TECHNICAL HANDBOOK

ON

PRESSURIZED IRRIGATION TECHNIQUES

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FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS

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Preface

Eradication of hunger and food security for all is FAO's main objective. Water and food security are intimately connected and irrigated agriculture has been an extremely important source of food production over recent decades. Food requirements will increase in future, while global water resources are limited. Therefore, to make the best use of water for agriculture and to improve irrigation efficiency is a prerequisit for the future. Shifting from surface irrigation to pressurized irrigation will contribute substantially to the above goal.

The objective of this handbook is to provide a very practical guide to irrigation and agriculture technicians and extension workers in the field. The binder format of the handbook will permit future update of individual chapters, which may become necessary with the rapid changing pressurized irrigation technology.

Within the Land and Water Development Division of FAO, the following people have contributed to the CD-ROM: Andreas Phocaides, Irrigation Consultant, Davide Casanova, FAO Junior Irrigation Expert, Simone Morini, New Media Expert, and Reto Florin, Chief, Water Resources, Development and Management Service.

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CHAPTER 1: Introduction

In the Proceedings of the Consultation on Irrigation in Africa (Lomé, Togo, 1997) irrigation was defined as “the application of water supplementary to that supplied directly by precipitation for the production of crops”.

Although clearly defined, irrigation has not been clearly identified and separated from the wide-ranging area of water development activities, such as major and minor constructions for water harvesting, storing, conveyance and allocation; the drilling of tube-wells; and pumping. Most of the efforts and investments made in many countries for irrigation development result in water resources development and very few in on-farm water use improvement.

The application of improved irrigation methods and techniques on small farms is expanding rapidly as a result of the increasing demand for higher irrigation efficiency, improved utilization of water and intensification and diversification of production.

An irrigation system consists of canals and structures to convey, regulate and deliver the water to the users. Two basic types of irrigation systems exist: open canal systems and pressured piped systems. This book concentrates in the latter one.

Experience gained from many countries in arid and semi-arid zones has shown that pressure piped irrigation techniques are replacing successfully the traditional open canal surface methods at farm level.

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FIGURE 1.1 - Wasteful surface irrigation method

CHAPTER 2: Pressure Piped Irrigation Techniques

PRESSURE PIPED IRRIGATION SYSTEMS

A pressure piped irrigation system is a network installation consisting of pipes, fittings and other devices properly designed and installed to supply water under pressure from the source of the water to the irrigable area.

The basic differences between traditional surface irrigation and piped irrigation techniques are:

- The water flow regime: With traditional surface methods the size of the stream should be large, while in pressure piped irrigation systems very small flows, even 1 m^3/h, can be utilized.
- The route direction of the flow: With traditional surface methods the irrigation water is conveyed from the source and distributed to the field through open canals and ditches by gravity following the field contours. The piped system conveys and distributes the irrigation water in closed pipes by pressure following the most convenient (shortest) route, regardless of the slope and topography of the area.
- The area irrigated simultaneously: With traditional surface methods the water is applied in large volumes per unit of area, while piped irrigation systems distribute the water at small rates over a very large area.
- The external energy (pressure) required: Traditional surface gravity methods do not need external energy for operation, while piped irrigation systems require a certain pressure, 2-3 bars, which is provided from a pumping unit or from a supply tank situated at a high point.

NETWORK LAYOUT

The pipelines that convey and distribute the irrigation water to the individual plots are usually buried, and are so protected from farming operations and traffic hazards. Offtake hydrants, rising on the surface, are located at various spots according to the planned layout. With surface methods the irrigation water can be delivered directly to the open ditches feeding the furrows or the basins.

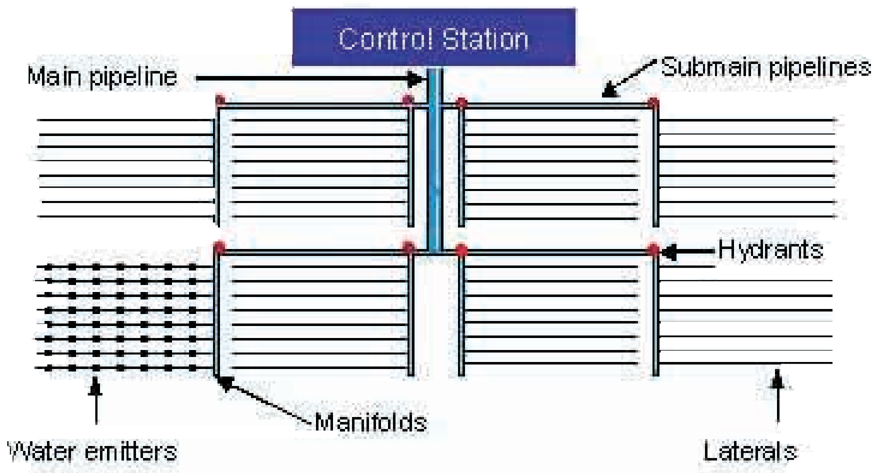
In micro-irrigation and other complete systems, e.g. sprinkler, the hydrants are coupled with smaller manifold feeder pipelines placed along the edges of the plots. These feed the lateral irrigating lines which are laid along the plants rows perpendicular to the manifolds. The laterals are equipped with water emitters at frequent spaces and distribute uniformly the irrigation water to the plants under certain pressure.

There are many kinds of irrigation systems. However, a thorough examination of the various system layouts, the equipment and the principles in operation shows that the same approach is always employed from the planning procedure to their application and that all of them have most of their features and components parts in common.

In all piped systems the main component parts (Fig. 2.1) are:

- the control station (head control unit);
- the mains and submains (pipelines);
- the hydrants;
- the manifolds (feeder pipelines);
- the laterals (irrigating pipelines) with the emitters.

FIGURE 2.1 - Scheme of a network layout.



Head control: This consists of a supply line (rigid PVC, or threaded galvanized steel) installed horizontally at a minimum height of 60 cm above ground. It is equipped with an air release valve, a check valve, two _-in hose outlets for connection with the fertilizer injector, a shut-off valve between the two outlets, a fertilizer injector and a filter. Where a gravel filter or a hydrocyclone sand separator is needed, it is installed at the beginning of the unit complex.

Main pipeline: It is the largest diameter pipeline of the network, capable of conveying the flow of the system under favourable hydraulic conditions of flow velocity and friction losses. The pipes used are generally buried permanent assembly rigid PVC, black high density polyethylene (HDPE), layflat hose, and quick coupling galvanized light steel pipes in sizes ranging from 63 to 160 mm (2-6 in) depending on the area of the farm.

Submains: These are smaller diameter pipelines which extend from the main lines and to which the system flow is diverted for distribution to the various plots. The pipes are the same kind as the mains.

Offtake hydrants: These are fitted on the submains or the mains and equipped with a 2-3-in shut-off valve. They deliver the whole or part of the flow to the manifolds (feeder lines).

Manifolds (feeder lines): These are pipelines of a smaller diameter than the submains and are connected to the hydrants and laid, usually on the surface, along the plot edges to feed the laterals. They can be of any kind of pipe available (usually HDPE) in sizes of 2-3 in.

Laterals (irrigating lines): These are the smallest diameter pipelines of the system. They are fitted to the manifolds, perpendicular to them, at fixed positions, laid along the plants rows and equipped with water emitters at fixed frequent spacings.

Emitters: A water emitter for irrigation is a device of any kind, type and size which, fitted on a pipe, is operated under pressure to discharge water in any form: by shooting water jets into the air (sprinklers), by small spray or mist (sprayers), by continuous drops (drippers), by small stream or fountain (bubblers, gates and openings on pipes, small diameter hoses), etc.

These component parts replace the ones in the traditional surface systems, i.e. the main gate, the main and submain canals, the canal gates the field ditches, and the furrows or the basins, respectively.

FIGURE 2.2 - Improved surface irrigation method with pipes.

SYSTEM CLASSIFICATION

Piped irrigation systems are classified according to the pressure required for operation, the method of delivering water to plants, and the type of installation.

a. Pressure

The pressure of the system is the maximum water pressure required for normal system operation and encompasses: a) the friction losses in the piping network from the control station to the distal end of the system; b) the pressure required at the emitter; and c) the difference in elevation (plus or minus). Systems can be classed as:

- low pressure systems, where the pressure required is 2.0-3.5 bars;
- medium pressure, where the pressure required is 3.5-5.0 bars;
- high pressure, where the pressure required exceeds 5.0 bars.

b. Water delivery method

The water delivery method is the way the water is distributed to the plants. Systems can be classed as:

- Sprinkler (overhead) irrigation. The water is delivered in the form of raindrops precipitated over the entire area. There are many variations of this method in terms of the discharge and diameter coverage, the height of the water jet above ground (overhead, under the foliage), the type of sprinkler mechanism, etc.
- Surface irrigation (furrow, basin, border, etc.). The water is delivered to the field plots direct from the main or submain pipelines through the hydrants and it is spread all over the area, or it is side applied.
- Micro-irrigation (localized irrigation) by drippers, sprayers, bubblers, microjets, etc. The water is delivered to the plants without being spread over the entire area but by being applied in low rates to a limited soil surface area around the plants.

The water delivery method and the kind of the water emitter are the main characteristics of a piped irrigation system. In many cases they influence and specify the other characteristics (pressure and type of installation) and performances, such as the flow capacity of the system and the duration of application.

The flow capacity of a system is the water flow (in cubic metres per hour or litres per second) given, or designed to meet the irrigation requirements of the irrigable area at peak demand. It is inversely proportional to the duration of application. Where designed, it is usually the minimum permissible in order to economize on pipe size and other equipment. The duration of application is the time required for the completion of one irrigation cycle.

c. Type of installation

Systems can be classed as:

- Solid installations (fixed systems), where all the components are laid or installed at fixed permanent or seasonal positions.
- Semi-permanent installations, where the mains and submains are permanent while the laterals are portable, hand move or mechanically move.
- Portable installations, where all the component parts are portable.

PIPED IRRIGATION TECHNIQUES COMPARED WITH TRADITIONAL IRRIGATION METHODS

Irrigation efficiency: In open canal distribution networks, the water losses are estimated at up to 40 percent in unlined ditches and up to 25 percent in lined canals. These losses are due to seepage, phreatophytes and leakage in gates, spillways, etc. In piped systems, no such losses occur. During the application to the plants, the water losses range from 10 percent in localized micro-irrigation to 30 percent in overhead conventional sprinkler and surface methods. As a result, water losses can be minimized and an irrigation efficiency of 75-95 percent can be achieved. In open canals, the irrigation application efficiency ranges from 45 percent to a maximum of 60 percent.

Economic return per unit of water. Piped systems facilitate the manipulation of the irrigation water under more favourable conditions than do open canals. This can result in a yield increase of 10-45 percent and an improvement in quality.

Operation and maintenance (O&M). The man-hours needed in the piped systems range from one-tenth to one-quarter of those required for open canals. Any person can easily operate the piped systems, while the open canals can require skilled labour. In the open canals, expensive operations are carried out to prevent damage caused by roots; seepage through banks; the spread of weeds; siltation and sedimentation; clogging of outlets and gates; etc. In the piped systems, no maintenance or continuous repair of constructions is required. The basic component parts of the piped systems require minimal maintenance during the first seven years. The complete piped system requires a yearly maintenance costing about 5 percent of the initial investment.

