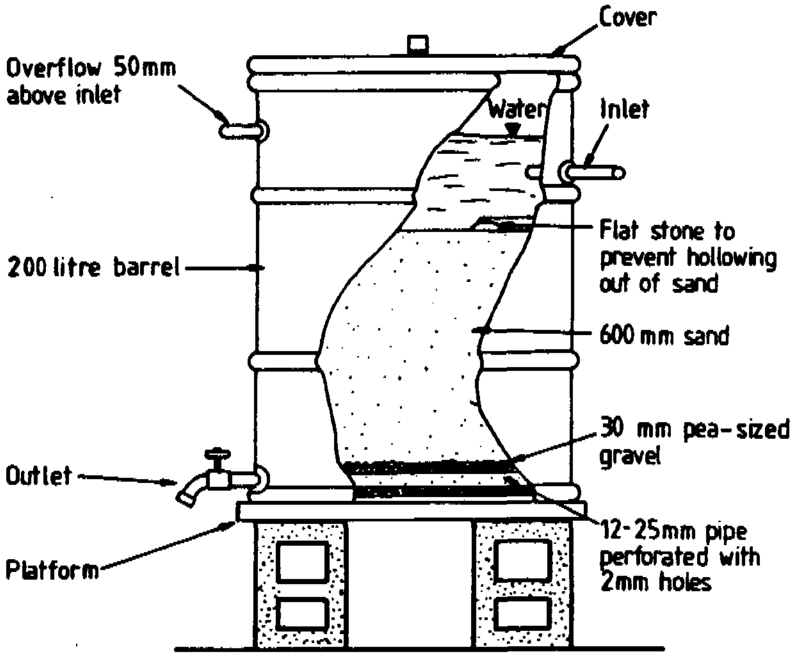
Drip Feed Chlorinators are suitable for liquid chlorine solutions - see Fig.D10/3.

Floating Bowl Chlorinators are an alternative method of adding chlorine solution at a controlled rate - Fig.D10/4.

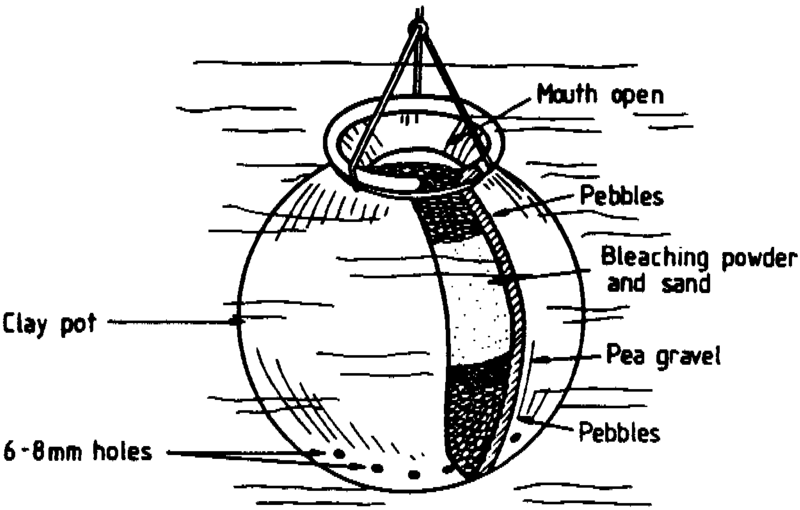
A possible alternative to chlorination in some localities is solar disinfection - see separate Note D11.

Table - Quantity of material to be added to 1 litre of water to give a 1% solution of chlorine

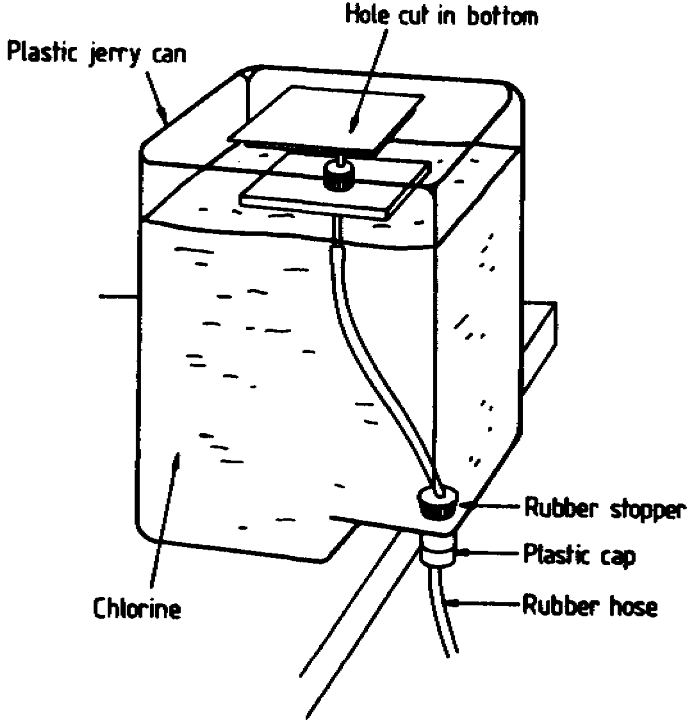
Material	%available chlorine	Approx.Qty Required per Litre
Calcium Hypochlorite		
'High-test' or Perchloron Powder	70	15 gms (1 level table spoon)
B-K powder	50	18.6 gms (1.25 level table spoons)
Chlorinated lime	35	37.5 gms (2.5 level table spoons)
Sodium Hypochlorite		
Liquid (commercial)	12	120 ml (half cup)
Chlorox	5	240 ml (1 cup)
Purex	3	540 ml (2.25 cups)



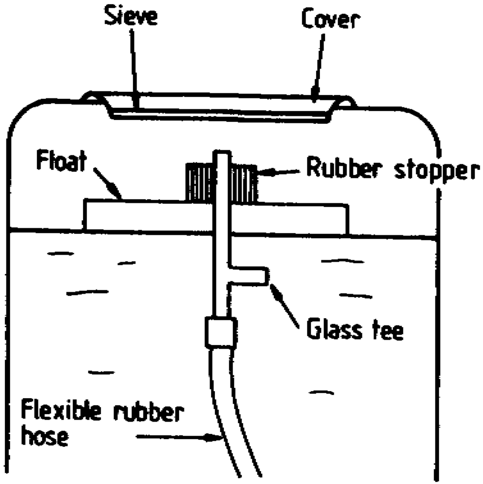
Household Sand Filter Fig DIV/1



Pot Chlorinator Fig DIV/2

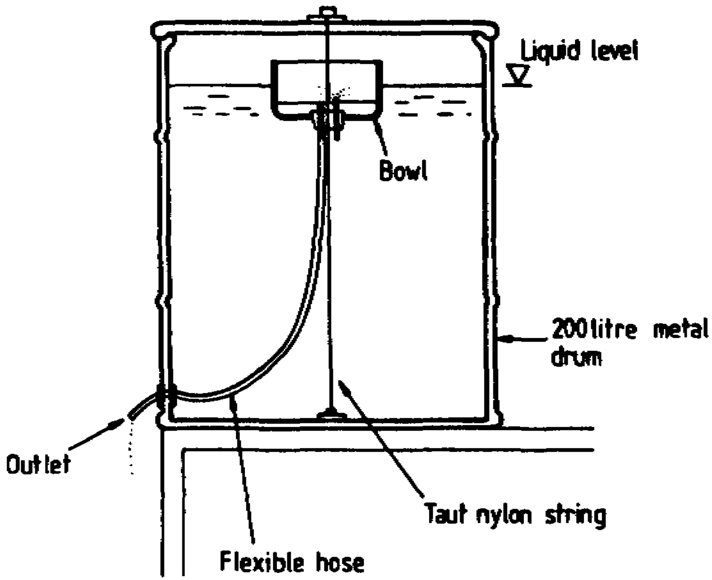


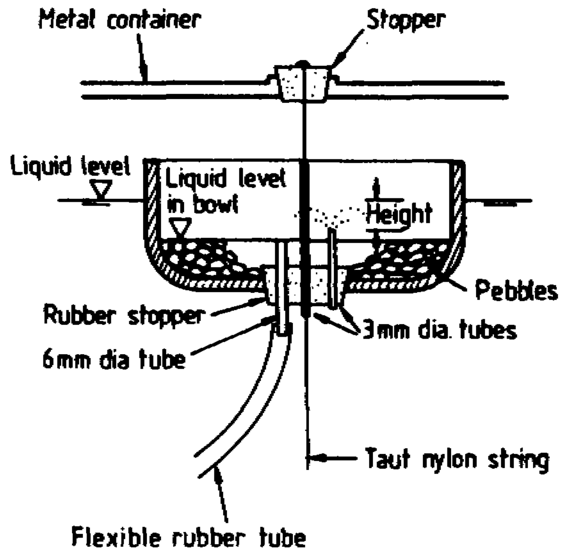
Drip Feed Chlorinator



Detail of Float and Tube

Fig D[illegible]/3





Detail of Bowl

Floating Bowl Chlorinator

Fig DW/4

Solar Disinfection

Solar disinfection is the simplest possible technique for providing safe water in small quantities, but is feasible only in localities (such as parts of the Middle East) where adequate sunshine can be expected virtually every day. Suggested limits are 35°N to 35°S in areas having at least 300 clear sunny days each year.

The active sterilising agent is ultra-violet light. In good conditions this can effect 99.9% reduction of coliform bacteria and associated pathogenic bacteria in less than an hour (it may be less effective with viral diseases).

This entails leaving the water exposed to the sun, and the following are important:

1. Exposure should be for at least 60 minutes between 2 hours before and after mid-day.

2. The water should be clear - if necessary filter through sand first.

3. Clear glass or plastic containers should be used not exceeding 1 litre capacity.

More detail can be found in a UNICEF publication 'Solar Disinfection of Drinking Water' by Aera, Raffoul and Karabagoptian.

The sun can also be used in simple non-mechanised 'stills' to produce potable (distilled) water from brackish or salt water.

Sedimentation Basins for Water

Source - Water for the World Technical Note RWG 3D2.

The quality of water from streams etc can often be materially improved by removal of suspended matter, and a simple sedimentation basin is the easiest method.

Most suspended particles are heavier than water (a small proportion may float) and will settle in quiescent conditions (very fine particles will not). Almost any structure which stores water will function as a sedimentation basin - natural or artificial ponds and lakes for example - but purpose-made structures should incorporate efficient inlet and outlet arrangements, and facilities for removing settled matter, and emptying to clean.

The inlet should be designed to minimise turbulence and distribute the inflow as evenly as possible. Simple board, trough or box baffles will be suitable - see Fig.D12/1.

The outlet should be arranged to take water from the top of the basin, but a shallow scum baffle is useful to exclude leaves and other floating matter - see Fig.D12/2.

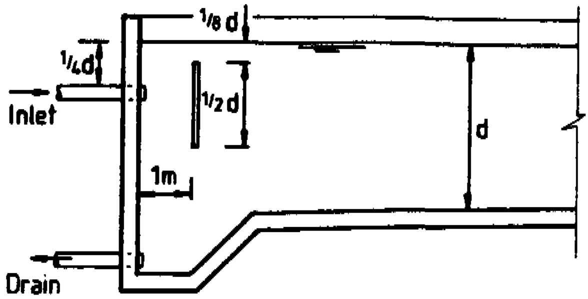
A rectangular plan with length about three times the width is usually preferred but not essential. With a rectangular tank it is easy to show that for perfect conditions without turbulence the performance is independent of depth, and the settling rate of particles removed equates to the rate of flow through the tank divided by the plan area. But flow distribution in very shallow tanks is poor, and there is insufficient sludge storage capacity, so that in practice tanks of 1.5 - 2 m depth are usual (although in Nepal silt removal is effected in tanks 0.8m deep, with length 6 times the width).

A simple jar test will show the rate of settlement of suspended particles, but the following table gives some guidance.

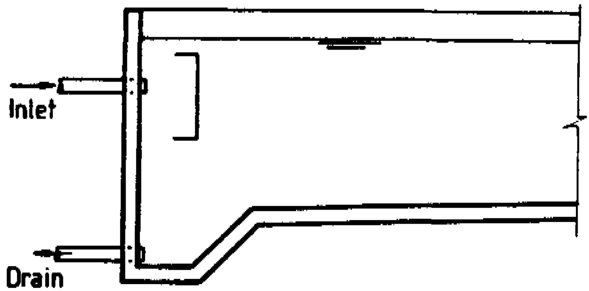
Material	Particle Diameter (mm)	Settling Velocity (m per hr)
Coarse Sand	1	365
	0.5	194
Fine Sand	0.25	98
	0.10	29
Silt	0.05	11
	0.005	0.15
Clay	0.001	0.005
	0.0001	0

In practice, a basin 2 m deep with a capacity of 2 - 4 hrs at the maximum flow rate is practicable and will remove most sand and silt. Bigger basins will usually only be justified if they also serve a storage function.

For very small installations, it may be helpful to fill the basin with large gravel or broken stone. This overcomes the difficulty of the inflow disturbing settled solids, but makes cleaning difficult (it will be necessary to wash sediment from the stone into the drain with a hosepipe, or buckets of water).