Cost: The use of thermoplastic pipes and fittings, made of unplasticized polyvinyl chloride (rigid PVC), low density polyethylene (LDPE), high density polyethylene (HDPE), and polypropylene (PP), which are manufactured in almost every country in many sizes and classes, has reduced the cost of piped irrigation installations to a relatively low level at a time when open canal networks are becoming increasingly expensive.

The initial capital investment for the application of these techniques varies according to the method of irrigation and the type of the installation. The cost of the solid installations for localized methods is higher than that of the semi-portable hand-move sprinkler systems and the piped networks for surface methods. The costs for various piped irrigation systems installations in Europe are presented in Table 1 and the average percentage costs of the various parts of a piped system calculated on the basis for smallholdings (about 1.0 ha) are presented in Table 2. A detailed cost analysis of all the kinds and types of the piped systems has shown that the pipes (laterals included) account for about 50 percent of the total cost of the system.

The design complexity and the multiplicity of costly equipment is only apparent. The technology of piped irrigation systems is simple and flexible, and the investment yields a good return. Several mechanical difficulties are to be expected in the early stages. Subsequently, the farmers become familiar with the system's features and components and make the best use of it. The application of piped irrigation techniques produces a drastic change in irrigation management practices at farm level.

FIGURE 2.3 - Modern irrigation techniques.

FIGURE 2.4 - Sprinkler irrigation techniques.

TABLE 1 - Comparative costs of piped irrigation systems

	Piped surface method			Sprinkler conventional hand-move			Micro-irrigation solid installation		
Area (ha)	1	1-2	2-3	1	1-2	2-3	1	1-2	2-3
Installation cost (US$/ha)	1 700	1 600	1 400	2 800	2 700	2 100	3 950	3 300	3 000
Annual maintenance cost (US$/ha)	85	80	70	140	135	105	200	165	150

Note: Average 1997 prices in Europe.

TABLE 2 - Cost breakdown for piped irrigation systems

Component parts	Sophisticated installation	Simple installation
Control station	>23%	13%
Mains, submains and manifolds	10%	21%
Fittings and other accessories	22%	24%
Laterals (pipes and emitters)	45%	42%

CHAPTER 3: Irrigation equipment and jointing techniques

INTRODUCTION

Irrigation system installations consist of various pipes, fittings, valves and other equipment depending on the kind of system and the type of installation. Most installations have the same structure, and thus a relatively small range of equipment can meet the requirements of a whole region.

Irrigation equipment can be divided into:

- pipes;
- pipe connector fittings;
- flow control devices;
- filters;
- fertigation equipment;
- water emitters;
- automation equipment;
- operation equipment;
- water-lifting devices.

The main characteristics of the irrigation equipment are:

- material, e.g. galvanized steel, rigid PVC, etc.;
- size, i.e. the nominal diameter (DN) of the ISO metric range in millimetres (16-160 mm) and/or of the BSP threaded range in inches (_-4 in);
- type of joint, e.g. threaded, quick coupling, solvent welded, etc.;
- working pressure PN (nominal pressure) or PR (pressure rating) in bars, e.g. 6.0 bars;
- national and/or international standards conformed to, e.g. DIN, ISO, BS, ASTM.

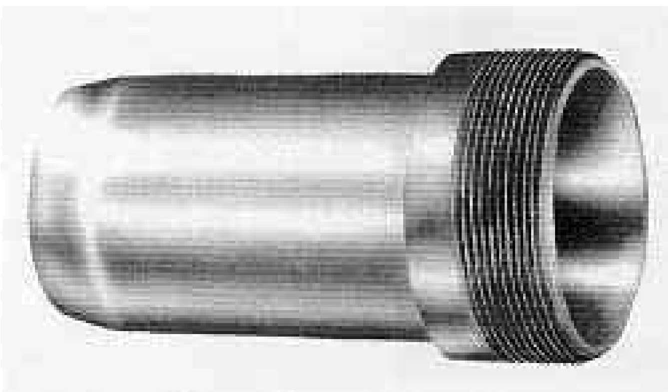
The working pressure of a pipe or a fitting is the maximum internal water pressure to which the pipe or the fitting is subjected continuously in ordinary use, with certainty that failure of the pipe will not occur. It is specified as nominal pressure (PN) or pressure rating (PR).

PIPES

The pipes are the basic component of all irrigation networks. There are various kinds and types available in many pressure ratings and in different sizes (diameters). The pipes in use for farm-level irrigation systems are mainly in rigid PVC and polyethylene (PE). Quick coupling light steel pipes and layflat hoses are used on a smaller scale. Threaded galvanized steel pipes are of limited use. All these pipes are described below.

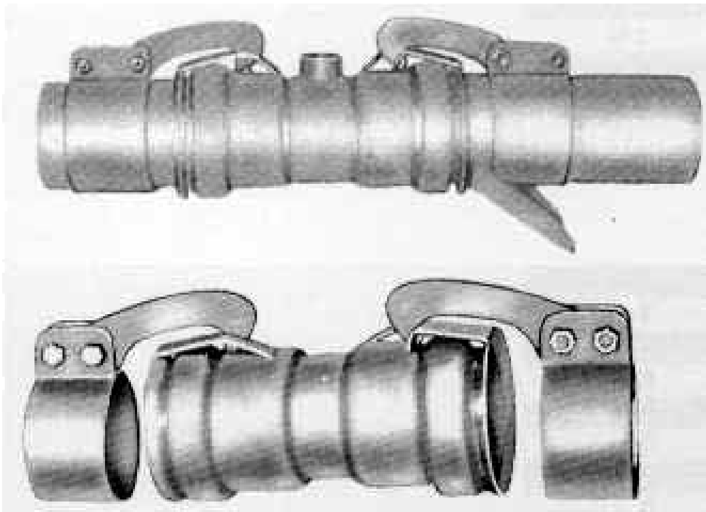
A. Steel threaded pipes. Galvanized steel pipes have been used widely in every country for all kinds of water works. In the past they were used as mains and submains in pressure piped irrigation solid installations. Due to their excellent properties, they have the ability to withstand stress, to resist high pressures and to maintain their strength for the duration of their service life, unlike plastic pipes which suffer a continuous creep strength with time and temperature fluctuations. They are not often used nowadays for irrigation because they are very expensive. However, they are useful in small pieces needed for risers in the hydrants, connector tubes in the head control units and similar applications. They are available in nominal diameters (DN), usually in inch-based series of _, _, 1, 1_, 1_, 2 in, etc., which correspond more or less to the actual bore diameter, and in several high pressure rates (classes) in accordance with various standards and recommendations (ISO R-65, BS 1387, DIN 2440/41/42, or to American Standards, etc.). Supplied in random lengths of 6 m, they are for permanent assembling with screw-type (threaded) joints. Each pipe carries an internal threaded socket. Welded hot-dip galvanized steel pipes have an average life of 15-20 years on the surface 'in the atmosphere' and of 10-15 years in soil depending on soil physical properties. There is a large range of pipe connector fittings made of galvanized malleable iron for jointing these pipes.

FIGURE 3.1 - A threaded steel pipe fitting (male adapter).



B. Quick coupling light steel pipes. These pipes are made of light rolled strip steel which has been hot-galvanized inside and outside. Each pipe is equipped with a hand-lever quick coupling welded on one end while the other end is arranged accordingly for water and pressureproof tight closure. The standard pipe length is 6 m and the working pressure (PN) ranges from 12.0 to 20.0 bars. They are light in weight, easy to install and remove, and they are used as mains, submains, manifold feeder lines and laterals with sprinklers. They have a full range of pipe connector fittings of the same type of joints. They are available in many sizes and in diameters (DN) of 70, 76 and 89 mm, which are convenient for farm-level pressure irrigation techniques.

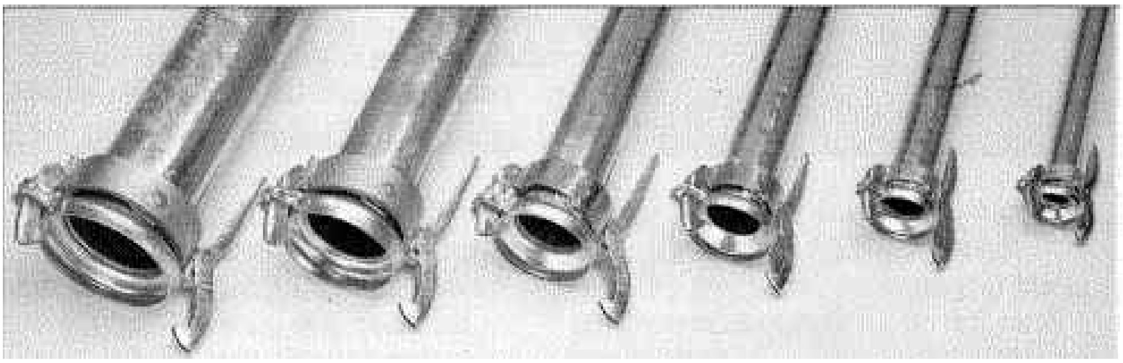
FIGURE 3.2 - Quick coupling light steel galvanized pipes and fittings.



C. Quick coupling aluminium pipes. They are mostly used, always above ground, as moveable lateral lines in sprinkler irrigation portable installations. Made of aluminium alloy by extrusion or by fusion welding, they are light in weight (about half that of the light steel ones), relatively strong and durable. In accordance with ASAE S263.2, they are manufactured in nominal diameters quoted in inches, corresponding to the outside pipe diameter, of 2, 3, 4, 5 and 6 in (51, 76, 102, 127 and 159 mm). The minimum working pressure is 7.0 bars. In accordance with ISO 11678, the same sizes in the metric series are 50, 75, 100, 125 mm and so on with working pressures of 4.0, 10.0 and 16.0 bars. They are supplied in standard lengths of 6, 9 and 12 m, complete with aluminium quick couplings. These are either detachable by means of clamps and rings, or permanently fixed on the tubes. With the use of U-shaped rubber gaskets, the couplings seal automatically under high water pressure during operation and drain in pressures below 1.0 bar. There are several types of quick couplings which allow the farmer to couple or uncouple the connections from any location along the pipe.

The most widely used are the latch system (single or dual), with a _ or 1 in threaded outlet for sprinkler risers, or hose extensions. Quick coupling provides a high degree of flexibility to aluminium pipelines laid on uneven ground. The expected life of these pipes is 15 years under good management. The light portable quick coupling pipes, steel or aluminium, can be used not only as sprinkler lateral lines, but also as water conveyance and distribution lines. In micro-irrigation systems they are often used as manifolds. These pipes maintain their value for a considerable length of time. Indeed, some cases have been reported of farmers selling many of these pipes at a profit even after extensive use.

FIGURE 3.3 - Quick coupling aluminium pipes.



D. Rigid PVC pipes. Extruded from unplasticized polyvinyl chloride, also called uPVC, these pipes are ideal for irrigation, (cold) water conveyance and distribution lines as mains and submains. In many cases they can also serve as manifolds and laterals. Very light in weight, they are easy to transport and to handle on site. Their only limitations are that they must always be laid permanently underground, protected from high or very low ambient temperatures and solar radiation. The maximum flow velocity should not exceed 1.5 m/s. They are manufactured in standard lengths of 6 m, and in several series and classes denoting the working pressure, in accordance with various national and international standards applied in Europe, the United States and elsewhere (ISO 161-1/2: 1996, ISO 3606, BS 5556, DIN 8062, ASTM D 2241, ANSI/ASAE S376.1, ANSI/ASTM D 1785). These standards, although equivalent to each other, vary in the pipe dimensioning, i.e. the pipe's actual diameter, the working pressure (PN), the safety factors, etc. In the United States, thermoplastic pipes are mainly classified in terms of SDR (standard dimension ratio between the pipe's outside diameter and the pipe wall thickness) and schedules (for higher pressures). In Europe, the hydrostatic design stress (hoop strength) of PVC common material is 100 bars. In the United States, several compounds are used with different stress values, thus a great variety of pipes are produced, all in inch sizes. In accordance with the European standards and ISO 161, rigid PVC pipes are available in nominal diameters (DN), which is the approximate outside diameter, in 50, 63, 75, 90, 110, 125, 140, 160, 200 and 225 mm. The working pressures are 4.0, 6.0, 10.0 and 16.0 bars at 24°C. At higher temperatures, the working pressures decrease accordingly. Usually, small diameter pipes up to 50 mm and inch-sized pipes have one end plain with a preformed socket at the other end for solvent cement welding. Larger diameter pipes have a tapered spigot at one end while the other end consists of a wall-thickened, preformed grooved socket with a rubber sealing ring for a push-fit integral mechanical joint. There is a complete range of connector fittings for these pipes; some made of uPVC and others of cast iron. The compression-type polypropylene (PP) fittings are also suitable for uPVC pipes up to 110 mm. All the fittings and the valves of underground PVC pipelines should be thrust blocked to prevent them from moving whilst in operation due to the thrusting force of the water pressure. The estimated average life of buried uPVC pipes is 50 years.

Rigid PVC pipes are made for underground installation, where they are protected from temperature changes and hazards imposed by traffic, farming operations, etc. The trench should be as uniform as possible, firm, relatively smooth and free of large stones and other sharp edged material. Where ledge rock or hardpan is encountered, the trench bottom should be filled with embedment material, such as compacted grained soil or sand, to provide a bed depth of about 10 cm between pipe and rock. The minimum depth of cover should be 45 cm for pipes up to 50 mm, 60 cm for pipes up to 100 mm, and 75 cm for pipes over 100 mm DN. Where rigid PVC pipes are installed under roads, the depth of cover should not be less than 1 m; otherwise the pipes must be sleeved in a protective steel tube.

FIGURE 3.4 - Rigid PVC pipes.

E. Polyethylene (PE) pipes. Flexible black PE pipes are extruded from polyethylene compounds containing certain stabilizers and 2.5 percent carbon black which protect the pipes against ageing and damage from sunlight and temperature fluctuations. LDPE (low-density resin) pipes are also known as soft polyethylene and PE 25, while HDPE pipes (high-density resin) are more rigid and known as hard polyethylene or PE 50 (the numbers correspond to the pipe material's hydrostatic design stress). They are manufactured in accordance with various standards in inch-based and metric series (ISO 161-2, DIN 8072/8074, etc.) Both sorts have proved successful in pressure piped irrigation techniques and are the predominant kind of pipes in micro-irrigation systems. All laterals with micro-emitters are LDPE pipes (hoses) of 12-32 mm. HDPE pipes of larger diameters are used for main lines, submains and manifolds. They are also often used as water conveyance pipelines. LDPE pipes are less affected by high temperatures than HDPE pipes are. PE pipes are supplied with plain ends in coils of 50-400 m, depending on the diameter. Laid on the surface, they have a service life of 12-15 years. Conforming to European and international standards, they are available in the following sizes and working pressures:

DN (external diameter) millimetres:
12, 16, 20, 25, 32, 40, 50, 63, 75, 90 and 110;

PN (working pressure) bars:
2.0, 4.0, 6.0, 10.0 and 16.0.

Jointing PE pipes is simple. A full range of PP connector fittings is available in all diameters and types suitable for pressures from 2.0 to 10.0 bars.

FIGURE 3.5 - Polyethilene pipe in a coil.

The manufacturers of PVC and PE pipes recommend that the maximum flow velocity in the plastic pipes should not exceed 1.5 m/s. Based on this recommendation, Table 3 presents the flow rates in various plastic pipes with a flow velocity of 1.7 m/s, which should be taken as the maximum permissible under normal operating conditions.

TABLE 3 - Maximum recommended flow in plastic pipes without outlets

Rigid PVC 6 bars (DIN 8062)	DN mm	63	75	90	110	125	160
	Inside d. mm	59.2	70.6	84.6	103.6	117.6	150.6
	m_/h	17	24	34	51	66	109
HDPE 6 bars (DIN 8074)	DN mm	50	63	75	90	110	
	Inside d. mm	44.2	55.8	66.4	79.8	97.4	
	m_/h	9	15	21	30	45	
LDPE 4.0 bars DIN(8072)	DN mm	16	20	25	32		
	Inside d. mm	12.4	16.4	20.6	27.2		
	m_/h	0.75	1.3	2.0	3.5		

V = 1.7 m/s

F. Layflat hose. Layflat tubing has been used in irrigation for a number of years. It is an alternative to rigid PVC pipes for surface use as water conveyance lines, mains and manifolds, in drip and other low pressure micro-irrigation installations. It is made of soft PVC reinforced with interwoven polyester yarn. Layflat hoses are flexible, lightweight, and available in various sizes (millimetres or inches) from 1-6 in and for working pressures (PN) of 4.0-5.5 bars. They are manufactured with plain ends and supplied in coils in standard lengths of 25, 50 and 100 m.

There are no special connector fittings for layflat hoses. The hoses are connected by inserting small pieces of PE piping into the ends of the hoses, or by metallic quick couplings attached to both pipe ends. Small diameter PE tubes are used to connect laterals to the layflat manifolds. In these cases, wire ties are needed to secure the connections. However, several micro-irrigation industries have designed and manufactured special connector fittings for jointing their drip lines with layflat hoses.

FIGURE 3.6 - A layflat hose.

PIPE CONNECTOR FITTINGS

A. Malleable iron threaded. These fittings are made for use with galvanized steel threaded pipes and they are available in a wide range as elbows, bends, reducers, tees, plugs, nipples and other. They are characterized by toughness and ductility and they provide a sound joint able to withstand pipeline expansion and contraction and other stresses. They are manufactured with screw type joints male and female (taper threads) in accordance with BS 21, DIN 2999, ISO R 7 and American standards in nominal sizes (inside diameters) as in the galvanized steel pipes. The sizes, usually quoted in inches, may be converted to millimeters i.e.. 1/2″ for DN 15mm, 3/4″ for 20mm, 1″ for 25mm, 1 1/4″ for 32mm, 2″ for 50mm, etc. Mostly they comply to BS 143&1256, DIN 2950, ISO R 49 for working pressures of minimum 14.0 bars.

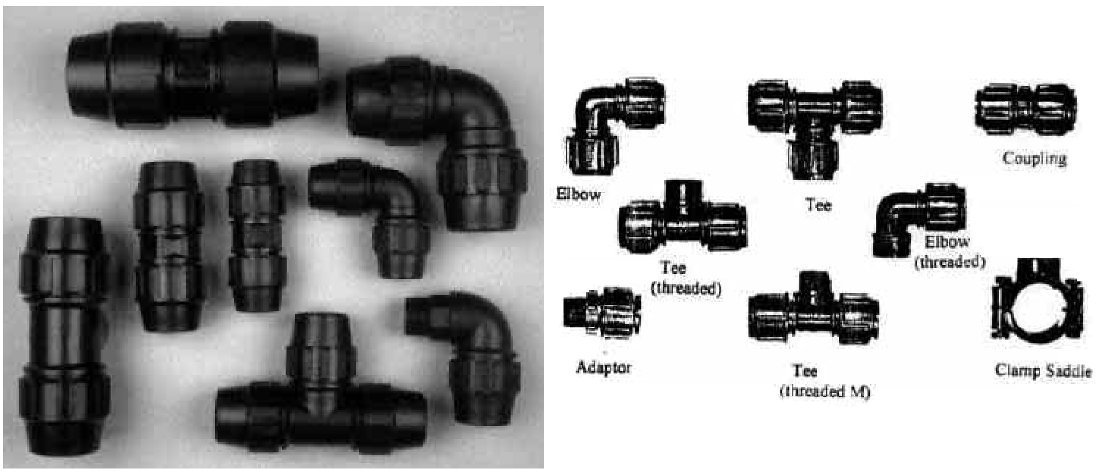
FIGURE 3.7 - Threaded galvanized steel pipe fittings.

B. Polypropylene (PP) pipe connector fittings. PP connector plastic pipe fittings (joints) are primary suitable for use with PE plastic pipes. There is a full range of all kinds, sizes and types of these pipe fittings worldwide. There are three main types with several modifications. These are:

- lock connector fittings, inserted into the pipe, with a locking ring which securely fastens the hose pipe to the fitting and can withstand high pressures;
- barbed type fittings, also inserted into the pipe, available only in small diameters up to 20 mm, and for pressures up to 2.0 bars only;
- compression quick release type, which are available in all diameters and are for high pressures, 10.0 bars. The compression fittings are also suitable for larger size rigid PVC pipes. They are easily mounted and dismantled without cutting the pipe. They are more expensive than the other fittings but last longer and can be used in several installations.

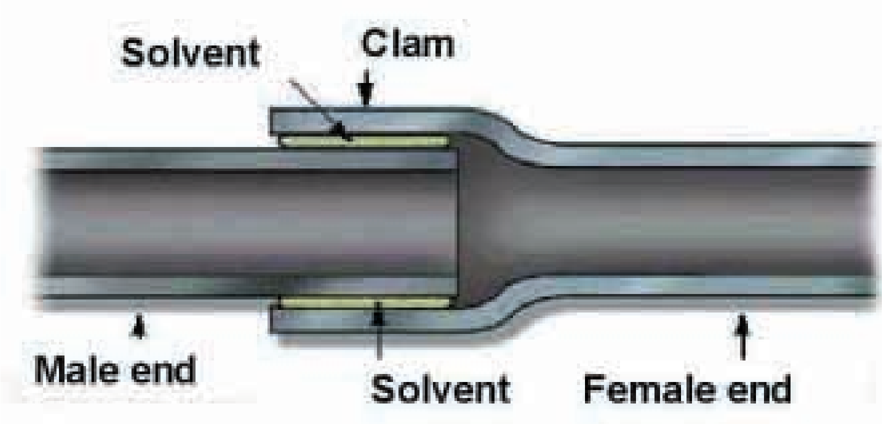
All PP connector fittings are also available with one or both ends threaded.

FIGURE 3.8 - Polypropylene (PP) fittings with a lock connector.



C. PVC fittings. Pipe fittings made of PVC are available in the inch system following the same dimensioning with the metal pipes and fittings and in the metric system (mm) conforming the ISO and DIN dimensioning. They are manufactured for solvent welding, threaded jointing and for push-fit integral mechanical jointing.

FIGURE 3.9 - PVC solvent welding pipe fitting.



FLOW CONTROL DEVICES

Any device installed in a fluid supply system, in order to ensure that the fluid reaches the desired destination, at the proper time, in the required amount (the flow rate), and under the right pressure, is called a control appliance.