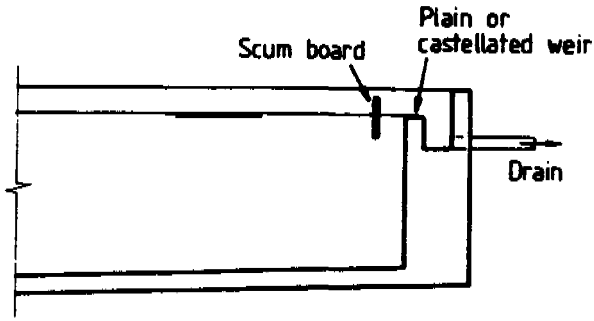
a Board Baffle



b Box Baffle

Inlet Arrangement

Fig D12/1



Outlet Arrangement

Fig D12/2

Slow Sand Filters

Source - Water for the World Technical Note RWS 3D3

If good quality sand is available, a slow sand filter is an effective method of treating impure water and is relatively easy to operate. It functions by forming a film of bacteria etc on the surface of a sand filtration bed. The rate of flow through the filter must be carefully controlled, and the top 50mm of the sand cleaned at intervals.

Fig.D13/1 shows a typical design of which the essentials are:

(a) An <u>open</u> tank about 3m deep.

(b) A bed of about 1m clean coarse sand (of effective size 0.15 - 0.35mm) graded to be as near single size as practicable (i.e. a uniformity coefficient - the ratio of sieve sizes passing 60% and 10% of the sand respectively - of less than 3).

(c) Sand support medium of graded pea gravel - ideally between 2 and 10mm.

(d) A floor drainage system - eg open-jointed pipes in the gravel, or floor of bricks or blocks with open joints.

(e) A baffled inlet with 1 to 1.5m of water above the sand.

(f) An outlet control weir and valve to enable the filtration velocity to be adjusted to between 0.1 and 0.2 m/h.

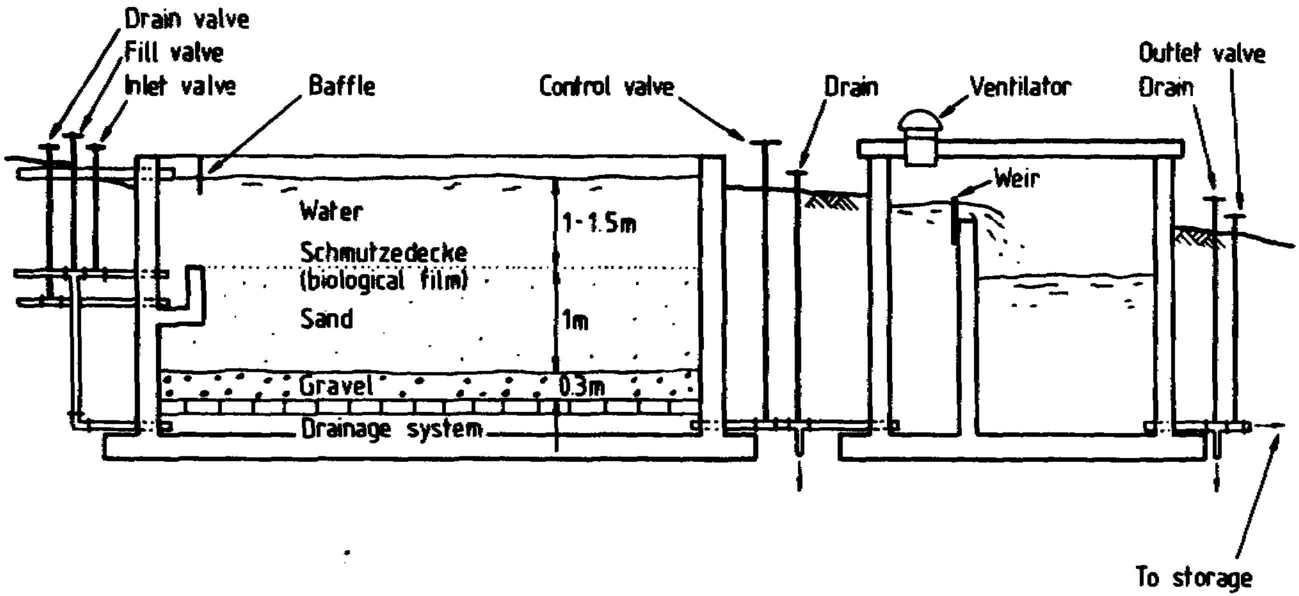
(g) Start up at low flow, fill in reverse direction to avoid air pockets, build up to full flow over 12 hours or more and run to waste for a further 2 days, unless there is post-filter disinfection.

(h) At least 2 filters in parallel, to allow each to be cleaned without interruption to supply. Cleaning comprises draining down some 200mm below surface, and skimming off the top 50mm of sand at periods of weeks or months (depending on how dirty the water is). After cleaning, run water to waste for 24 hours to allow the biological film (Schmutzedecke) to be rebuilt. Top up sand periodically as necessary.

(i) Personnel involved in cleaning and operation should be free from infection, and wear clean footgear and clothes.

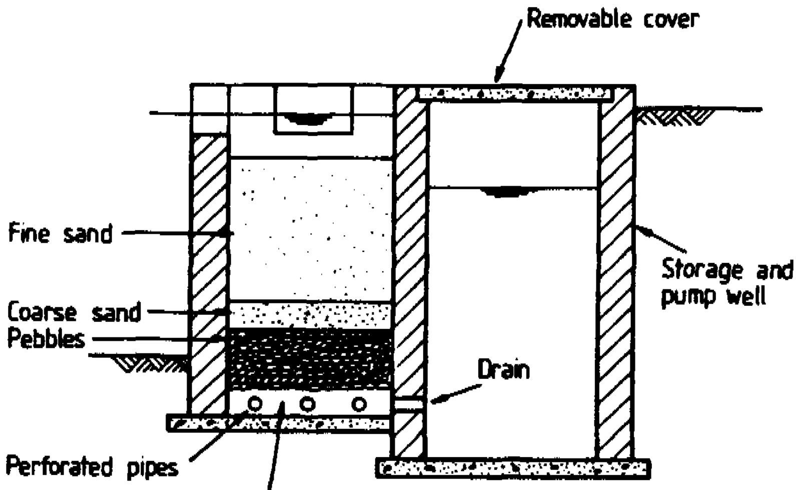
Fig.D12/2 illustrates a simple design which has been used in China.

If a permanent installation is intended, it would be advisable to get specialist advice on design and operation.

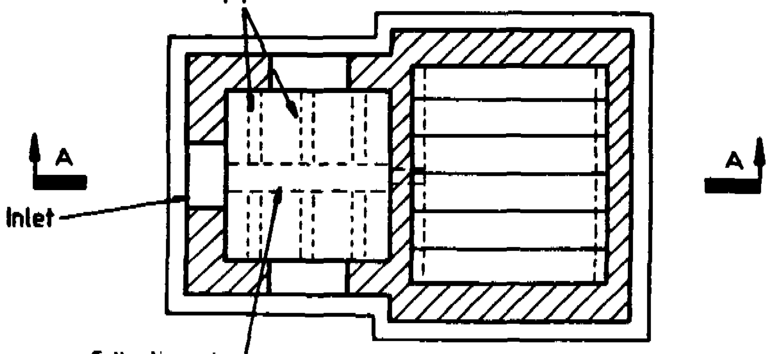


Slow Sand Filter with Valve System and Clear Water Well

Fig D13/1



SECTION A-A



PLAN

Vertical pond-side filter Fig D13/2

Pour Flush (water-seal) Latrines

If the ground is permeable, a water-seal latrine has the advantage of being odour, fly and insect free. A dual pit system is proposed as it has the advantage that each pit is used alternatively and emptied after a minimum retention of two years. During this period the pit content is converted to odourless and rich organic humus which can be used as fertiliser and handled safely. Fig.D14 shows a typical arrangement.

A long pit service has the advantage of less frequent emptying but at the expense of a deeper and hence more costly pit. In the present design, pit service life of three years is recommended to keep the cost low and to demonstrate to school children the recycling of waste as manure for school gardening.

Water-seal pans and traps which require no more than 2 litres of water for flushing are recommended. The main characteristics are a steep base slope and a minimum waterseal.

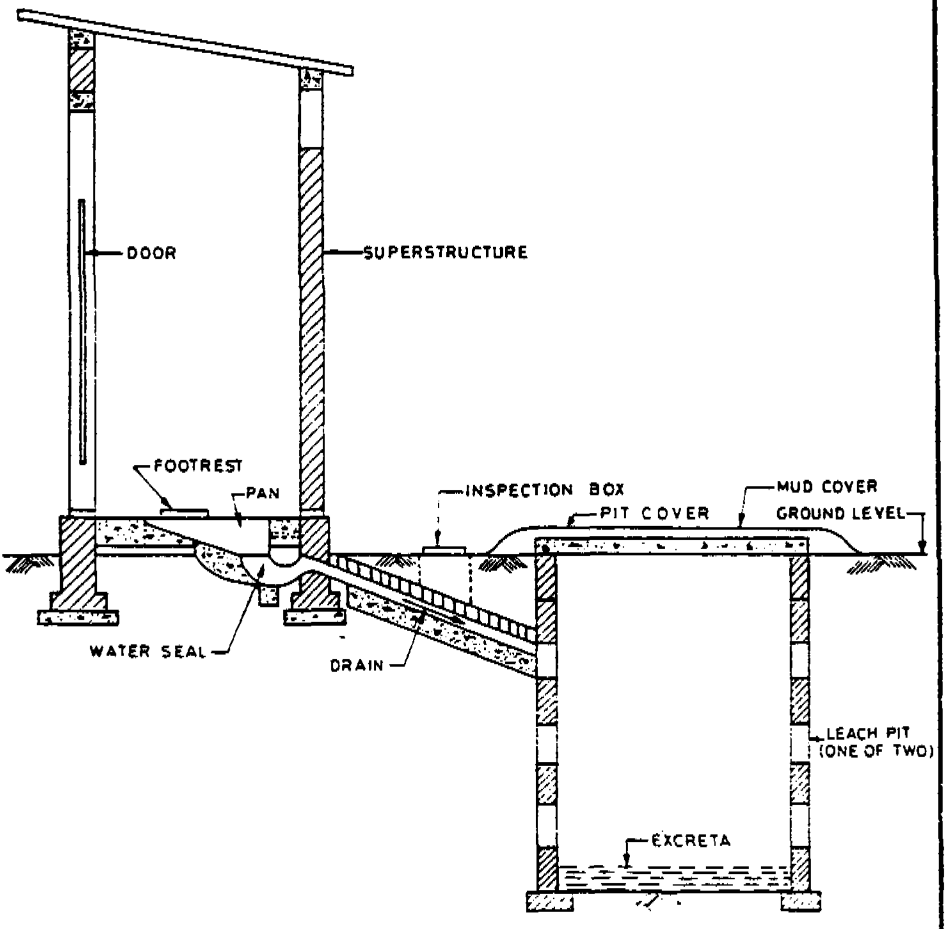

DOOR
SUPERSTRUCTURE
FOOTREST
PAN
INSPECTION BOX
MUD COVER
PIT COVER
GROUND LEVEL
WATER SEAL
DRAIN
LEACH PIT
(ONE OF TWO)
EXCRETA

Fig D 14

VIP Latrine

Source - Blair Research Bulletins.

The ventilated improved pit latrine was introduced in Africa in the 1970s and has proved successful in rural areas in overcoming fly/odour problems. Fig.D15/1 gives the outline design. The superstructure can be adapted to local situations. Points to note:

Siting At least 30m from wells. Not close to trees or bushes. Downwind of houses and on firm and, if possible, elevated ground. Approach area laid to falls, and if possible paved.

The Pit For family use, 1.2 dia. and at least 3m deep. This should last 10 people for 7 years.

Cover Slab Best in concrete. Essential to seal joint with pit lining. Precasting useful, but watch weight and handling.

Vent Pipe PVC 110mm i.d. preferred. Steel or asbestos alternative. Brick possible but less efficient and should be 225mm sq.smooth internally.

Screen Stainless steel 16 mesh preferred. Aluminium alternative. PVC-coated fibreglass has been used but life less than 5 years.