As such an appliance controls proper operation of a fluid system, selecting its type, size and placement is of uppermost importance and ought to be done with the full knowledge of the various features of the device and with complete understanding of the way it performs. Equally important is proper maintenance in order to ensure faultless and sound performance of the appliance. Made of metal base material or reinforced high engineering plastics, the common flow control devices used in irrigation systems can withstand high pressures (PN 10.0-16.0 bars) with screw-type end connections with internal or external threads for in-line installation.

Fluid control devices can be divided into three main classes (Table 4):

- Directional devices or valves. These serve to directly regulate the fluid flow. Installed in the pipeline, they enable starting or stopping the flow, and setting its rate, pressure and direction. Examples of such devices are the stop valves, the check valves and the regulating valves.

- Measuring devices or valves. In order to ensure the appropriate flow regime, just regulating the flow is not enough. It is also necessary to obtain accurate information about flow parameters, so that adjustments can be made, as required, to achieve the desired flow conditions. Water and flow meters and pressure gauges belong to this group.
- Auxiliary devices. These do not directly influence fluid flow, but ensure an undisturbed functioning of a system. To this group belong air valves and safety valves.

TABLE 4 - Scheme for flow control devices.

Directional devices or valves	Shut-off valves (stop valves)	• ball valves • butterfly valves • gate valves • disk* valves (globe, angle and oblique or Y valves) • radial valves
	Check valves (non-return valves)	• swing check valve • parallel check valve
	Regulating valves**	• disk* valves (globe, angle and oblique or Y valves) • radial valves
Measuring devices	Meters	• water meters • flow meters
	Gauges	• pressure gauges
Auxiliary devices	Air valves Safety valves	

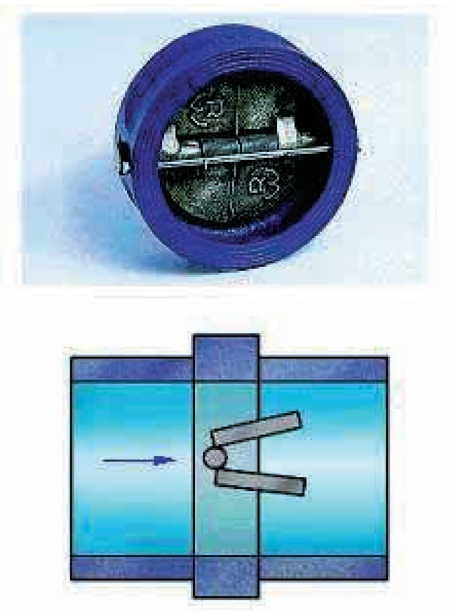
A. Shut-off valves or stop valves. They are most widely used valves, manually operated. Usually installed between the ends of two pipes they serve to start or stop the flow of fluid in the pipeline. Stop valves are primarily designed for just two extreme situations: either to be completely open, to freely pass the full flow of fluid, or to be completely closed, to prevent any flow. The most common are the gate, ball, butterfly, radial and disk valves. In gate valves, the water moves in a straight line without resistance when fully open. Gate valves are not recommended for regulating or throttling flow, they must be either fully open or full closed. Ball valves are used on a large scale in small sizes of _-2 in due to their many advantages. They feature quick on-off operation, quarter-turn and they can balance or throttle the flow. Of the disk valves, the most widely used model in irrigation networks is the oblique (Y-valve), ideal for throttling and regulating the flow. All types are made of brass in sizes of _-4 in, screw type with internal and/or external threads, at a PN of 16.0 bars. Oblique disk valves are also made of PP plastic material.

***:** *The sealing of a disk valves can be either a piston or a diaphragm.*
****:** *Regulating valves regulate pressure, flow or water level in either a direct acting or pilot operated way.*

FIGURE 3.10 - Various shut-off valves. From left to right a gate, a butterfly and ball valves.

B. Check valves. Check valves, also called non-return valves, permit flow in one direction only and prevent reversal flow in piping by means of an automatic check mechanism. They come in two basic types: the swing check, which can be installed in horizontal or vertical piping; and the lift check, for use in horizontal lines only. Water flow keeps the check valves open, and gravity and reversal of flow close them automatically. They are placed in-line at the head control unit immediately after the pump. Swing checks are used with gate valves, lift checks with disk valves. Check valves are made of several metal materials and brass, and are screw type (female joints) quoted in inches from _ to 4 in, at a PN of 16.0 bars.

FIGURE 3.11 - Scheme and photograph of a check valve.



C. Regulating valves. Regulating valves are directional, semi-automatic devices, which allow controlling pressure and flow in a water supply system. These valves operate without any intervention from the operator, but the parameters of their performance must be preset by hand or by remote control, according to the requirements of the water supply system.

Regulating valves can be divided basically in three categories:
- For reducing the downstream pressure.
- For sustaining or relieving the upstream pressure.
- As flow regulators.

A pressure reducing valve will throttle flow and maintain downstream pressure at the required level, but only if the upstream pressure is higher than the preset level. Hence, it is controlled only by the downstream pressure.

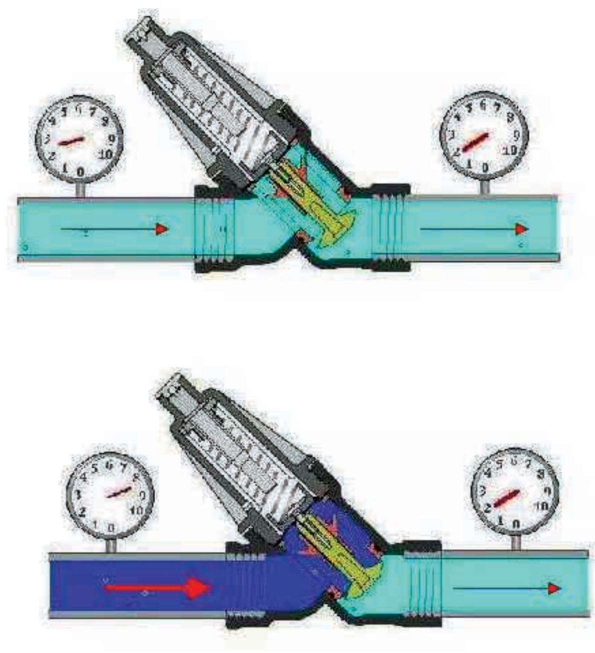
A pressure sustaining valve will maintain upstream pressure either at its maximum permitted level, by relieving the superfluous flow, or at its minimum required level, by throttling the flow. Hence, it is controlled by the upstream pressure level.

Flow regulators are in-line valves that maintain a constant predetermined flow rate, regardless of pressure changes in the system.

All the types of regulating valves work on the principle of flow throttling, being based on the principle of inverse relationship between the cross-sectional area of a flexible orifice and the line pressure. In most cases the valves are of the disk (globe, angle and oblique or Y) or the radial type. Radial valves are often preferred to disk valves. Gate, ball, butterfly and other types are unsuitable for automatic regulation.

Regulating valves are either direct acting or pilot operated. Pressure regulating valves are often installed at the entrance of the manifolds to ensure a constant operating pressure for the laterals. They are made of brass, bronze or plastic in sizes of _-3 in with threaded connections.

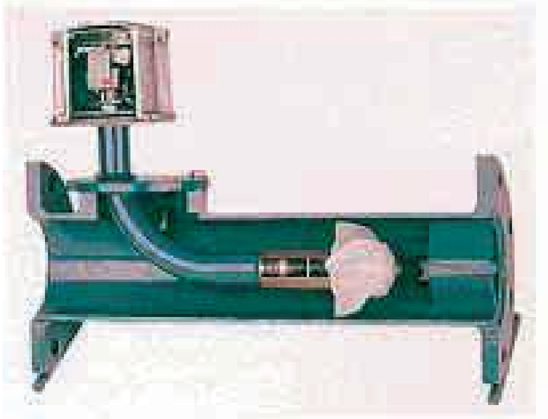
FIGURE 3.12 - A pressure reducing valve maintains downstream pressure constant when pressure upstream increases.



D. Meters. A distinction must be made between water meters and flow meters. Water meters measure and record the volumes of water passing through them, without considering the time element. Reading the output of a water meter gives information about the volume of water that passed through the appliance in a period, beginning with the last reading or zeroing of the meter. The most common type used for irrigation water is the Woltmann type with an impeller for axial flow. The velocity of flow activates the impeller and the turns are translated into total volume of water transmitted to the display dial through a series of reducing gears. They are manufactured in various designs, with the body made of cast iron, and constructed either as compact units or with an interchangeable inner mechanism. Sizes up to 2 in are available with threaded joints; larger sizes having flanges.

The flow meter measures the velocity of flow or, less often, the rate of flow or discharge. The most common type is the rotameter where a specially shaped float moves freely in a tube so that the flow velocity or rate is directly indicated by the float rim.

FIGURE 3.13 - Cross-section of a water meter.



E. Pressure gauges. Measurement of pressure in key points of a network is of major importance for water system operator. The pressure gauge should be installed in easily accessible places, so that it is convenient to read and to maintain in proper working condition. The most common pressure gauge used in water supply and distribution service is the Bourdon gauge, in which the primary element is an elastic metal tube. As the pressure inside the tube increases the oval tube tends to become circular and this causes it to uncoil slightly.

FIGURE 3.14 - A Bourdon type pressure gauge.

F. Air valves. These valves are of great importance as they protect the pipe network from damage by trapped air in the system or from collapse due to a vacuum. If improperly chosen or located in a wrong place, it can also cause severe functional problems.

The presence of free air in water installations causes many difficulties in the piping system at start-up, during operation and when draining the system. Air valves are needed so that air can be either released from or admitted into the pipelines. Its operation and air flow rate cannot be influenced either by the system operator or by the performance of any other appliance. There are three main kinds of air valves:

1. Single automatic air release valves, for the continuous automatic release under pressure of the trapped air pockets accumulated at the summits of the mains. The single air valves are small in size with a 1-in threaded connection, larger sizes not being required. They are installed on risers above ground at the high points of the conveyance and mains or every 200 m.

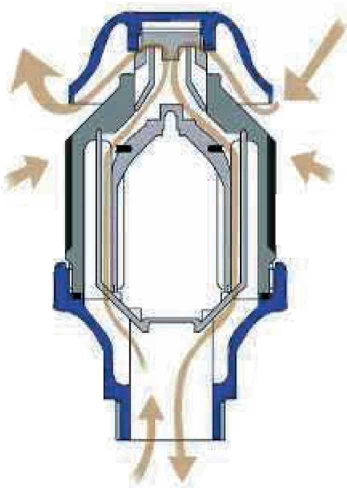
2. Large orifice air-vacuum valves (low pressure kinetic), for releasing or admitting air in bulk when filling or draining the system. They do not function under pressure. During normal operating conditions, a float held up by the system water pressure closes the large orifice. Sizes of 2 in can meet the system requirements of 160-mm pipelines. They are installed at high points of the system after the pump or the system's main service hydrant on the head control unit, and at the beginning and the end of long branch pipelines.

3. Double (dual) air valves, which are a combination of the two above. They are the safest and most efficient air valves in mains and conveyance lines during filling, draining and operating the piped irrigation systems. The 2-in size of the double air valve is appropriate for most on-farm piped irrigation installations up to 160 mm in diameter.

In addition to the above air valves, small vacuum breakers of 1/2 inch are available for preventing vacuums in drip laterals laid on the soil surface, thus protecting them from clogging.

Air valves are manufactured for high working pressures of at least 10.0 bars PN. They are installed on-line with threaded internal or external joints.

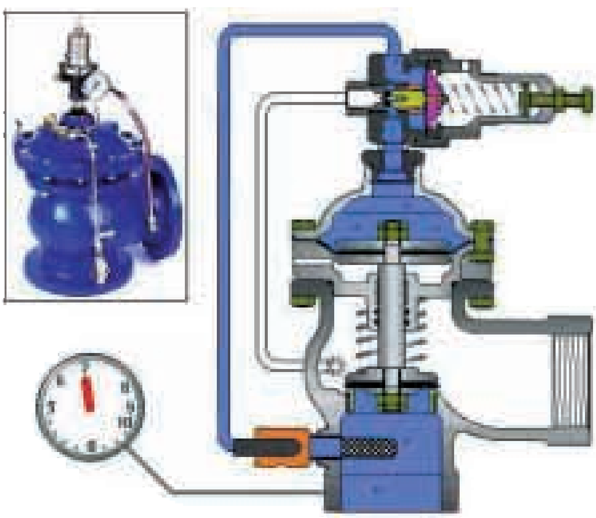
FIGURE 3.15 - Air valves operate by introducing and releasing air to the water system.



G. Safety valves (also called pressure relief valves). The practical use of safety valves began with steam boilers so that steam was released at critical pressures to avoid bursting of tanks and pipes. In water supply systems, the compressibility of water is very low and the problem of safety is therefore smaller. However, it is used mainly to ensure proper working of a system in cases of failure of other pressure control appliances.

Safety valves are on-line valves of smaller diameter than the pipelines, spring-loaded or otherwise, in which the outlet is inclined 90° to the inlet. When the pressure in the system exceeds the pre-set value, the valves open and release water into the air. Thus, they prevent the pipes from bursting due to sudden high pressures which might occur in the system. They are located immediately upstream of the main valve of the system. They are available in sizes of 1-3 in with threads.

FIGURE 3.16 - Scheme and photograph of a safe valve.

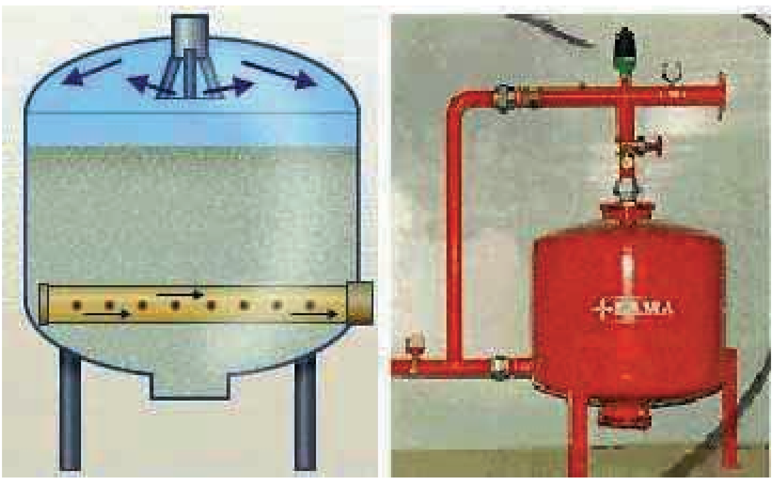


FILTERS

The filtration of the irrigation water is essential in order to avoid blockage damage to the micro-irrigation emitters. The type of filter used depends on the kind of impurities contained in the water and the degree of filtration required on the emitters. Their size should be the most economical with the lowest friction losses ranging from 0.3-0.5 bars. The following kinds of filters are available:

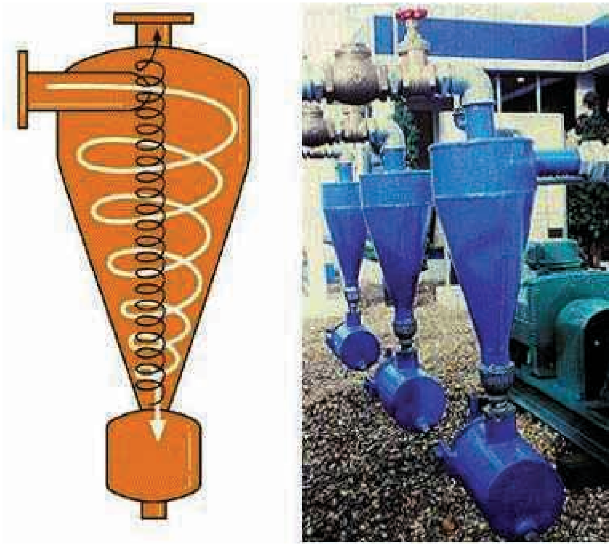
A. Gravel filters. These filters, also called media filters, are closed cylindrical tanks which contain a gravel grain of 1.5-3.5 mm or a basalt sand filter bed. Where the irrigation water source is an open reservoir, they are installed at the beginning of the head control of the system. Water entering the tank from top passes through the gravel bed, which traps the large particles of unbroken organic matter, mostly algae, and exits through the outlet at the bottom of the tank. They are equipped with the necessary inlet, outlet and drain valves, and a back-flushing arrangement. The filter body is epoxy coated metal, minimum 8.0 bars PN, and is 50-180 cm high and 40-100 cm in diameter. They are available in threaded connection sizes of 1-8 in.

FIGURE 3.17 - Scheme and photograph of a gravel filter.



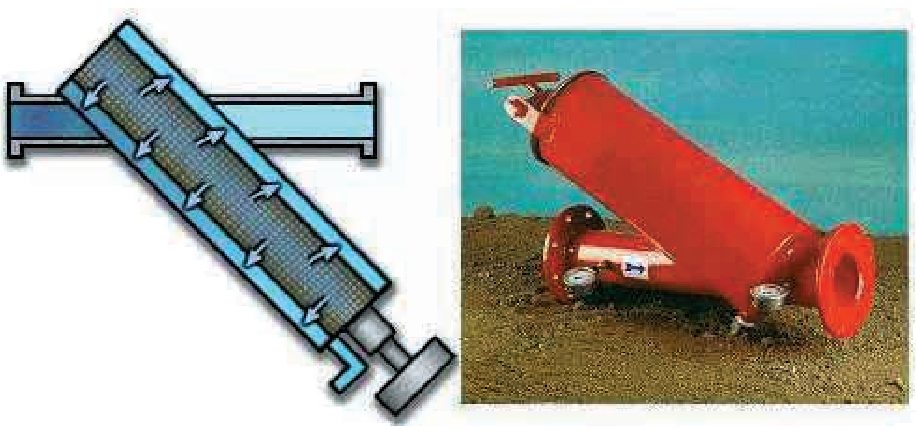
B. Hydrocyclone (sand separator) filters. These are closed conical metal tanks placed at the beginning of the head control unit where needed. They separate sand or silt from well or river water through the creation of a centrifugal force by a vortex flow inside the filter. This force drives the solids downward to a collecting chamber attached below and lets the clean water out. They are epoxy coated, PN 8.0 bars, and are available in threaded connection sizes of _-8 in.

FIGURE 3.18 - Scheme and photograph of hydrocyclones.



C. Screen type filters. These are used for final filtration as a safeguard for either moderate quality water or following a primary filtration with gravel or hydrocyclone filters. They are installed at the end of the head control before the main pipeline. They are made of epoxy coated metal or high engineering plastics in various cylindrical shapes (horizontal on-line, vertical angle, etc.), and are equipped with interchangeable perforated filtering elements, inlet, outlet and drain valves and pressure inspection gauges. They can withstand a working pressure (PN) of 8.0 bars. The degree of filtration ranges from 60 to 200 mesh (75 microns). They are available in sizes of _-4 in. Smaller sizes are made of reinforced plastic.

FIGURE 3.19 - Operational scheme and photograph of a screen filter.

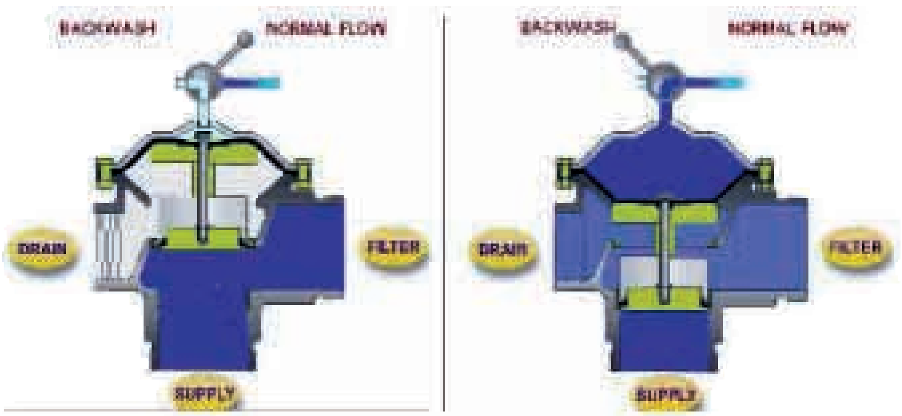


D. Disk type filters. They are cylindrical, made of reinforced plastic, horizontal in-line or vertical angle-shaped. The filtering elements consist of stacks of grooved plastic rings with multiple intersections providing a three dimensional filtration of high level. They are very effective in removing all kinds of impurities of inorganic and organic origin, algae included. The degree of filtration can range from 40 to 600 mesh (400-25 microns). They are available in all sizes (_-6 in), PN 8.0 bars, with threaded joints. They are placed at the end of the control unit before the main pipeline.

FIGURE 3.20 - A grooved disk and a disk filter.

E. Automatic self-cleaning filters. Most of the different kinds and types of filters can be supplied with an automatic cleaning capability, as determined by pressure differential, duration of filtration, volume of water filtered, or by any combination of these. The cleaning mechanism, usually back flushing, for the removal of accumulated debris uses the system's water pressure. It is activated: a) whenever the pressure difference across the filter body increases to a predetermined value, e.g. 0.5 bar; and b) at fixed time intervals with an electronic timer back-up.

FIGURE 3.21 - An automatic self-cleaning filter uses the back flushing mechanism for the removal of accumulated debris.

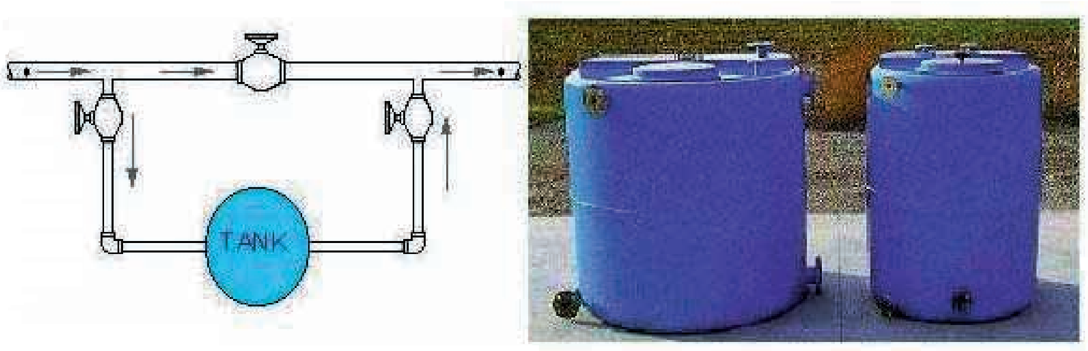


FERTIGATION EQUIPMENT.