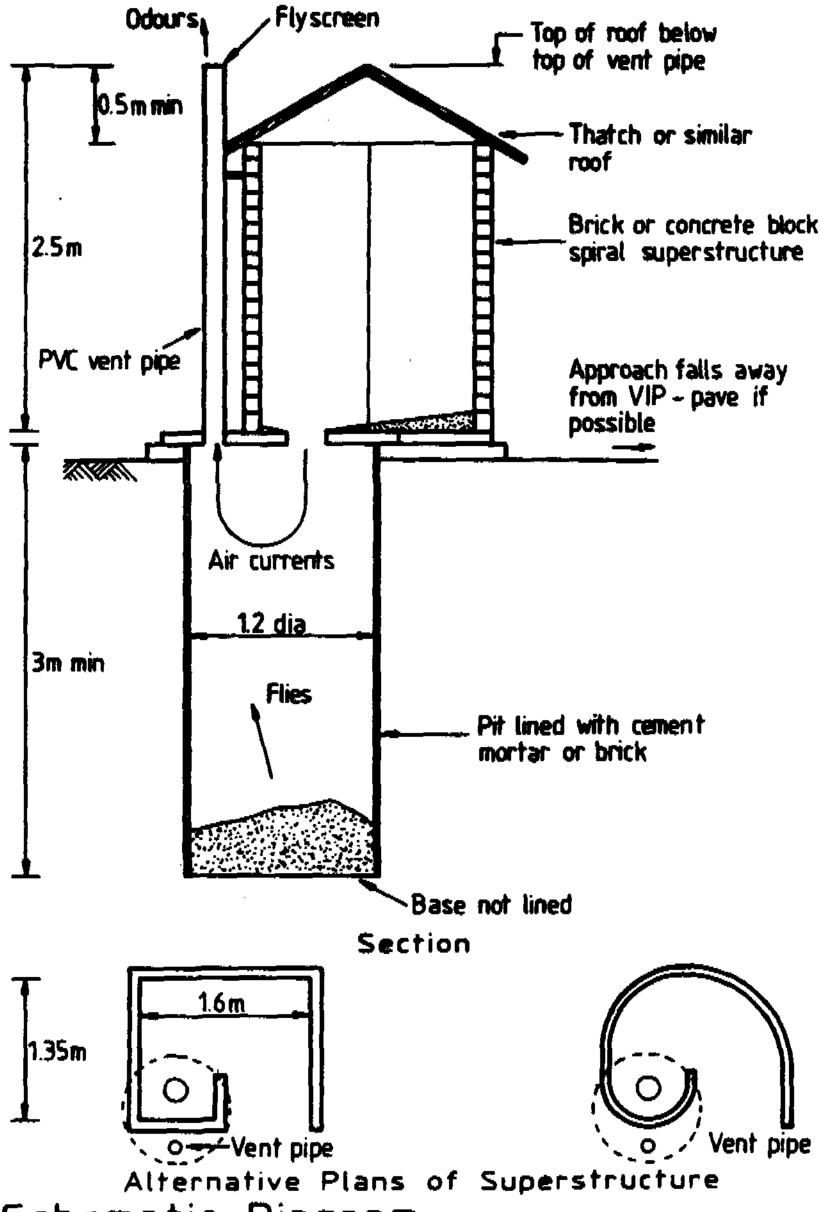
Orientation Priorities should be to face opening

(a) For privacy.
(b) To face the prevailing wind.
(c) Face North or South rather than E/W, with the vent pipe facing the sun.

Note - Muslims do not turn their backs to Makkah when defaecating.)

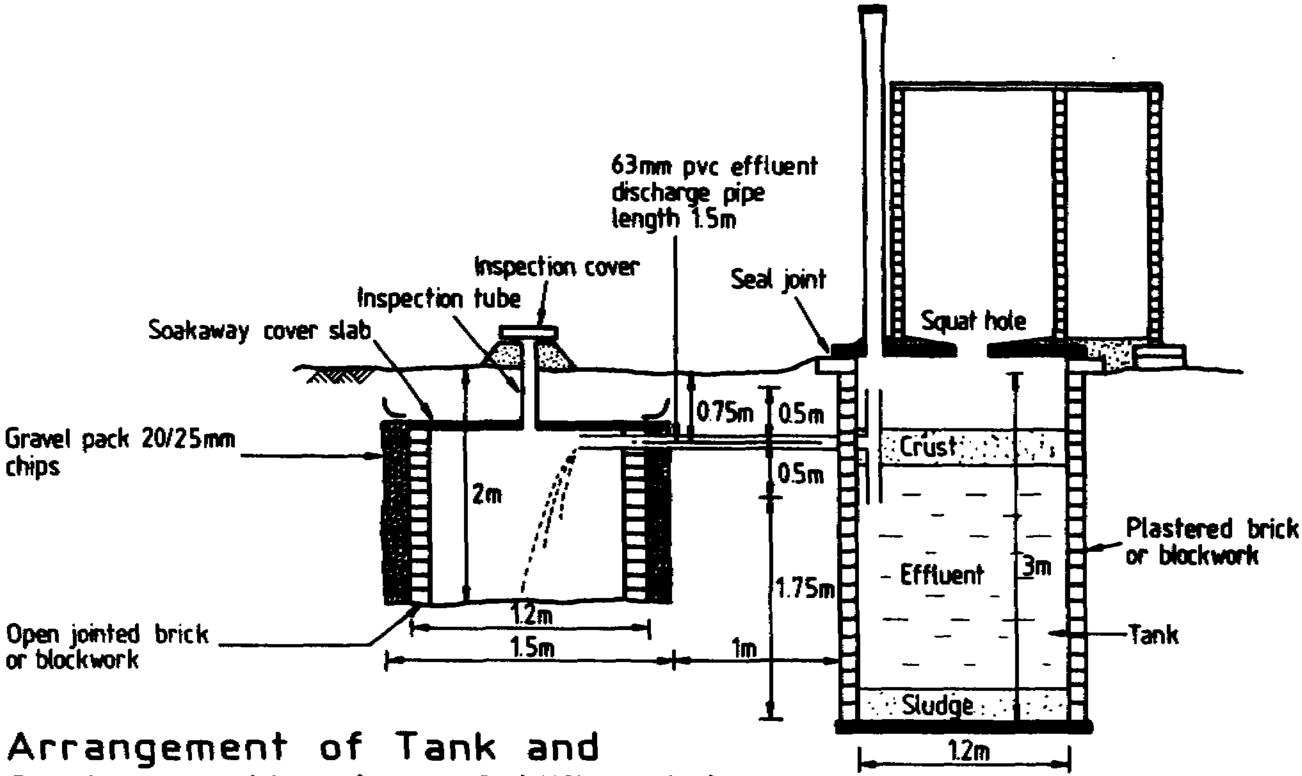
Adaptation Capacity can be increased by:

(a) Deeper pit.
(b) Double (or more) compartments.
(c) Overflow to separate adjacent soakaway (use a dip pipe as shown in Fig.D15/2). In suitable soils a soakaway will enable use in peri-rural situation with a pour-flush toilet, or with piped water and flush toilet Fig.D15/3) - this is essentially a form of Aqua-privy (see D16).



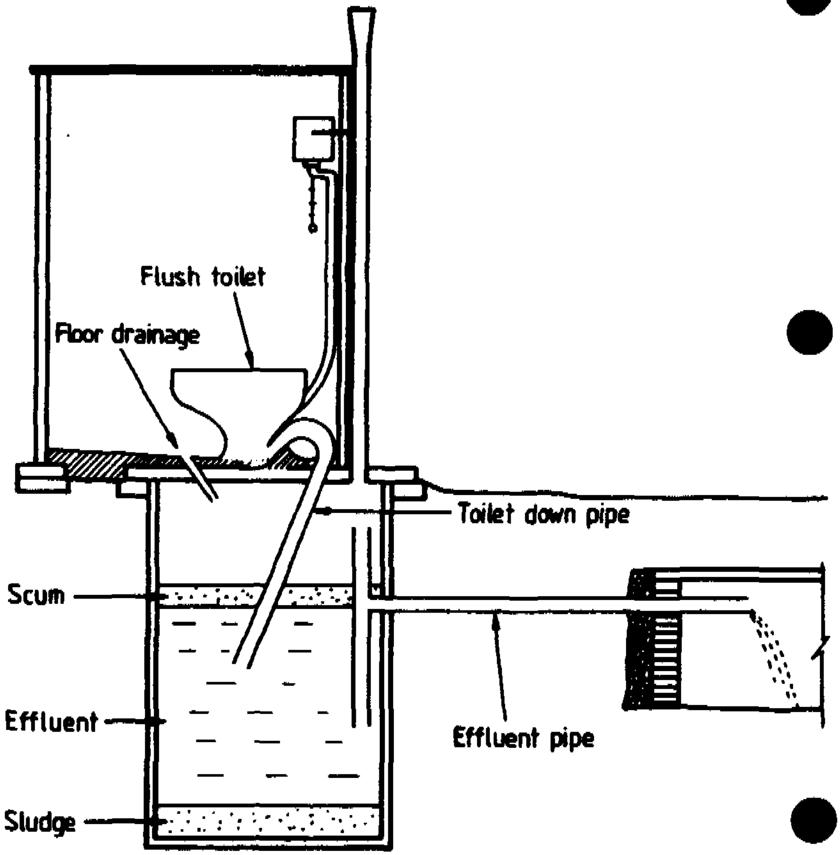
Schematic Diagram of a Ventilated Improved Pit Latrine

Fig D15/1



Arrangement of Tank and Soakaway Version of VIP Latrine

Fig D15/2



VIP Latrine
with Flush Toilet

Fig D15/

Aqua Privies

Source - Water for the World Technical Note SAN 1D4

The aqua privy comprises a watertight vault which receives excreta and washwater from a drop pipe and discharges effluent to a separate soakaway or trench.

The vault should be 15m from the nearest water source
" " " " 3m from the nearest dwelling

The soakaway " " 30m from a water source
6m from a dwelling
3m from trees or bushes

The vault should be 1m^3 capacity for every 8 people (and 1m^3 minimum) with a liquid depth of 1 - 1.2 m.

Concrete or rendered brickwork are suitable for the vault.

The VIP latrine with flush toilet is essentially an aqua privy (see D15).

Section 2 - Electrical and Mechanical Engineering

These notes are arranged in 3 groups:

1 - Electrical	Sheets prefaced E
2 - Mechanical	" " M
3 - Miscellaneous	" " X

These Groups are separated by coloured dividers. A subject index appears at the front of each Group.

Index - Group 1 (M & E) - Electrical

Units and Formulae

Common Units

Quantity	Symbol	Unit Name
Current of flow	I	Ampere (amp)
Potential Difference) Electro-Motive Force)	E(V)	Volt
Resistance/Impedance	R	Ohm (Ω)
Capacitance	C	Farad
Power	W	Watt
Frequency (Cycles per second)	f	Hertz (Hz)

Formulae

(i) Ohm's Law The current flowing in a circuit depends upon the voltage producing the current and the overall resistance of the circuit:-

$$I = \frac{V}{R}$$

where I = current in amperes
V = potential difference in Volts
R = resistance in ohms

NB: In electromagnetic circuits (transformers, motors, etc) the combined effects of inductance and capacitance will create additional impedance (resistance).

(ii) Voltage Drop Conductors should always be sized to limit the amount of voltage drop between the supply and any point in the installation. For circuits with electric motors the voltage drop at full load should not exceed 7.5% of the rated supply voltage.

For DC (direct current) and single phase AC (alternating current) 2 wire circuits:-

Voltage drop = Current x Total Resistance of Cables, (lead and return) = 2IR.

Temperature rise increases resistance. As an approximate correction add 15% to the volt drop as calculated from the above formula for rubber, PVC and polythene insulated cables when operating at maximum permitted temperatures.

For 3 phase AC circuits:-

Voltage Drop = 1.73 x IR (where I = line current per phase and R = Resistance of one core only).

(iii) <u>Motor Horse Power</u>

1hp = 550 foot-pounds per second = 746 watts.

Brake horse power (bhp) is the net available horse power at the motor driving end after deducting all losses within the motor itself.

$$\text{Motor efficiency} = \frac{\text{Power output}}{\text{Power input}}$$

Motor efficiency varies from 85% for small motors to 90% and above for large motors.

Power factor varies with size, speed and loading of the motor, but, if not known, an average figure of 0.8 can be used in approximate calculations. The current taken by a 3 phase motor at full load, where E is the voltage between phases is :-

$$I = \frac{\text{bhp} \times 746 \times 100 \quad \text{amps}}{1.732 \times E \times \%\ \text{efficiency of motor} \times \text{power factor}}$$

(iv) 'Water' Horse Power

$$\text{bhp} = \frac{\text{I.g.p.m x ft.hd}}{3{,}300} \times \frac{100}{\text{efficiency \%}}$$

$$= \frac{\text{I.g.p.m. x psi}}{1{,}430} \times \frac{100}{\text{efficiency \%}}$$

$$= \frac{\text{l/s x m}}{75} \times \frac{100}{\text{efficiency}}$$

$$\text{Fluid kW} = \frac{\text{l/s x m}}{101.92} = \frac{\text{l/s x bar}}{10}$$

$$\text{Motor output kW required} = \text{fluid kW} \times \frac{100}{\text{efficiency \%}}$$

(v) 3 Phase Formulae

$$\text{kW} = \text{kVa x power factor} = \frac{\text{hp x 746}}{\text{1000 x Efficiency}}$$

$$= \frac{\text{Line amps x Line volts x 1.73 x pf}}{1{,}000}$$

$$\text{kVa} = \frac{\text{kW}}{\text{pf}} = \frac{\text{hp x 746}}{\text{1000 x Efficiency x pf}}$$

$$= \frac{\text{Line amps x Line volts x 1.73}}{1{,}000}$$

AC (alternating current)

Ac (alternating current) is the normal system used in public supply systems or for local generation for power purposes. Whilst single phase (2 wire) systems are adequate for lighting and heating loads, single phase a.c. motors are not very satisfactory as there are difficulties in making such motors self-starting. However if three phases are used, each displaced by one third of a cycle, then the motors are self-starting, more reliable and more efficient. Transmission with three phases allows generation and distribution at high voltages over long distances with economically sized conductors. Three phase transformers are used to step the voltages up or down. The normal final stage of distribution is at 11,000 volts (11kV) transformed down to between 400 to 420 volts. (Fig.E2/1.)