Fertilizers are applied with the irrigation water through the system using special devices called fertilizer injectors installed at the head control. There are three main types of fertilizer injectors: closed tank, Venturi type and piston pump. All of them are water driven by the operating pressure of the system.

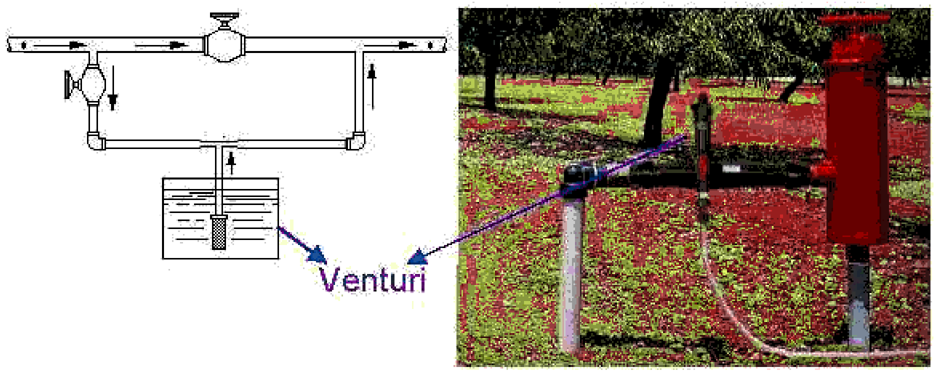
A. Fertilizer (closed) tank. This is a cylindrical, epoxy coated, pressurized tank, resistant to the system's pressure, and connected as a bypass to the supply pipe of the head control. It is operated by differential pressure created by a partially closed valve, placed on the pipeline between the inlet and the outlet of the tank. Part of the flow is diverted to the tank entering at the bottom. It mixes with the fertilizer solution and the dilution is ejected into the system. The dilution ratio and the rate of injection are not constant. The concentration of fertilizer is high at the beginning and very low at the end of the operation. However, this apparatus is still in service on a very small scale in some countries because of its low cost and easy manufacture.

FIGURE 3.22 - Scheme and photograph of a fertilizer closed tank.



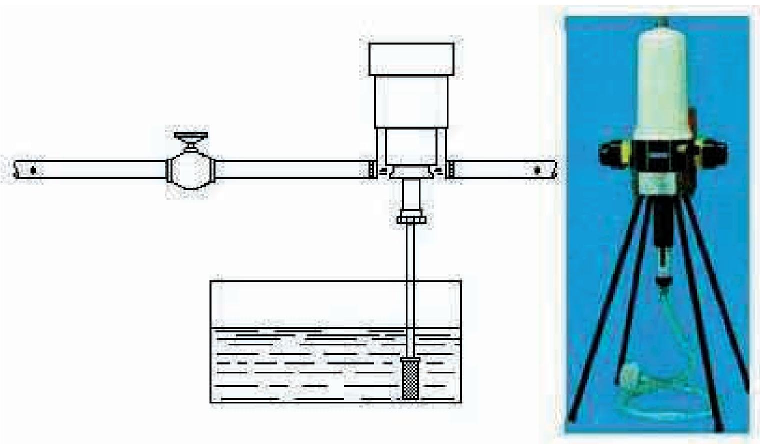
B. Venturi type. This is based on the principle of the Venturi tube. A pressure difference is needed between the inlet and the outlet of the injector. Therefore, it is installed on a bypass arrangement placed on an open container with the fertilizer solution. The rate of injection is very sensitive to pressure variations, and small pressure regulators are sometimes needed for a constant ejection. Friction losses are approximately 1.0 bar. The injectors are made of plastic in sizes from _ to 2 in and with injection rates of 40-2 000 litres/h. They are relatively cheap compared to other injectors.

FIGURE 3.23 - Scheme and photograph of a Ventury type fertilizer.



C. Piston pump. This type of injector is powered by the water pressure of the system and can be installed directly on the supply line and not on a bypass line. The system's flow activates the pistons and the injector is operated, ejecting the fertilizer solution from a container, while maintaining a constant rate of injection. The rate varies from 9 to 2 500 litres/h depending on the pressure of the system, and it can be adjusted by small regulators. Made of durable plastic material, these injectors are available in various models and sizes. They are more expensive than the Venturi type injectors.

FIGURE 3.24 - Scheme and photograph of a piston pump fertilizer.



WATER EMITTERS

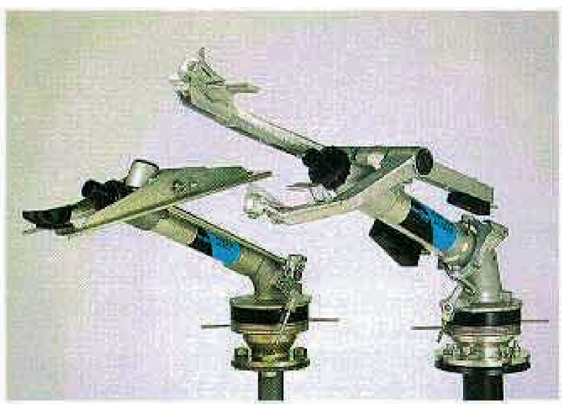
The water emitters specify the kind of system and in most cases the type of installation. Fitted on the laterals at frequent spaces, they deliver water to the plants in the form of a rain jet, spray, mist, small stream, fountain or continuous drops. All kinds and types of emitters in use now are of the small orifice-nozzle, vortex or long-path labyrinth types. Thus, the flow in the water emitters is turbulent. Some drip emitters of laminar flow used in the past are no longer available.

A. Sprinklers. Most of the agricultural sprinklers are the hammer-drive, slow rotating impact type, single or twin nozzle. The sprinklers shoot jets of water into the air and spread it to the field in the form of raindrops in a circular pattern. They are available in various nozzle sizes, flow discharges, operating pressures and wetted diameters or diameter coverage, full circle or part circle. They are classified as low, medium and high pressure/capacity, as shown in Table 5; according to the height of the water jet above the nozzle, they are divided into low angle (4º-11º), or high angle (20º-30º). They are made of brass or high engineering plastics with internal or external threaded connections of _-1_ in. They are installed vertically on small diameter riser pipes, 60 cm above ground, fitted on the laterals. The sprinkler spacing in the field is rectangular or triangular at distances not exceeding 60 percent of their diameter coverage. Filtration requirements, where necessary, are about 20 mesh.

TABLE 5 - Sprinkler classification

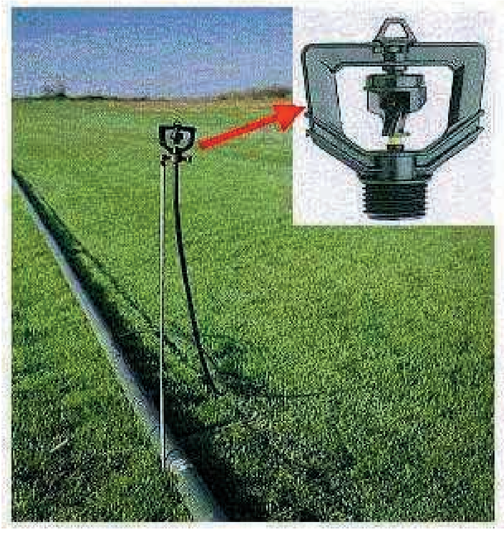
Agriculture sprinklers (two nozzle)	Nozzle size mm	Operating pressure (bars)	Flow rate (m_/h)	Diameter coverage (m)
Low pressure	3.0-4.5 x 2.5-3.5	1.5-2.5	0.3-1.5	12-21
Medium pressure	4.0-6.0 x 2.5-4.2	2.5-3.5	1.5-3.0	24-35
High pressure	12.0-25.0 x 5.0-8.0	4.0-9.0	5.0-45.0	60-80

FIGURE 3.25 - Polypropylene (PP) fittings with a lock connector.



B. Microsprinklers. These water emitters are small plastic sprinklers of low capacity with flow rates less than 300 litres/h. Their main characteristics are their rapid rotation/whirling, less than a minute per rotation, the very small size of the water drops and the low angle of the water jet above nozzle. They have only one nozzle, of about 2.0 mm. They discharge 150-250 litres/h at 2.0 bars operating pressure. They are full circle and the wetted diameter is only 10-12 m. Mounted at a height of 60 cm on metallic or plastic rods inserted into the ground, they are connected to PE laterals (25 or 32 mm) through small flexible tubes 7 mm in diameter and 80 cm long. The spacing arrangement in the field is the same as for conventional sprinklers. The spacing does not exceed 6.0 m, i.e. 50 percent of the wetting diameter. The filtration requirements are about 60 mesh (300 microns).

FIGURE 3.26 - A microsprinkler with a rotating spinner.

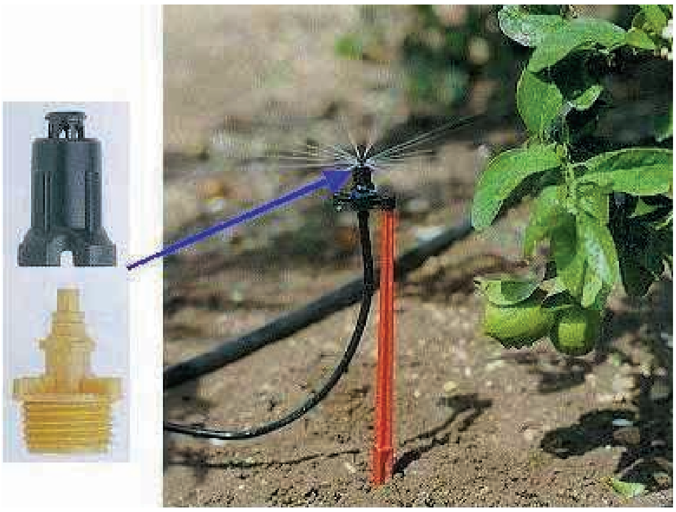


C. Spitters, micro-jets and sprayers. These are small plastic emitters with a low water discharge at a low angle in the form of fine drops in a sectorial or full circle pattern. They are mainly used for tree crops. They are of various mechanisms with a wide range of flow rates and water diameters. They have a small passage diameter, thus filtration of the water is essential. Their main performance characteristics are:

- operating pressure: 1.5-2.0 bars;
- flow rate: 35-250 litres/h (generally 150 litres/h);
- wetting diameter: 3-6 m;
- precipitation rate: 2-20 mm/h (generally 4-8 mm/h);
- filtration requirements: 60-80 mesh (250-200 microns).