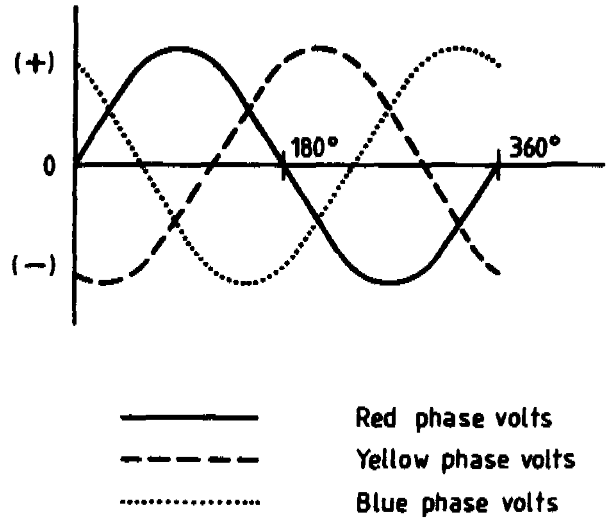
This three phase voltage is used for motors and large appliances. For domestic circuits one of the phases is used with a neutral (Fig. E2/2) (single phase and neutral or SP and N) and the voltage is then equal to the phase voltage divided by $\sqrt{3}$. For example with a phase voltage of 415 volts, the single phase and neutral voltage would be $\frac{415}{\sqrt{3}} = 240$ volts.

The three phases of the supply have a normal frequency of 50Hz (cycles per second) or, in some cases, 60Hz and the voltages are displaced at 120° to each other.

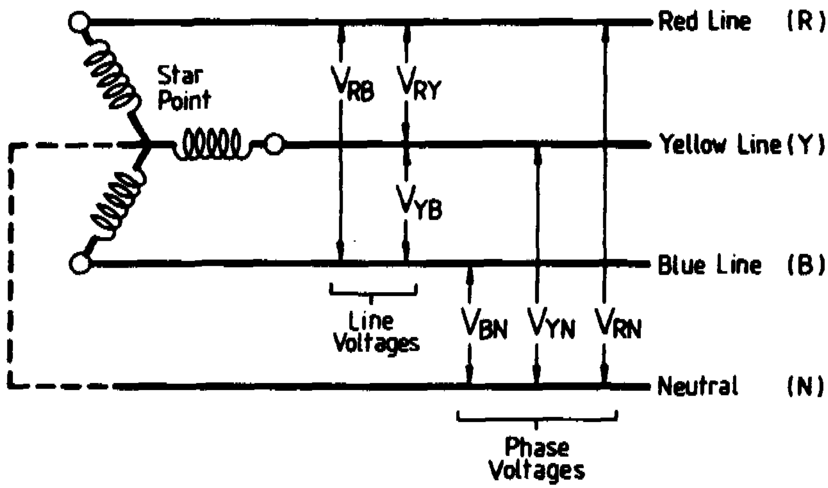
As can be seen from Fig. E2/1, the sum of the coordinates of the three phases on any vertical line is zero. If the load on the three phases is balanced then the algebraic sum of the currents in each phase will also be zero. Thus the three windings of a three phase machine can be interconnected and this is done using either a Star (⅄) or Delta (Δ) connection. The three phases are usually designated as Red (R), Yellow(Y) and Blue(B) lines.

Star Connection

This method is shown in Fig. E2/2 where it can be seen that the three windings are connected in common at the neutral mid-point. At this point, in a balanced circuit the current will be zero as the value of the current flowing towards the mid-point in any one phase is balanced by the current flowing away to the other two phases.



Three Phase Waveforms Fig E2/1



Star Connection Fig E2/2

The mid-point connection of a transformer connected in 'Star' is used to provide the neutral in a three phase and neutral (TP and N) supply as is shown in Fig. E2/2 by the dotted line. the mid-point of the star connected to 'Earth'.

In the star connected supply system there are two different voltages. There is the line voltage between any two of the three phases and the phase voltage between any one of the three phases and the neutral.

$$\text{Line voltage} = \sqrt{3} \times \text{Phase voltage}$$

The line current and the phase current are equal in a star connected circuit.

$$\text{Line current} = \text{Phase Current}$$

Delta Connection

Fig. E2/3 shows the windings connected to form a closed circuit. The voltage across any phase is equal to the voltage between the lines connected to that phase:

$$\text{Line Voltage} = \text{Phase Voltage}$$

The Line and Phase currents are not equal:

$$\text{Line current} = \sqrt{3} \times \text{Phase Current}$$

Protective Switchgear

Every circuit requires means of isolation and automatic means of interrupting the circuit in the event of faults. Manual switchgear comprises switch-fuses with fuses incorporated in the switch-box or separate switch-boxes and fuse-boxes or fuse-switches where the HRC fuses are fitted to the moving carriage. Fuses may be rewireable but should preferably be HRC (high rupturing capacity) sealed cartridges. HRC fuses are designed to rupture rapidly on heavy short-circuit faults, not to deteriorate in service and are less liable to incorrect replacement. The significantly higher cost is justified by the greater safety but care must be taken with electric motor drives that the fuse is rated adequately to prevent operation during the short period heavy starting currents.

Automatic circuit breakers have many advantages. These can be oil immersed or air break for large loads, but for the normal loads experienced in the field miniature circuit breakers (MCB's) or moulded case circuit breakers (MCCB's) will meet most applications. They are tamperproof, have a high breaking capacity, accurate and reliable overload protection and time-delay characteristics to avoid tripping on harmless transient overloads. The cost and delays of fuse replacement are avoided as the circuit breaker can be reset once the fault has been removed. Thermally operated MCB's are sensitive to ambient temperatures, but magnetic hydraulic types are not affected.

Ratings of fuses, switches and circuit breakers must be adequate in size to carry the anticipated full load but must never exceed the rating of the cables being protected. If larger fuses have to be fitted to cater for the surge of motor starting currents then, it may be necessary to provide heavier circuit cables between the supply point and the motor starter. Fuses must never be fitted in the neutral line. (NB: See Section 3 - Electric Motors, for details of motor protection circuits).

Earth Leakage Protection

Reliable protection is essential against the dangers of electric shock or earth leakage fire risk caused by insulation failures. All exposed metalwork, e.g. switchgear cases, and metallic cable sheaths, conduits or trunking must be bonded together by adequately sized protective conductors and connected to a main earthing terminal or bar. The main earthing terminal on a public supply would usually be connected to the earthed point of the source of supply as provided by the utility. The use of earth electrodes is not practible unless there is a significant moisture content and , therefore, should only be used in permanently marshy ground or where the electrode is deep enough to reach the water table. In any situation where simultaneous contact between earthed metal work of the electrical system and other metalwork of the structure or other services (e.g. water pipes) is possible, then the latter metalwork must also be bonded to the main earth. The impedance (resistance) of any earthing system must always be sufficiently low to ensure that no potential difference can exist between any part of the system and earth without operating the protective fuse or circuit breaker rapidly.

Table 1 - Relative Sizes of Phase and Earthing Conductors of Similar Materials

Cross-sectional area of phase conductors (mm^2)	Minimum cross-section of earthing conductor conductor (mm^2)
1	1
1.5	1.5
2.5	2.5
4	4
6	6
10	10
16	16
25	16
35	16
50	25
70	35
95	50
120	50
150	70
185	95
240	120

It is difficult to give a complete protection to installation metalwork against the risk of shock. With high risk equipment such as portable tools and inspection leads it is possible to use safe, low voltages below 50 volts by using step-down transformers. Another method is to attempt to restrict the maximum earth leakage current to a figure around 25mA (milli-amps), but with circuit sensitivity of this order it is difficult to avoid nuisance tripping. The third method is to try to restrict the duration of any possible shock. The aim is instantaneous isolation of the circuit when voltages in excess of 40 volts appear on the installation metalwork.

Fuses alone cannot protect against many earth leakage fire risks. To provide complete protection the maximum earth leakage current would have to be limited to about 1 amp. This can be achieved with an earth leakage circuit breaker capable of detecting 1 amp, which would give good protection to a 60 amp circuit. However, if the same circuit was protected only by a 60 amp fuse an earth leakage current of 100 amp could flow for at least one minute, creating a serious fire hazard. Earth leakage circuit breakers and monitoring devices are reasonably priced and readily available.

Overcurrent Protection

The following checks to ensure overcurrent protection should be made on each installation:-

a) That the installation as a whole and each circuit is protected against overcurrent by fuses or circuit breakers.

b) That each circuit is protected by a device which will operate automatically and safely for the protected circuit.

c) That the current breaking capacity of the device is sufficient to handle the maximum prospective fault current.

d) That, should the device operate, there is no danger from overheating, arcing or scattering of hot metal fragments and the supply can be reconnected without danger.

e) That, where 3 phase motors are connected, arrangements are made for all three phases to be disconnected from the motor should a fuse blow in one phase only to prevent damage to the motor by "single phasing".

f) That, on any system of supply where the neutral supply point is permanently earthed, no fuses or protective devices are fitted in the neutral conductors.

g) That, every fuse or circuit breaker is marked with the nominal current rating for the circuit being protected. The type of fuse link and its fusing factors should be indicated.

h) That, if unskilled persons might replace fuses without supervision, it should not be possible to insert a fuse of the wrong rating.

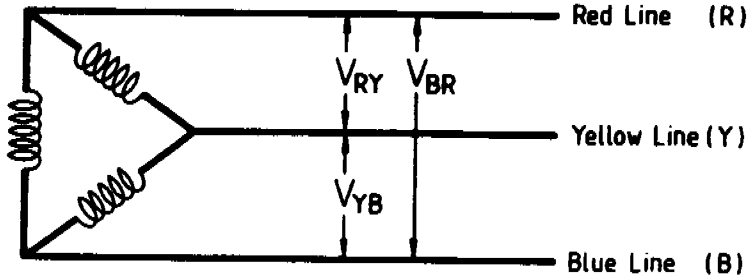
i) If the fuses might be removed or replaced while the circuit is alive, it must be possible to do so without danger by fitting fully shrouded fuse carriers and holders, or preferably by using cartridge fuse links.

j) Circuit breaker settings for overcurrent release should not be adjustable by unskilled persons. A key or special tool should be needed to alter the calibrated setting and a visual indication given of the actual setting.

Table 2 - Sizes of Plain or Tinned Copper Fuse Wire, (for use in semi-enclosed fuses)

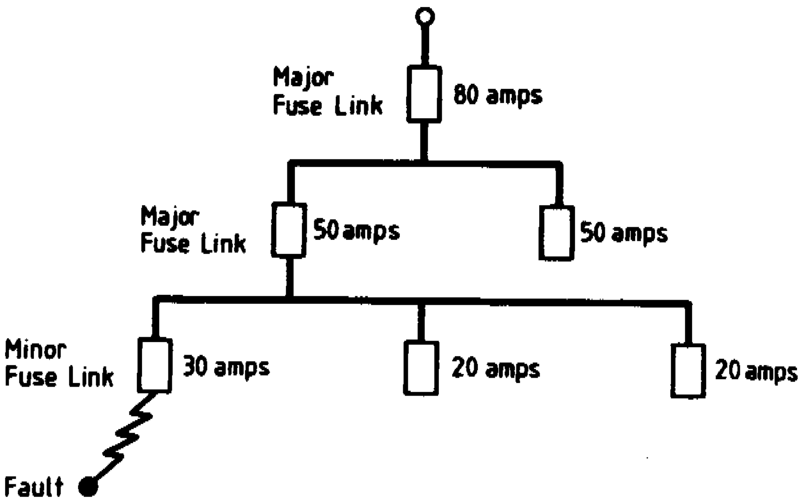
Nominal current of fuse Amps	Nominal diameter of wire mm	Approx.Imperial equivalents inches	swg
3	0.15	0.006	38
5	0.2	0.0084	35
10	0.35	0.0136	29
15	0.5	0.020	25
20	0.6	0.024	23
25	0.75	0.028	22
30	0.85	0.032	21
45	1.25	0.048	18
60	1.53	0.056	17
80	1.8	0.072	15
100	2.0	0.080	14

The characteristics and settings of overcurrent protective devices should be chosen to ensure that a fault in one circuit will not disconnect another circuit. The fuse or circuit breaker nearest the fault should be the only one to operate. (Fig. E2/4).



Delta Connected
Three Phase System

Fig E2/3



Example Illustrating
Discrimination between
Overcurrent Protective
Devices

Fig E2/4

Common Types, Characteristics and Application

These are outlined in the following Table.