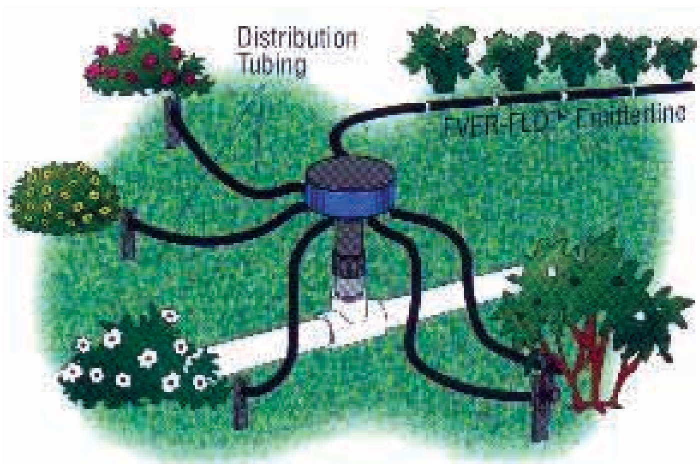
Their heads are fixed to small plastic wedges 20-30 cm above ground and they are connected to the PE laterals with 7-9-mm flexible plastic tubes 60-120 cm long and a barbed plunger. They are placed one per tree, 30-50 cm apart.

FIGURE 3.27 - Photograph of a micro-jet irrigating a citrus tree and in detail the microjet's head with no-moving parts.



D. Bubblers. Low pressure bubblers are small-sized water emitters designed for localized flood irrigation of small areas. They deliver water in bubbles or in a low stream on the same spot. The flow rate is adjusted by twisting the top and ranges from 110 to 250 litres/h at operating pressures of 1.0-3.0 bars. The bubbler heads are installed, as are the minisprinklers, on small plastic wedges inserted into the ground and connected to a PE lateral with a 7-mm flexible plastic tube 80 cm long. They are placed in a tree basin; one or two per tree. The basin is always needed to contain or control the water because the bubbler discharge usually exceeds the soil infiltration rate.

FIGURE 3.28 - Scheme of a bubbler.



E. Drippers. The drippers are small-sized emitters made of high quality plastics. They are mounted on small soft PE pipes (hoses) at frequent spaces. Water enters the dripper emitters at approximately 1.0 bar and is delivered at zero pressure in the form of continuous droplets at low rates of 1.0-24 litres/h. Drippers are divided into two main groups according to the way they dissipate energy (pressure):

- orifice type, with flow areas of 0.2-0.35 mm^2;
- long-path type, with relatively larger flow areas of 1-4.5 mm^2.

Both types are manufactured with various mechanisms and principles of operation, such as a vortex diode, a diaphragm or a floating disc for the orifice drippers, and a labyrinthine path, of various shapes, for the long-path ones. All the drippers now available on the market are turbulent flow ones.

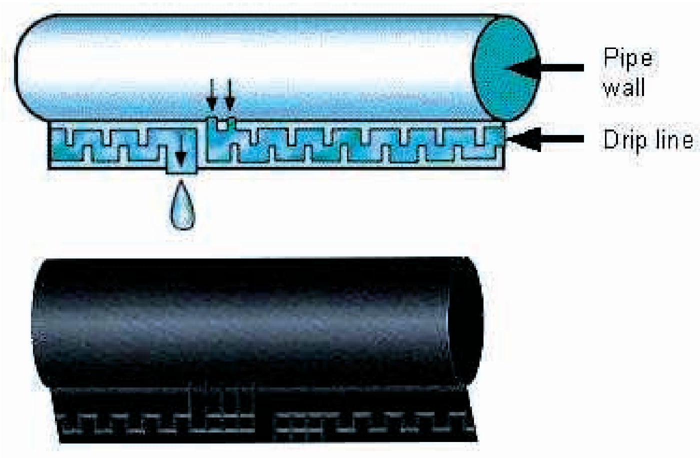
Drippers are also characterized by the type of connection to the lateral: on-line, i.e. inserted in the pipe wall by the aid of a punch; or in-line, where the pipe is cut to insert the dripper manually or with a machine.

On-line multi-exit drippers are also available with four to six 'spaghetti' type tube outlets.

FIGURE 3.29 - On top an on-line dripper, below an in-line dripper.

F. Drip tapes. These are thin-walled integral drip lines with emission points spaced 10, 20, 30, 45 cm or any other distance apart, delivering lower quantities of water than the usual drippers at very low pressures, i.e. 0.4-1.0 litres/h at 0.6-1.0 bar. They are integrated drip lines where the drippers are built in the pipe walls at the desired spacing during the manufacturing process. They are ready-made dripper laterals with a very high uniformity of application. Drip tapes are made of LDPE or other soft PE materials in various diameters from 12 to 20 mm and in several wall thicknesses (0.10-1.25 mm). Thanks to a filtration system incorporated inside the tubing, they are less susceptible to mechanical and biological blockages than conventional drippers are.

FIGURE 3.30 - Scheme and photograph of a drip tape.



G. Pressure compensated (PC) emitters. Several sprinklers, drippers and other water micro-emitters are available with built-in flow regulators. These emitters deliver a constant flow of water at any pressure exceeding the fixed operating one. Uniform rates of discharge are achieved along the laterals regardless of the number of emitters, spacing, length of line or elevation, where excessive pressure is available. Therefore, pressure variations in the laterals due to friction losses can exceed 20 percent. Thus, less expensive smaller diameter pipes can be installed in certain cases. However, the self-regulated emitters, called pressure compensated, are normally operated under pressures exceeding the fixed operational pressures and cost more than the conventional ones.

FIGURE 3.31 - Differences in discharge between a normal emitter and an ideal and a real pressure compensated emitters.

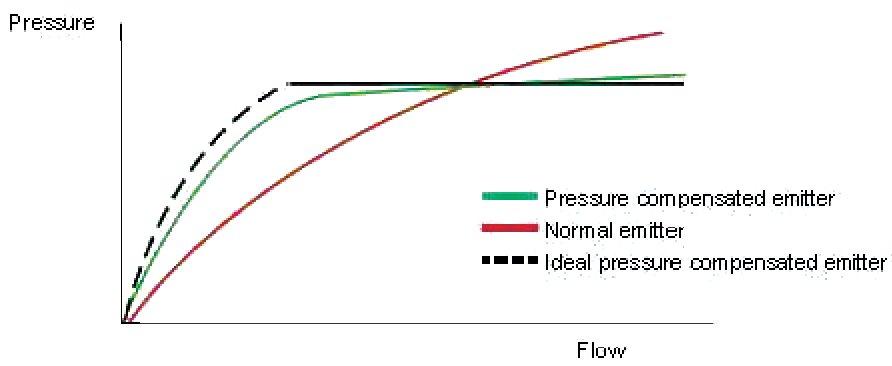
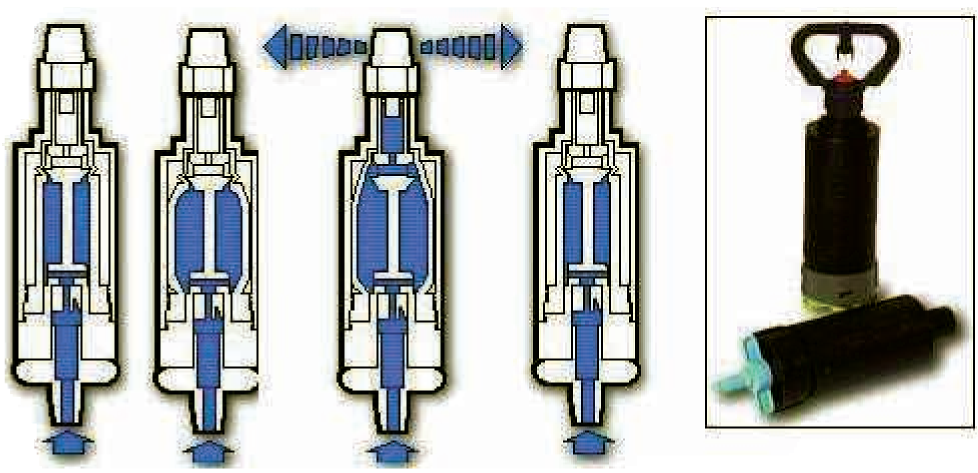


FIGURE 3.32 - Picture of a pressure compensated emitter showing the membrane that is used as flow-regulator.

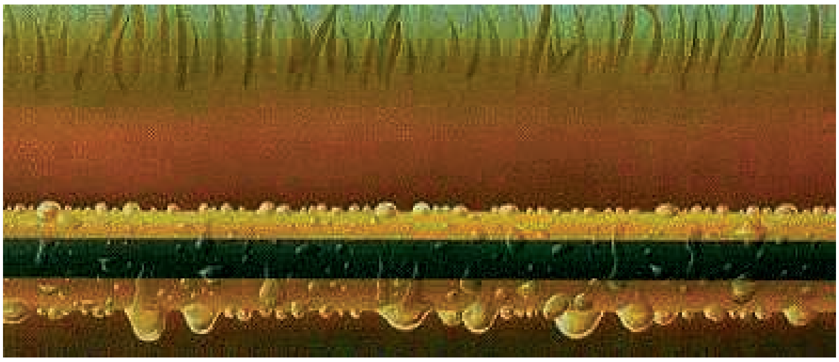
H. Pulsators. Pulsators are small plastic hydraulic devices used in micro-irrigation systems to reduce emitter and system flow rates to very low levels for higher efficiencies. The pulsators employ a built-in dripper with a discharge of 4-8 litres/h that feeds an integral silicone sleeve chamber. This in turn acts as a miniature pulsating pump generating hundreds of pulses per hour and so emitting the water. Thus, they can convert a low continuous flow into an instantaneous pressurized emission of water in short pulses. This process enables application rates of 0.3-0.8 mm/h with spitters, minisprinklers and sprayers, and 100-300 cm3/h with drippers. They are attached to the emitters, one for each minisprinkler or sprayer, and one for 20-70 drippers accordingly. The emitted water per pulse is roughly 0.5 cm^3. The silicone sleeve remains closed when the water pressure drops with the termination of the irrigation and prevents the water in the system from draining. Pressure compensated pulsators are also available for use on mountains and sloping terrain.

FIGURE 3.33 - Operational scheme and photograph of a pulsator.



I. Porous pipes. These pipes are small-sized (about 16 mm) thin-walled porous flexible hoses made from PE fibres, PVC, ABS or rubber. They permit water and nutrients under low pressure to pass from inside the tube, by transpiration, and irrigate the crops. The porous pipeline discharge is not accurate because the size of the pores varies and is not stable. They are used as lateral drip lines beneath the surface. Their application is limited although they do offer some advantages.

FIGURE 3.34 - Scheme of a porous pipe.



J. Garden hoses. Flexible garden hoses are made of various plastic materials, usually soft PVC, reinforced with textile or polyester yarn. They come in nominal diameters, the approximate inside diameter, of _-1_ in (15, 19, 25, 32 and 38 mm) with plain ends. They have a wide range of water applications.

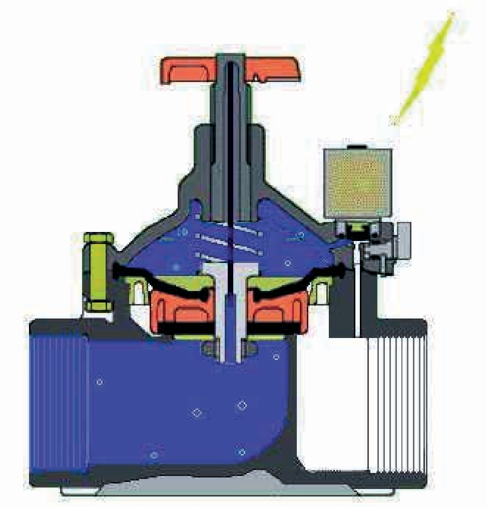
FIGURE 3.35 - Photograph of a garden hose with outlet.