DC motors are included for completeness, but will seldom be met. Most motors supplied by WaterAid will be squirrel cage.

Table 1

Motor	Characteristics	Applications
<u>DC Motors</u>		
Shunt-wound	Speed relatively constant over the working range of loads. Drop in speed between no load and full load varies from 2% to 6%.	Machine tool drives, wood working machinery, centrifugal pumps.
Series-wound	Torque increases and speed decreases with increasing current. Speed high on low load and complete loss of load will cause motor to race.	Fans, air compressors, cranes.
Compound-wound	Differing speed/torque can be achieved by varying the ratio of shunt to series windings.	Lifts, rolling mills, fans with heavy rotors.

Continued/

Table 1 (Continued)

Motor		Characteristics	Applications
Single-Phase AC Motors			
Series-wound:			
a)	Universal	As for series-wound DC motors	Normally in fractional sizes only - vacuum cleaners, sewing machines, domestic appliances.
b)	Repulsion	" " "	Lifts,cranes.
Induction Motors			
c)	Shaded pole	As for shunt-wound DC motors.	Small fans,clocks.
d)	Split-phase	" " "	Non-reversing fractional h.p drives
e)	Capacitor	" " "	Constant speed with intermittent loads - refrigerator compressors.
f)	Repulsion-	" " "	Machine tools, pumps, mixers.

Continued/

Table 1 (Continued)

Motor	Characteristics	Applications
<u>Three-phase AC Motors</u>		
<u>Induction Types</u>		
Squirrel Cage	Can be designed for a wide range of starting and maximum torques. Standard types have starting torques from 100% to 175% of full load torque, with starting currents from 500% to 800% of full load current. Double-cage machines give high starting torque with low starting current.	All applications except where very high starting torque is needed or where starting currents have to be severely limited.
Slipring wound rotor	Relatively constant speed over the load range. Speed/torque can be varied by addition of resistance in the rotor circuit.	Air compressors, ram pumps cranes, high inertia drives, variable speed duty.

Table 1 (Continued)

Motor	Characteristics	Applications
Induction Types (Cont/'d)		
Commutator type	Variable speed with constant torque. Speed ranges of 3:1 to 15:1 dependent on design. Speed controlled by induction regulator or by brush shifting.	Large machinery, lifts, fans, pumps.
Synchronous Types		
Salient Pole) Synchronous) Induction)	Straight line speed/torque characteristics from no load to 140% full load. Low starting torque. Salient pole type runs constantly at synchronous speed. Power factor controllable.	Large outputs with non-reversing duties and infrequent light duty starting. Motor generator sets, compressors, ventilating fans.

AC Induction Motor Speeds

The no-load speed in rpm of an AC motor

$$= \frac{\text{Frequency (Hz/cycles per second)} \times 60}{\text{No. of pairs of poles}}$$

Approximate full load speeds (rpm) allowing for slip are shown in Table 4.

Table 4 - Approximate Full Load Speeds of AC Motors

kW	No. of Poles	Supply 50	Frequency (Hz) 60
	2	2 820	3 380
0.75 to 2.2	4	1 405	1 685
	6	930	1 115
	2	2 855	3 425
3 to 7.5	4	1 420	1 700
	6	945	1 130
	2	2 910	3 490
11 to 22	4	1 445	1 730
	6	960	1 145
	8	720	860
	2	2 935	3 520
30 to 75	4	1 475	1 1770
	6	975	1 170
	8	735	880

Induction Motor Currents

These are shown in Table 3 below.

Table 3 - Current per phase in amps (amperes) for 3 phase induction motors at full load with average power factors and efficiencies

HP	3 phase Voltage 380	400	415	440
1	1.9	1.8	1.7	1.7
2	3.6	3.4	3.3	3.1
3	5.1	4.8	4.6	4.4
5	5.1	4.8	4.6	4.4
7.5	11.5	11	10.6	10
10	15	14.3	13.8	13
15	22	21	20	19
20	29	28	27	26
25	37	35	34	32
30	43	41	39	38
40	59	56	54	51
50	73	69	66	63
60	87	83	80	75
70	102	97	93	88
80	117	111	107	101
100	145	138	133	126

3-Phase Motor Fuse Ratings

The table below shows recommended fuse ratings.

Table 4 - Recommended HRC Cartridge Fuse Ratings for 3-Phase Motors

Motor Full Load Current (amps)	Fuse rating	
	Direct on-line starting	Assisted starting (Star-Delta etc)
0 - 1.5	6	4
1.6 - 2.2	10	6
2.3 - 3.0	15	6
3.1 - 5.2	15	10
5.3 - 6.6	20	15
6.7 - 9.6	25	15
9.7 - 10.8	30	20
10.9 - 13.0	35	25
13.1 - 19.2	50	30
19.3 - 23.3	60	35
23.4 - 30.8	80	40
30.9 - 42.2	100	60
42.3 - 64.3	200	100
64.4 - 93.0	200	125
93.1 - 128.6	250	200
128.7 - 150.0	300	200

The recommended sizes of HRC (High rupturing capacity) cartridge fuse-links are based on short circuit protection only. Overload protection relays must be provided in addition. For direct-on-line starting a starting current of seven times full load current and a duration of ten seconds has been allowed to cover normal conditions.

For the assisted start ratings using star-delta, auto transformer or rotor resistance starters, the recommendations are based on a starting current of 3.5 times full load current for a duration of 20 seconds.

The ratings will need to be modified if the following special circumstances apply:-

(i) Heavy accelerating torque which causes an excessively long starting period.

(ii) Frequent, successive starts without intermediate cooling periods.

(ii) An ambient temperature in excess of 25°C.

The use of rewirable fuses in motor control circuits should be avoided wherever possible and should never be used where the circuits exceed a 30 amps rating.

Effect of Voltage Variations

These are shown in the table below:

Table 5 - Effect of 10% Voltage Variations on 3-Phase Motor Characteristics

Characteristic	Voltage Change	
	Plus 10%	Minus 10%
Starting Torque	Increases by 21%	Decreases by 19%
Speed at full load	Increases by 1%	Decreases by 1.5 %
Current - Starting	Increases by 10 to 12%	Decreases by 10 to 12%
Current - Full Load	Decreases by 7%	Increases by 11%
Power Factor at Full Load	Decreases by 3%	Increases by 1%
at 75% Full Load	" 4%	" 2 to 3%
at 50% Full Load	" 5 to 6%	" 4 to 5%
Efficiency at Full Load	Increases by 1%	Decreases by 2%
at 75% Full Load	No change	No change
at 50% Full Load	Decreases by 1 to 2%	Increases by 1 to 2%
Temperature rise	Decreases by 3 to 4°C	Increases by 6 to 7°C

Standard Methods of Starting AC Motors

Single-phase machines

Most single-phase motors used as industrial drives will have separate 'start' and 'run' windings and will incorporate a centrifugal switch to isolate the 'start' winding when the motor has run up to speed. Direct switching starters are suitable for such applications. If no centrifugal switch is fitted a three-position starter would be required to change over from 'off' to 'start' and to 'run'.

Three-phase machines with squirrel-cage rotor

The most common type of 3-phase AC motor is the squirrel-cage induction motor in which the rotor windings are internally short circuited. This motor is simple robust, requires minimum maintenance and should be chosen whenever possible. However, when connected direct-on-line (DOL) a heavy current is taken during the acceleration period with maximum torque on start up. The level of current surge varies with the motor design but is, typically in the range of 6 to 8 times the full load current (FLC).

On a public electric supply there will probably be a limit on the horsepower which can be connected direct-on-line. Also, if the motor is driving high inertia plant (e.g. high lift pumps starting against an open delivery valve) the acceleration period may be extended causing difficulty in starting due to operation of the overload devices. Current surge can be reduced by the following methods of reduced voltage starting but starting torque is also reduced.

a) Star-Delta Starting This is the most common and requires a six terminal motor with both ends of each motor winding brought out to the terminals for connection to the starter. The windings are first connected in 'star' and after the motor has run up to nearly full speed are reconnected in 'delta'.

When the motor is connected in 'star' the applied voltage per phase in 57.7% of the line voltage and the starting current is reduced to one-third of the direct-on-line starting current. The starting torque is also reduced by one-third.

With a manually operated start the handle is held in the 'star' position until the motor has accelerated to full speed. The handle is then rapidly pushed over to the 'run' position. Preferably, an automatic push button contactor starter should be used which provides the following sequence when the 'star' button is pressed:-

i) The 'line' and 'star' contactors operate simultaneously to start the motor.

ii) An adjustable timing device set to operate at the end of the acceleration period changes over and opens the 'star' contactor and closes the 'delta' contactor.

The 'star' and 'delta' contactors are interlocked both mechanically and electrically to ensure that both cannot be closed together as this would cause a short-circuit.

At the instant of change-over with a star-delta starter the motor is temporarily disconnected and a slight loss of speed occurs. When the 'delta' contactor closes there will be a current surge similar to direct-on-line starting. The magnitude of the surge is controlled by allowing the motor to run up to as near as possible to full speed in the 'start' position and achieving the change-over to 'delta' as rapidly as possible.

b) Auto-Transformer Starting These starters are expensive and would not normally be used with small motors. An exception would be submersible pumps in boreholes where star-delta starting would require six cables cores to be fitted to the unit, whilst only three cores would be needed for auto transformer starting.

The auto-transformer is provided with a number of selectable tappings, usually arranged to give voltages of 50, 60, or 75 per cent of line voltage. The tapping chosen is the one that reduces the starting current sufficiently whilst still allowing sufficient torque for starting. The motor torque and current in relation to the direct-on-line values can be calculated by multiplying the direct-on-line values by the square of the voltage tapping used. For example if the motor when switched direct-on-line has a starting torque of 2.5 times full load and a starting current of 8 times full load current, then if started on a 75% auto-transformer tapping, the figures would be:-

Starting torque

$= 0.75^2 \times 2.5 = 1.4 \times$ Full load torque

Starting current

$= 0.75^2 \times 8 = 4.5 \times$ Full load current

If a 60% auto-transformer tapping is selected for the same motor the figures would be:-

Starting torque

$= 0.6^2 \times 2.5 = 0.9 \times$ Full load torque

Starting current

$= 0.6^2 \times 8 = 2.88 \times$ Full load current

Typical Connections of 3-Phase Induction Motors

1. Direct-on-line or Auto-transformer starting (Fig. E5/1)

   N.B. To reverse rotation:-
   Change over any two line leads.

2. Star-Delta starting (Fig.E5/2)

Sequence:

START. Switch makes Star connection
RUN. Switch makes Delta connection

N.B. To reverse rotation:-
Change over any two lines leads.

3. Slip-ring Motors (not often met)

Three Stator and three
Rotor motor terminals

N.B. To reverse rotation:-
Change over any two line leads.

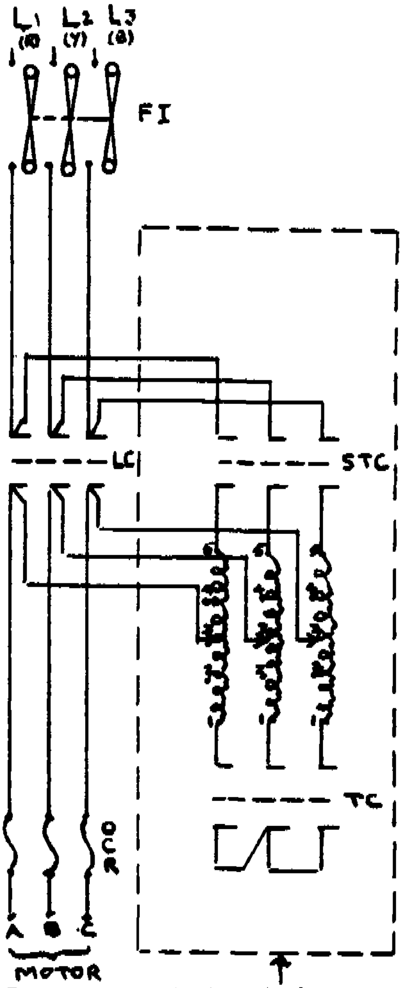
TC = Transformer Conn.

FI = Fused Isolator

LC = Line Contactor

STC = Starting Contactor

OCR = Thermal or Magnetic Overloads



Method of Operation in Auto-transformer is:

1. TC contactor closes putting transformer in star connection
2. STC closes and places reduced voltage onto motor windings
3. TC opens and transformer acts as choke
4. LC engages putting motor DOL and STC opens

Method of Operation Direct on Line (DOL) is :-
LC closes putting power onto motor.

(For DOL ignore circuitry in this box)

Fig. E 5/1

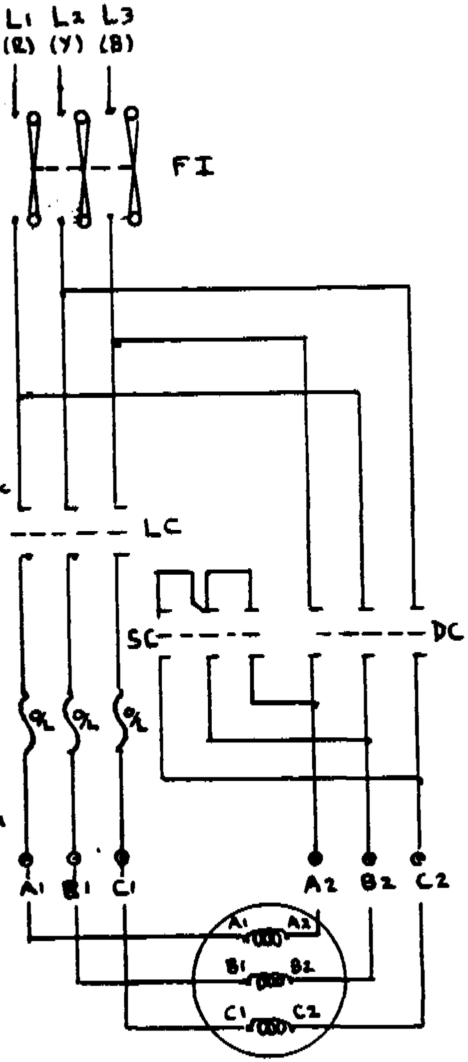
FI = Fused Isolator

LC = Line Contactor

SC = Star Contactor

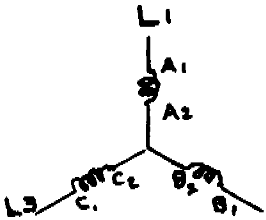
DC = Delta Contactor

O/L = Thermal or Magnetic Overload

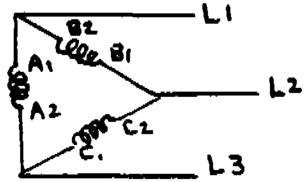


Method of Operation:

1. LC closes and puts power onto motor coils A_1 B_1 C_1
2. SC closes and shorts motor coils A_2 B_2 C_2 giving Star connection
3. SC opens and DC closes putting motor into Delta connection



Star Connection



Delta Connection

STAR DELTA STARTING

Fig. E5/2

Motor Installation

Inspection

Ensure that no parts are broken or missing. If the motor has to be stored before use keep in a clean, dry place, free from foundation vibrations.

Check that the supply details and rated output on the motor nameplate conform with the specification. Check the insulation resistance of the motor winding with a 500 volt insulation tester ('megger'). The insulation resistance in megohms should be not less than

$$\frac{\text{Motor rated voltage}}{1000 + \text{motor rated hp}}$$

Check the bearings for correct lubrication. With sleeve bearings check that the oil wells are filled to the level indicated and that oil rings are free to rotate.

Ball and roller bearings are correctly packed with grease by the manufacturer and require no additional lubrication during the first few months of service. If stored for more than six months the grease may deteriorate and may shrink away from the bearing cage. Before commissioning the bearing caps should be removed and if the grease is dry and hard it should be renewed.

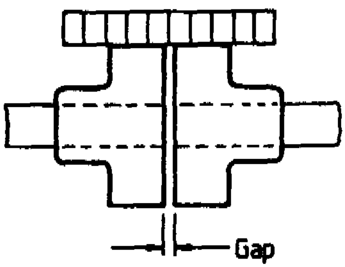
Check for any bearing damage by spinning the rotor by hand and listening at each bearing using a short stick held against the bearing cap. Check fit of any coupling or pulley which has to be fitted to the motor shaft. A pulley requires a 'tap-on' fit and a coupling should have a force fit. When fitting a pulley or coupling on to the motor shaft ensure that the opposite end of the shaft is supported.

Check the starter to ensure that it is the correct type as specified and that protective devices are correctly rated and adjusted for the actual load conditions.

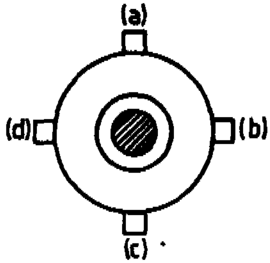
Alignment

Bed-plates or slide rails must be securely bolted to a solid and level foundation of concrete or solid masonry. Mountings must be rigid, free from vibration and level. When erecting machines with direct coupling drive between motor and driven machine, both shafts must be in line. Check the gap between the faces of the half-couplings, place a straight edge across the edge of both half-couplings and check on each side into a feeler gauge for alignment. Rotate the coupling and check at 12, 3, 6 and 9 o'clock positions (see Fig. E6/1). Adjustments should be made by inserting metal shims under the machine feet as required to align the coupling accurately. Flexible couplings must be used for coupling machines with ball and roller bearings or sleeve bearings. Only if coupling to a single bearing machine must a solid coupling be used.

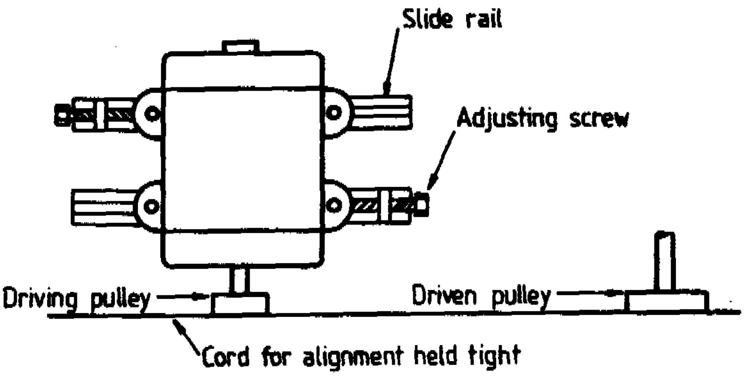
With a belt drive, the tight side of the belt should be on the underside. Minimum distance between pulleys should be four times the diameter of the large pulley. Belts should be tightened just enough to prevent slipping. Excessive tension will cause damage. Adjusting screws of slide rails should be arranged as shown in Fig E6/1 and a cord used, as shown, for alignment.



1. Aligning a Coupling



2. Checking Positions



3. Alignment for Pulley Drive

Couplings

Fig E6/1

Operation and Maintenance

Lubrication

Ball and roller bearings must not be overfilled with grease as this causes overheating and bearing failure. When a bearing is filled with grease take care to fill all the bearing space between the rolling elements, but the outer bearing caps should be only two-thirds full. When the motor is operating a small amount of additional grease should be added every 2000 running hours.

Every two years completely renew the grease. Ensure that only grease recommended by the manufacturer is used.

For sleeve bearings or oil-filled thrust bearings, check the levels at frequent intervals and top up to the indicated level with the motor stopped.

Every six months completely change the oil.

Ensure that only oil recommended by the manufacturer is used.

Keep all covers closed and plugs tight.

Cleanliness

Except with totally enclosed motors dust and dirt will be drawn into the motor by the rotor fan. This can lead to overheating and damage to the windings. Clean out any dust regularly, preferably by using a powerful suction cleaner. The use of a high powered blower can lead to dust accumulating within the windings.

Temperature

Ensure adequate ventilation. The temperature rise of a normal protected motor is 21°C. If motors are to operate in ambient temperatures above 24° the final temperature could be excessive unless high temperature windings have been specified or motors with a lower temperature rise.

Single Phasing

If a 3-phase motor is running and one phase becomes disconnected (e.g. a blown fuse or bad connection) the motor will continue to run as a single phase machine but will take excessive current through the phase windings leading to rapid burning out. If an attempt is made to start a motor under these conditions it will not rotate or, if it does, will only turn very slowly. The motor will make a load humming noise and take extremely high currents from the main destroying the windings until the other fuses operate.

To reduce the risk of such a break in one phase of the supply check that the circuit main fuses have a capacity of at least three times the full load current of the motor, that the overload trips are correctly set and that protection is fitted, to ensure that rapid disconnection of the motor, should there be reduced or nil voltage in one or more of the phases.

Table of common electric motor faults

Fault	Possible Cause	Remedy
Detection by sight:		
No rotation	Supply failure - either complete or single phase	Disconnect motor immediately (with a single phase fault serious overloading and burn out could occur rapidly. Ensure that correct supply is restored to motor terminals.
	Insufficient torque	Check starting torque required and and compare with motor rating taking into account type of starter in use.
	Reversed phase	Change to larger motor or to different type of starter. Check connections in turn and correct.

Continued/

Table of common electric motor faults (Continued)

Fault	Possible Cause	Remedy
Detection by hearing:		
Steady electrical hum	Running single phase	Check that all supply lines are alive with balanced voltage.
	Excessive load	Compare line current with motor rating. Reduce load or change motor.
	Reversed	Check connections in turn and correct.
	Uneven air gap	Check with feelers. If due to worn bearings fit new ones.
Pulsating electrical hum	Defective rotor	Check speed at full load. If it is low and there is fluctuating current, the rotor could be defective.

Continued/

B/3/88

Table of common electric motor faults (Continued)

Fault	Possible Cause	Remedy
Pulsating electrical hum. (Cont/'d)	Defective wound rotor - loose connection or partial short circuit	Check rotor resistance and open-circuit voltage between sliprings.
Mechanical Noise	Foreign matter in air gap	Check, dismantle and clean.
	Bearings damaged	Check with listening stick - fit new bearing.
	Coupling out of line	Check coupling gap and realign.
Detection by touch:		
Vibration	Uneven foundations	Check level and alignment - realign.
	Defective rotor.	As above for pulsating electrical hum.

Continued

Table of common electric motor faults (Continued)

Fault	Possible Cause	Remedy
Vibration (Continued)	Unbalance	Uncouple from driven machine, remove motor pulley or coupling. Run motor between each of these operations to determine whether unbalance is in the driven machine, pulley or rotor. Rebalance.
Frame heating (NB frame temperature will be approx. 10°C *lower than* winding temperature)	Excessive load	Reduce load or change motor.
	Foreign matter in air gap	Check, dismantle and clean.
	Excessive ambient temperature	Check motor temperature rating.
	Partial short or open circuit in windings	Check with suitable meter.
Bearing heating	Too much/too little grease.	Remove surplus/wash bearings and replenish grease.

Starting Frequency

Avoid frequent starts unless the motor has been specifically designed for such duties. As a general guide:-

2 - pole motors (3000rpm) - 2 starts/hour
4 - pole (or above) (1500rpm or less) - 3 starts/hour.

INDEX - Group 2 (M & E) - Mechanical

Imperial to Metric		Metric to Imperial
gals (Imp) x 4.546	= litre (1)	x 0.22 = gals (Imp)
gals (Imp) x 0.004546	= m^3	x 220 = gals (Imp)
gals (US) x 3.785	=1	x 0.2642 = gals (US)
gals/min x 0.07577	= 1/sec	x 13.2 = gpm
000 gals/h x 1.263	= 1/s	x 0.792 = 000 gph
mgd x 52.61	= 1/s	x 0.019 = mgd
cusecs x 28.32	= 1/s	x 0.0353 = cusecs
psi x 0.06895	= bars	x 14.504 = psi
psi x 0.703 sg	= m.liquid	x 1.422 x sg = psi
m.liquid x 0.098065xsg	= bars	x 10.192 sg = m.liquid
hp x 0.7457	= kW	x 1.341 = hp

1 Imp. gallon	= 10lb cold freshwater = 1.2 US gal
1 cubicfoot	= 6.23 Imp. gal = 62.3lb cold freshwater
Feet-head	= psi x 2.31 sg
1 hp	= 33,000ft 1lbs per minute

Water horsepower (Whp) =

$$\frac{\text{gpm x ft hd x sg}}{3{,}300} \times \frac{100}{\text{Efficiency \%}} = \text{bhp}$$

$$\frac{\text{gmp x psi}}{1430} \times \frac{100}{\text{Efficiency \%}} = \text{bhp}$$

$$\frac{\text{gal/hour x psi}}{85{,}800} \times \frac{100}{\text{Efficiency \%}} = \text{bhp}$$

$$\text{Fluid hp} = \frac{\text{1/s x m x sg}}{75}$$

$$\text{Fluid kW} = \frac{\text{1/s x m x sg}}{101.92} = \frac{\text{1/s x bar}}{10}$$

$$\text{Driver output kW required} = \frac{\text{Fluid kW} \times 100}{\text{Pump Efficiency \%}}$$

$$\text{Efficiency \%} = \frac{\text{Fluid kW} \times 100}{\text{kW input to pump}}$$

Pumps - Basic Types

Pumps available are either hand or power operated.

Hand Operated Pumps (see also T18)

There are three main categories - suction, direct action and lever action.

Suction Pumps: These are suitable where the water is close to ground level and will only operate in practical terms to depths of less than 6m. They are found in places such as Bangladesh and Nepal where tube wells are easily sunk into the soft deposits in a river basin or delta.

Direct Action Pumps: These have a cylinder below water level. The piston is operated by rods and there is a separate rising main. They are suitable to depths of 15m.

Lever Action Pumps: When the water has to be pumped from a depth greater than 15m a hand pump requires some form of lever operation, and can then be operated to a depth of 45m.

There are many different types of handpump in current use or available. we recommend only those which meet the criteria of VLOM (Village Level of Maintenance).

WaterAid aims to provide manufacturers' literature for the types likely to be encountered in each country.

Power Driven Pumps: These may be surface units or borehole pumps used too raise water from below ground level.

Surface Units are usually centrifugal or progressively cavity types.

Centrifugal (rotodynamic) pumps are manufactured to very tight tolerances and aggressive materials such as sand cause excessive wear, with loss of efficiency and output.

Progressive Cavity Pumps consist of a single helix rotor inserted into a double helix stator and are useful where small quantities of water are required at high heads.

Borehole Pumps may be reciprocating, submersible, centrifugal or progressive cavity types.

Reciprocating pumps have a piston driven by shafts from a surface power unit moving within a cylinder below water level, and have inlet and outlet valves. Water is drawn into the cylinder (normally by the downward stroke) and forced into the rising main by the upward stroke. Whilst some of these may still be met spares are very expensive and submersible centrifugal pumps are preferred, which, together with the motor unit, are submerged below water level. They have a number of disadvantages:-

(a) Because boreholes in the countries in which we operate tend to be of small diameter (6" or 8"), the pumps are small, multi-stage, and suffer excessive wear if the water has abrasive qualities.

(b) They depend on water for cooling and if installed without low water level protection the motor or pump fails if the borehole runs dry.

(c) Similarly, when the flow of water into the borehole is restricted, insufficient water flows across the motor unit (which is below the pump inlet) causing rapid overheating of the motor. This can be overcome by fitting a shroud to the unit to ensure that water always passes over the motor.

(d) In many of the countries in which we operate it is impossible to get submersible motors rewound and if they are of the encapsulated type rewinding is impossible in any case.

(e) For a submersible pump installation to be of any practical use there must be a good supply of electricity so that Direct on Line starting can be used. (Star-Delta starting should not be used for this type of pump as the inertia gained during the star phase will rapidly fade on the switch to delta giving a virtual DOL start with resultant high current and voltage drop).

(f) It is advisable to fit a footvalve to prevent water in the rising main forcing the pump to contra rotate or "back plane" when the motor is switched off. If an attempt is made to restart during this period the motor will suffer serious if not fatal damage. (The disadvantage is that when the pump is raised the valve increases the weight to be lifted).

Progressive cavity pumps are described for surface units, but in this case the pump unit is attached to the rising main and driven by a shaft from the surface which has bobbins to centralise it in the main. The shaft normally has couplings every 3m and in many cases this also incorporates the bobbin. The drive head and power unit are at ground level, usually occupied by V-belts.

These pumps do have a number of advantages:-

(a) There are no electrical components down the borehole.

(b) The pumps can be driven by either petrol diesel engines or electric motors and since the power unit is at ground level maintenance can more easily be carried out.

(c) Since the weight of the pump unit is less, the rising main is sometimes smaller and lighter.

(d) They are much better at handling waters which contain fine abrasive particles and tend to have a much longer period of operation between overhauls.

(e) They can be simply adjusted to increase or decrease output should there be a change in borehole characteristics or consumer demand, either by changing the drive pulley ratios, or on diesel driven units by increasing or decreasing the speed of the engine.

   Increasing the engine speed should give no problems but when reducing the speed take into account:

   (i) Ensure that the load on the engine does not fall below half the designed output as this will result in excessive coking if the engine is run on light load.

   (ii) On this type of pump a reasonable torque is required on starting, especially when new, to overcome the "sticksion" between the stator and the rotor, and when diesel engines are used as the motive power, centrifugal clutches are put on the engines, usually operating at 1100 rpm; if the engine speed is reduced below this level no drive will be obtained.

(f) Footvalves do not need to be fitted to this type of pump as no contra rotation occurs when the pump stops or is shut down as the unit seals itself.

(f) Footvalves do not need to be fitted to this type of pump as no contra rotation occurs when the pump stops or is shut down as the unit seals itself.

Pumps - Data Required for Ordering

To obtain the correct pump for a given application, factual data must be supplied - remember it is better to give more information than required than too little.

A. Site Conditions

(i) Altitude (m/ft). (Especially important if diesel engines are to be used as the motive power).

(ii) Temperature (Deg C/Deg F)

B. Output required

(i) quantity (Litres/sec or Cubic metres/hour).

(ii) Quality of water, i.e. corrosive or abrasive substances and if possible PH value.

C. Static Suction Lift (m/ft). Wherever possible on surface units, suctions should be flooded giving a positive suction head; if this is not possible, give the suction lift required, bearing in mind the effect of altitude. (see M5)

D. Delivery Pipe Details

(i) Diameter of pipe (mm/ins). (Clearly state if this is the internal or external diameter as some standards such as MDPE and PVC differ).

(ii) Type and length of pipe (i.e. MDPE/PVC/GALV STEEL) and likely condition so that full consideration can be given to the friction head.

(iii) Static head (m/ft). Properly surveyed, not guessed from maps.

E. Type of Pump (Surface or Borehole)

(i) Surface

(a) Is this new or replacement pump?

(b) If replacement, are there any existing foundations to work to - if so give details of any bolts, including their size and the centres between them.

(c) Is there existing pipework and are special fittings and valves needed?

(ii) Borehole

(a) Is this a new or replacement pump?

(b) If replacement, give full details of existing pump unit, headworks, rising main and cables, stating condition and need for replacement.

(c) Diameter of borehole (mm/ins)

(d) Static level

(e) Level at the duty required

(f) Any additional lift required above GL at the borehole, together with the appropriate pumping main details.

G. Drive Unit

(i) Electrical. If from commercial electricity supply company, give full details, i.e. Voltage, Frequency, 3ph/1ph and also reliability and sustainability of the stated voltage.

(ii) Diesel. Important to remember altitude for derating.

Whatever the application, always try to give a sketch showing the detailed requirements.

Pump Installation

Surface Pumps

Location: The pump should be sited with the shortest possible suction pipework as the easier the suction conditions the more efficiently it will operate.

Ensure that it is located on a solid level foundation and leave ample floor space and headroom for inspection and maintenance purposes.

Foundations: The pump should be placed on firm foundations substantial enough to eliminate vibration and pump/motor misalignment. Allow about 1" below the pump baseplate for grouting. When the grout has dried out, the base should be drawn down evenly, checking the pump alignment. Misalignment will cause excessive wear to couplings and bearings. Fixing a flexible coupling between the pump and driving unit is not a cure for alignment inaccuracies.

Pipe Connections: All pumps should be installed with a suction and delivery valve to allow the pump to be removed for maintenance or renewal and the valve on the pump discharge can, provided the appropriate pressure gauges are fitted, be used for test purposes to obtain the main characteristics.

Ensure that the suction pipework has a continuous rise to the pump to avoid air traps and that all pipework is properly supported so that the pump casing is not subject to externally induced stresses.

Check the pump: Rotate the pump by hand to ensure there is no binding or seizure.

Ensure that the glands have been properly packed or that mechanical seals have not been damaged; always allow a slight leak from the gland, and never start a pump with new packing under compression.

Fully prime the pump and suction before starting and spin to check rotation under closed valves conditions before pumping under load.

Borehole Pumps

Before installing a new or replacement pump in a borehole the hole should be plumbed with a plate to ensure that there are no protrusions likely to impede the installation of the unit and that the exact depth of the hole is known (lowering the motor of a submersible into silt will result in burn-out).

Pipework Ensure that the pipework is strong enough to carry the weight of itself and the pump unit, and the stresses induced when the pump is operational.

Valves: Wherever possible fit a non-return valve at ground level so that the rising main water is not lost when the pump is topped.

Electric Cables: Ensure that the cable size is adequate to avoid voltage drops greater than those acceptable to the unit.

Maximum Suction Lift at Varying Altitudes

Altitude	Barometric Pressure Bar	mm hg	Equivalent head of water in m	Practical maximum suction lift of pumps m
Sea level	1.013	760	10.33	6.5
500m	0.954	716	9.73	6.0
1000m	0.899	674	9.16	5.5
1500m	0.846	634	8.62	5.0
2000m	0.796	597	8.12	4.5

Centrifugal Pump Fault Finding

(a) No delivery

Pump not fully primed.
Leaking footvalve, suction pipe or glands.
Hump in suction line (air-locking).
Wrong direction of rotation.
Strainer blockage or blockage in pump or pipes.
Low drive speed (motor under-voltage, belt slippage.)
Head too high for pump.
Suction lift too high.

(b) Loss of delivery

Leaky suction pipes or glands.
Air or gas in liquid.
Inlet becoming uncovered or inadequately submerged.
Suction lift exceeding pump capability owing to falling level.

(c) Excess Power

Speed too high.
Pump misalignment.
Head too low (or too high) according to pump characteristic.
Foreign matter in pump body.

(d) Noise/Vibration

Delivery head too high.
Suction lift too high.
Blocked suction line or impeller.
Air in liquid.
Misalignment.
Worn or faulty bearings.

Pumps - Starting and Stopping Procedures

Starting

Where fitted supply cooling water to:-

Bearing jackets.
Gland/mechanical seal connections.
Michell bearings.
Oil coolers.

Pumps with Positive Suction

a) Fully open suction valve

b) Check that correct suction head is available

c) Release all air from pump

d) Release all air from from suction piping

Pumps with Negative Suction

a) Prime pump against a foot valve or use priming equipment

b) Release all air from pump

c) Release all air from suction piping

d) Check suction valve fully open

e) Start drive unit

f) Observe oil-rings (if fitted) rotate freely

g) Open pump delivery valve

h) Check that electric motor current is normal and that pump delivery pressure is correct.

i) Check that packings/mechanical seal are running cool

Stopping

a) Close delivery valve.
b) Stop driver unit.
c) Close any auxiliary water supplies.

Pumps - Gland Repacking

See Fig. M8.

1) Use a pair of extractor tools to withdraw all the old rings of packing. Wipe the inside surfaces clean.

2) Check that the shaft runs true and is free from pitting, scoring or sharp edges beneath the packing. Check the gland follower for correct fit within the stuffing box. The maximum clearance between the inside of the gland and the shaft should be 0.4mm. The maximum clearance between the gland follower inside face and the stuffing box inside face should be 0.25mm.

3) Cut rings off the spiral, spool or coil at an angle of 45° to exact shaft size so that ends of packing meet around the shaft size and check the first ring fits correctly in box.

4) Metallic and extruded packing rings are spirally opened ready for fitting.

5) Fit each ring separately using a tamping stick to ensure that the ring is pushed hard home. NB. PTFE multi-filament yarns are just slid into the box and must not be driven home.

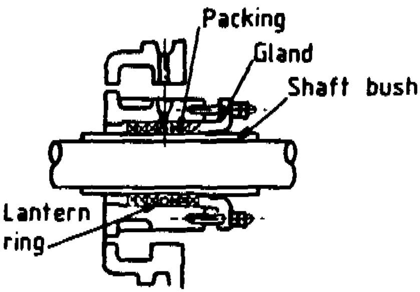
6) Joints are staggered by 120°. Before fitting each ring check that the shaft turns freely. If a lantern ring is fitted, position below inlet connection, allowing for slight compression of bottom packing rings.

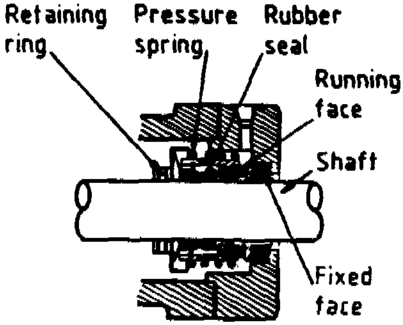
7) Bring the gland follower up squarely against the last packing ring and tighten the nuts evenly to <u>finger</u> pressure, checking the shaft turns freely.

8) With pumps, leakage should take place. After start-up the gland nuts should be tightened by one-sixth of a full turn at 10 minute intervals, until leakage is reduced to an acceptable level.

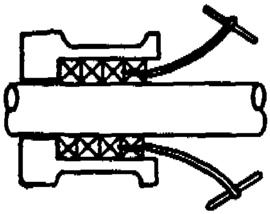
9) Ensure that the gland remains cool and re-adjust after a few hours' running.

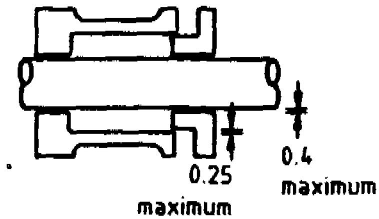
10) With packing glands of valves tighten the gland nuts until the packing offers moderate resistance to spindle movement. (Acknowledgements to Crane Packing Ltd., for the above procedure recommendations).





a) Soft-packed stuffing box b) Mechanical seal





c) Packing withdrawal d) Gland follower clearances

Pump Glands

Fig M8

Derating of Diesel Engines with Altitude

Where the motive power is supplied by a diesel engine it is important to remember that the manufacturers stated outputs are usually only applicable to 1500m (500ft) above sea level. For every 300m (100ft) of altitude above this level the power output should be derated by 3.5%.

Also, the manufacturers stated outputs are usually at an ambient temperature up to 30 deg C (85 deg F) and power output should be derated by 2% for every 2 deg C (10 deg F) in excess>

Derating for humidity can be up to 6%.

V-Belt Drives

The endless V-Belt drive is extensively used by pump and compressor manufacturers to transmit power from the drive unit and it is important that when replacements are required the correct belt is requested.

Where the manufacturer has fitted a multi belt pulley, ensure that all the belts are fitted, as running with less will result in damage to the remaining belts. Replacement should be made in matched sets and old and new belts should not be mixed.

Do not use automotive belts for industrial purposes as they are designed for and operate under quite different conditions, i.e. rapidly increasing and decreasing speed loads. The V-Belt is manufactured with a core of high tensile cord embedded in rubber or a synthetic and encased in a fabric and rubber reinforcement and all belts have a standard angle of 40 deg. The most common type are wedge belts and these come in four sizes, SPZ, SPA, SPB, SPC, and the number which follows the code is the length of the belt in mm.

The correct installation of belts is very important and they should be placed in their grooves by hand. The use of levers to force belts onto pulleys can damage the load bearing cords causing premature failure.

It is particularly important that during the early life of the belt, when bedding-in is taking place, belts are checked for tensioning as heat generated if the belt slips causes severe damage.

Petrol (Internal Combustion) Engines
Fault Tracing Chart

ENGINE WILL NOT START

Starter will not turn engine	1.	Battery discharged or corroded terminals.
	2.	Loose connections or faulty starter switch contacts.
	3.	Starter motor brush or commutator trouble.
Starter turns engine slowly	4.	Any of faults 1, 2, or 3 Engine partially seized.

Continued/

Fault Tracing Chart (Continued)

ENGINE WILL NOT START	
Starter turns engine normally but engine does not start	5. Loose or faulty low tension cable to coil. 6. Faulty capacitor. 7. Faulty ignition coil or contact breaker. 8. Faulty distributor rotor or high tension pick-up contact. 9. Damp HT leads or sparking plugs. 10. Lack of fuel. 11. Filters or pipes choked. 12. Petrol supply faulty. 13. Air leaks in induction system. 14. Sticking or leaking valve. 15. Valve timing incorrect. 16. Ignition timing incorrect. 17. Leakage past pistons and cylinders.

Continued/

Fault tracing Chart (Continued)

FAULTY IDLING

		Any of faults 5, 6, and 7.
	18.	Plug insulation defective, sooted up or gaps too wide.
Engine fires but dies out	19.	Ignition too retarded.
	20.	HT leads wrongly connected.
	21.	Fuel supply inadequate - Faults 11 and 12.
	22.	Mixture controls incorrect.
	23.	Water in carburettor.
	24.	Vent hole in petrol tank cap blocked.
Engine will not slow-run	25.	Valve sticking.
	26.	Slow running adjustment set incorrectly.
	27.	Slow running jet blocked.
	28.	Worn valves, guides or piston rings.
	29.	Valve clearances wrongly adjusted.

Continued/

Petrol (Internal Combustion) Engines
Fault Tracing Chart (Continued)

ERRATIC RUNNING

Engine will not open up and lacks power		Any of Faults 6, 7, 18 or 19.
	30.	Main jet blocked.
	31.	Petrol shortage.
	32.	Choked exhaust system.
Engine misfiring and spitting back		All ignition faults.
	33.	Unsuitable sparking plugs. All carburation faults.
	34.	Weak mixture.
	35.	Throttle not opening fully.
Engine overheats	36.	Engine tight.
	37.	Fan faulty - blades bent or belt slipping.
	38.	Cooling system faulty - radiator blocked, pump not working.
	39.	Slipping clutch or binding brakes.

Continued/

ENGINE RUNNING NORMALLY

Engine cuts out suddenly.	Usually electrical fault.
Engine dies out gradually.	Usually carburation fault.
Mechanical noise:-	
Medium low pitch knock	Big end bearing wear.
High pitch tap	Worn gudgeon pins.
Low pitch thud	Main bearing slack.
Intermittent thuds	Loose fly wheel or end play on crankshaft.
Shrill squeaking	Distributor cam.
Whistling or hissing	Air leaks in induction system.
Continuous tapping	Excessive valve clearances.

Diesel Engines - Fault Tracing

Diesel (Compression Ignition) Engine
Fault Tracing Chart

ENGINE WILL NOT START

Starter will not turn engine	1.	Battery discharged or corroded terminals.
	2.	Starter switch contacts faulty or loose connections.
	3.	Starter motor brushes or commutator faults.
Starter only turns slowly		Any of Faults 1, 2 and 3.
	4.	Engine partially seized.
Starter turns engine normally	5.	Lack of fuel
	6.	Choked filter.
	7.	Faulty fuel supply pump.
	8.	Air lock in fuel system.
	9.	Injection pump fault.
	10.	Loss of compression - defective valves.

Continued/

Diesel (Compression Ignition) Engine Fault Tracing Chart (Continued)

		FAULTY RUNNING
Erratic running		Any of Faults 8, 9, 10 and 11.
	12.	Leaks in fuel system.
	13.	Poor engine compression.
	14.	Water in fuel.
Lack of power		Any of Faults 6, 7, 8, 9, 11, 12 and 13.
	15.	Injection pump timing incorrect.
		ENGINE RUNNING NORMALLY
Excess fuel consumption		Any of Faults 12, 13, and 15.
	16.	Engine valve clearances need adjustment.
	17.	Fuel injection pump needs adjustment.
	18.	Fuel injection pump governor set wrongly.
	19.	Fuel supply controls set wrongly.

Continued/

Diesel (Compression Ignition) Engine Fault Tracing Chart (Continued)

		Fault 8
Excessive knocking (deonation)	20.	One or more injectors sticking.
	21.	Lack of water in cooling system.
	22.	Lack of engine lubricating oil.
	23.	Start of injection too far advanced.
	24.	Excessive carbon deposit.

Mechanical noise:-

Low pitch knock	Big end bearings worn.
Low pitch thud	Main bearing worn.
Intermittent thuds	Loose flywheel or excessive crankshaft end play.
High pitch tap	Worn gudgeon pins.
Continuous light tapping	Excessive valve clearances
Continuous slapping	Excessive piston clearance - may disappear when engine warm.

INDEX - Group 3 (M & E) - Miscellaneous

Planned Preventative Maintenance (P.P.M.)

Adequate maintenance can only be carried out on a satisfactory basis if planned. The following guidelines are suggested for instituting P.P.M. (Planned Preventative Maintenance) for vehicles, pumps and other equipment and installed plant.

1) List all equipment which needs regular maintenance and establish realistic frequencies for maintenance tasks.

2) Ensure, as far as practible that the need for frequent maintenance is 'designed out' by choosing equipment suitable for its duties and environment.

3) Determine those tasks of 'first line' routine maintenance, e.g. lubrication, gland packing, leakages, blockages, meter reading, which operational staff should be trained to carry out.

4) Fit 'fail safe' controls to avoid extensive damage from predictable causes, e.g. low voltage and phase-failure trips to protect motors, low water level trips to protect borehole pumps.

5) Plan safe working conditions and access to allow all maintenance tasks to be carried out.

6) Ensure that drawings and instructions are readily available.

Vehicle Maintenance and Loading

The following note refers specifically to Land Rovers, but the principles apply to other vehicles.

Maintenance

Every vehicle should be regularly serviced and in countries where temperatures are high and conditions are dusty, service intervals should not exceed 4000 km's (2500 miles).

It is of particular importance that drivers examine their vehicles on a regular basis between services and that any change in vehicle handling is noted and investigated. The sooner faults are rectified the less the chance of transfer of loading onto other components, causing a domino effect.

The checks that should be carried out on a regular basis are:

(a) Engine Compartment

- (i) Levels of oil in engine, gearbox and axles
- (ii) Levels of fluid in brake clutch and radiator reservoirs, investigate further if levels are down
- (iii) Drive belts
- (iv) Fuel sedimentors for water
- (v) Air filter (especially in dusty conditions)

(b) Suspension

- (i) Leaks on shock absorbers
- (ii) Suspension bushes
- (iii) Springs and spring fixings
- (iv) Look for uneven tyre wear
- (v) Tyre pressures and tyre condition (inc. spares)

(c) Steering

- (i) Wear on steering bushes and joints
- (ii) Alignment or toe in. Ensure that on major services caster and camber angles are checked

General

All lights including brake indicator

(i) Look around for fluid leaks, especially on brake system
(ii) Wear on drive system ie. universal joints
(iii) If soft pressures are ever used vehicle speed should not exceed 40 kph (25 mph)

Loading

Overloading or incorrect loading can have serious consequences for the vehicle and its driver and passengers. Care should always be taken to ensure that manufacturers weights are not exceeded and that loads are correctly distributed.

The total or GVW for which the LandRover is designed is 3050 kg. This consists of the kerb weight and payload and the following payloads are applicable:-

(a)	110 Station Wagon	1081 kgs
(b)	110 Pick Up	1211 kgs
(c)	110 High Capacity Pick Up	117 kgs

But equally important is the fact that the vehicle designed to have maximum axle weight of 1200 kg at the from and 1850 kg at the rear. So the actual load you can carry may be limited by the axle load factor.

Since in the field you will not have a weighbridge a practical guide is a correctly fully loaded LandRover should have about 50 mm (2") between the front bumper rubber and axle pad and 75 mm (3") clearance at the rear. The load should also be distributed with weight concentration forward of the rear axle.

If a roof rack is fitted the maximum load is 150 kg which includes the weight of the rack itself and it should be remembered that a roof rack allows you to carry more volume not extra weight. The roof rack should not be loaded on an empty vehicle and should not extend over the bonnet of the vehicle.

A vehicle overloaded or badly loaded can have serious consequences by causing unnecessary stress in the chassis and suspension, uneven wear in suspension components and serious imbalance when manoeuvring the vehicle over rough terrain.

Pump and Valve Maintenance

A. General

1. Pumps (of any type) should be inspected at regular intervals - before faults or output reduction occurs.

2. When dismantling pumps or any mechanical equipment cleanliness is essential lay parts on a clean board or sheet when dismantling.

3. Brass nuts should be used if possible lightly grease bolt threads before assembly and if necessary drill and pin the nut to prevent it working loose.

4. Screw valves can be either right left hand closing and the valve should have an appropriate indication on the valve wheel. Valves should never be left hard open against the stop as they can become jammed.

5. Non return (reflux) valves should need little attention but remove the cover occasionally and clear any accumulated scale or dirt.

6. Relief valves also should need little attention but turn the adjusting screw for setting the relief pressure from time to time to prevent its becoming seized up. If possible the relief valve discharge should be piped to the suction. The relief valve setting should be 10% above the normal maximum pressure.

7. Pressure reducing valves will usually be of the spring operated type but are not too accurate or reliable. The spring seating and adjustment, and the freedom of operation of the valve, must be checked frequently.

8. Check the operation or air release valves and air vents on storage tanks periodically.

B. Positive Displacement Pumps

1. There should be isolating valves on all positive displacement pumps (i.e.reciprocating ram or piston or Mono type) which must of course be open when starting the pump (whereas on a centrifugal pump the pump may be started against a closed delivery valve to reduce engine/motor starting load)

2. A pressure gauge, should be fitted on the delivery side of the pump and a compound or vacuum gauge on the suction; oscillating pressures will cause the gauges to flicker excessively if a cushioning arrangement such as an air bottle has not been installed, in which event try shutting the control cock slightly.

3. Although reciprocating pumps are self priming, valve glands on the suction side should be kept reasonably tight to prevent air ingress.

4. If the pump is belt driven it is important that the belt tension is kept to the supplier's recommendation - too tight will cause heaving damage and too slack belt slip.

C. Air Compressors

1. Correct type (non-detergent) and viscosity of lubricating oil and correct levels should be maintained. Too much oil in the sump will cause inlet and outlet valves to stick, and may also affect the loading/off loading control valve.

2. If there is continuous requirement for the air the compressor should be of a capacity that it does not need to run more than ½ at a time.

3. If there is an air receiver it should have a relief value set about 10% above the maximum working pressure. Air receivers should be fitted with a drain which should be opened daily to evacuate accumulated water.

4. Air compressors get hot and it is therefore essential that they are sited in a well ventilated space.

5. Compressors are very susceptible to suction conditions and care should be taken that the suction (inlet) filter is kept clean. Inlet, outlet valves also are critical and their seating has to be perfect, otherwise the compressor will be worked excessively and may not attain its proper working pressure.

6. As a general rule compressors and pneumatic equipment requires very much more maintenance than an oil pump and hydraulic system.

Hand Tools

Most field offices will have access to a commercial repair shop/workshop, but a basic set of hand tools is always useful, and the following is offered as a check list:

- Socket set
- Universal joint sockets
- Ring spanners
- Open spanners
- Combination spanners
- Screw drivers (straight and Phillips)
- Electricians screw drivers
- Allen keys
- Taps and dies set
- Breast drill
- Files (flat and round)
- Adjustable wrenches
- Pliers
- Chisels and punches
- Hammers
- Hacksaws
- High speed twist drills
- Pipe wrenches
- Chain wrenches
- Extractors
- Tin snips
- Pop rivet kit
- Valve lapper and feeler gauges
- Vice
- 12V. inspection lamp