AUTOMATION EQUIPMENT

The main component parts for automation in an irrigation system are the remote control (electric) valves, the controller and the field wiring, where electricity is the transmitting power.

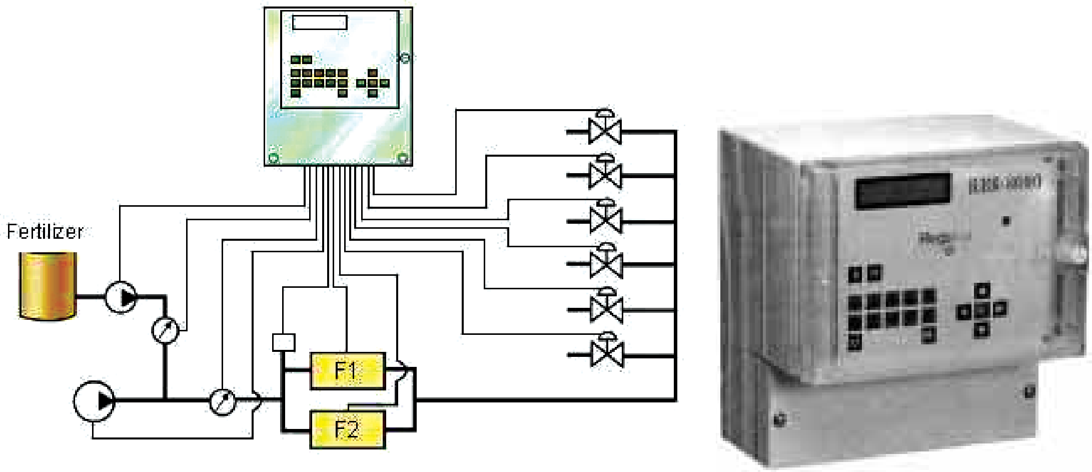
A. Electric (solenoid) valves. These are automatic valves which can be commanded from a distant point to turn the water flow on and off. The body construction is based on the globe valve design. They open and close by means of a flexible diaphragm or a piston, utilizing hydraulic pressure controlled by an electrically actuated solenoid valve mounted on top. Made of reinforced glass or plastic, the electric valves, normally closed, are in inches with screw-type connections, a working pressure of 10.0 or 14.0 bars, and with a handle for manual operation and flow control.

FIGURE 3.36 - Operational scheme and photograph of an electric control valve.



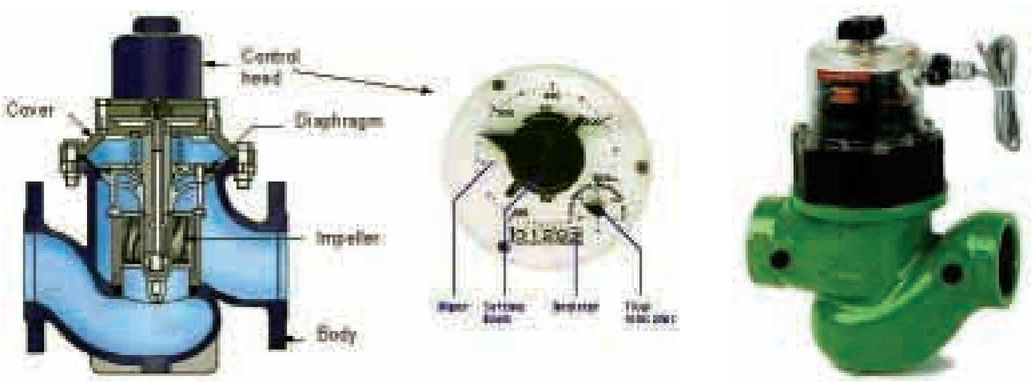
B. Controllers. These are automatic timing devices which supply the actuating power to operate the remote control (electric) valves, i.e. to open and close on a pre-set programme. They contain a transformer which reduces the standard voltage to 24-30 V. The power output from the electric controllers is transmitted to the electric valves through underground wiring. Their main features are the stations and the programmes. Each station usually operates one valve. The operation of the stations is sequential. There are many types of controllers available in many stations, up to 30, with dual or triple programmes for different scheduling and variable cycles of more than 14 days, and 0-12-hour station timing. Battery powered controllers are also available for independent stations.

FIGURE 3.37 - Operational scheme and photograph of an irrigation controller device.



C. Automatic volumetric metering valves. These valves consist of a water meter, a pilot assembly and a shut-off mechanism. Once the pre-set volume of water has been delivered, they shut off automatically. Small sizes are operated mechanically and larger ones hydraulically by means of a diaphragm or a piston. Small sizes are available with screw-type joints while larger sizes, made of cast iron, come in flanged connections. They have a relatively limited application, mainly due to their high cost.

FIGURE 3.38 - Operational scheme and photograph of an automatic volumetric metering valve.



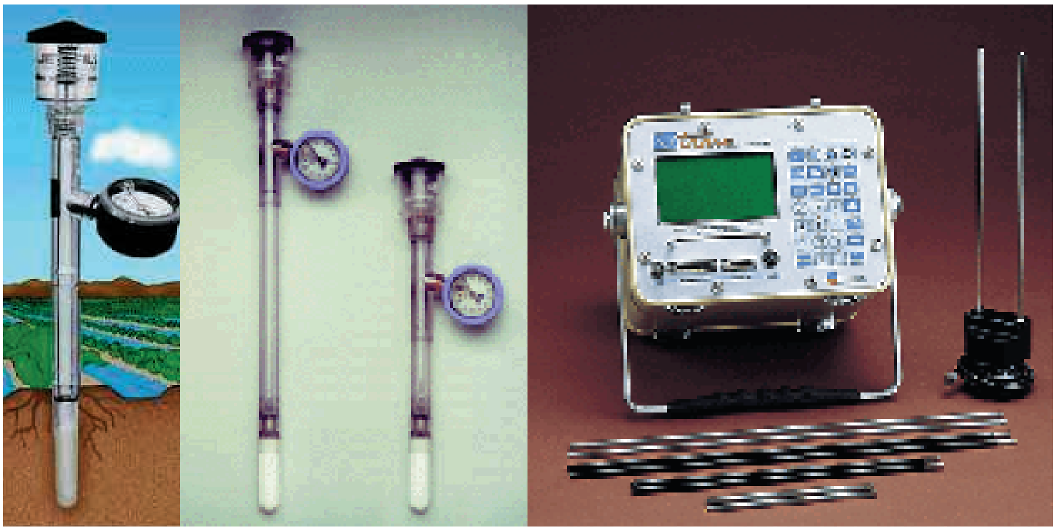
OPERATION EQUIPMENT

For the proper management of the irrigation systems, frequent simple water and soil checks and other measurements must be carried out on site. For this purpose, there are several instruments that give direct readouts of the results.

A. Soil moisture sensors. Soil moisture measurement is difficult mainly because of the variability in soil types, calibration of the sensor, area of influence of the sensor, and the extrapolation of that measurement to crop management. Basically, two parameters are of interest: (i) the volumetric soil moisture because it provides information on the ratio of soil water to solid phase plus air (it is a useful measurement for irrigation control informing about how much water is needed in order to "fill the sponge") and (ii) the soil moisture tension because it informs about the effort the plant has to make to extract moisture from the soil. At present, there are various technologies for soil moisture measurement. Two of them, because of their relevance, are briefly explained below:

- Tensiometers operate by allowing the soil solution to come into equilibrium with a reference pressure indicator through a permeable ceramic cup placed in contact with the soil. At the state of field capacity the soil moisture tension is normally 10 cbars in sandy soils, 20 cbars in medium soils and 30 cbars in clays. Readings below 10 cbars indicate saturated soil, readings of 20-40 cbars indicate excellent soil water availability, while readings exceeding 55 cbars indicate a risk of water stress. A characteristic is that they are not affected by the osmotic potential of the soil solution (the amount of salts dissolved in the soil water), as the salts can move into and out of the ceramic cup unhindered, and they measure soil matric potential with good accuracy in the wet range. Their main disadvantages are that they provide point measurement, slow reaction time, usually only operate between saturation and about 70 cbars (thus they cannot operate in relatively dry soils), require maintenance to refill after dry periods, and if the ceramic cup looses contact with the soil then this could cause an apparent "lack of response" of the instrument.
- Time Domain Reflectometry (or TDR). The method is based on the principle that velocity of an electromagnetic wave depends on the conducting medium. The larger the soil water content is, the slower the wave will travel. Thus, the wave travelling time along a probe of known length can be related to the soil water content. The main advantages of the method is that it is accurate, continuous, and it does not require calibration. The main disadvantage is that it has complex electronics and expensive equipment.

FIGURE 3.39 - Scheme and photographs of tensiometers and a TDR.



B. Conductivity meters. These portable instruments are battery powered and enable rapid and accurate determination of the concentration of soluble salts in the soil solution and the irrigation water. They are temperature compensated but they need frequent calibration.

FIGURE 3.40 - Measurement of irrigation water with a conductivity meter.

C. Class A evaporation pan. This is an open circular pan which is widely used to measure evaporation. It is made of 22-gauge galvanized steel plate, all surfaces painted aluminium, or of 0.8-mm Monel metal. The pan has a standard size: 121 cm in diameter and 25.5 cm deep. It is placed level on a wooden beamed base support 15 cm above ground.

It is filled with water to 5 cm below the rim. It has a simple or advanced reading mechanism to indicate the decrease in water level due to evaporation. Measurements are recorded every morning at the same time. The water is topped up when its level drops to about 7.5 cm below the rim.

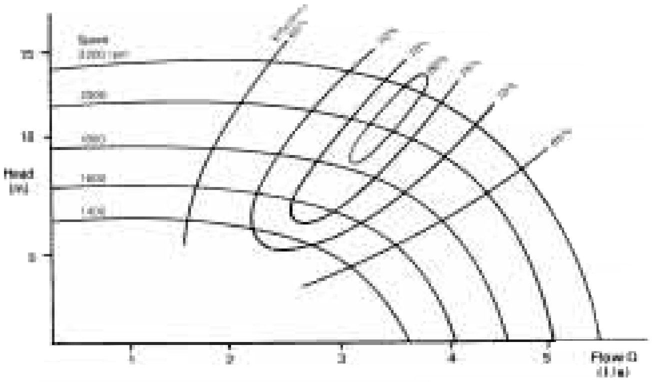
FIGURE 3.41 - A class A evaporation pan in the field.

WATER-LIFTING DEVICES

Pumps and lifting/propelling devices are often classified on the basis of the mechanical principle used to lift the water: direct lift, displacement, creating a velocity head, using the buoyancy of a gas or gravity. Most categories sub-divide into further classifications “reciprocating/cyclic” and “rotary”. The first of these relates to devices that are cycled through a water-lifting operation (for example, a bucket on a rope is lowered into the water, dipped to fill it up, lifted, emptied and then the cycle is repeated); in such cases the water output is usually intermittent, or at best pulsating rather than continuous. Rotary devices were generally developed to allow a greater throughput of water, and they also are easier to couple to engines or other mechanical drive.

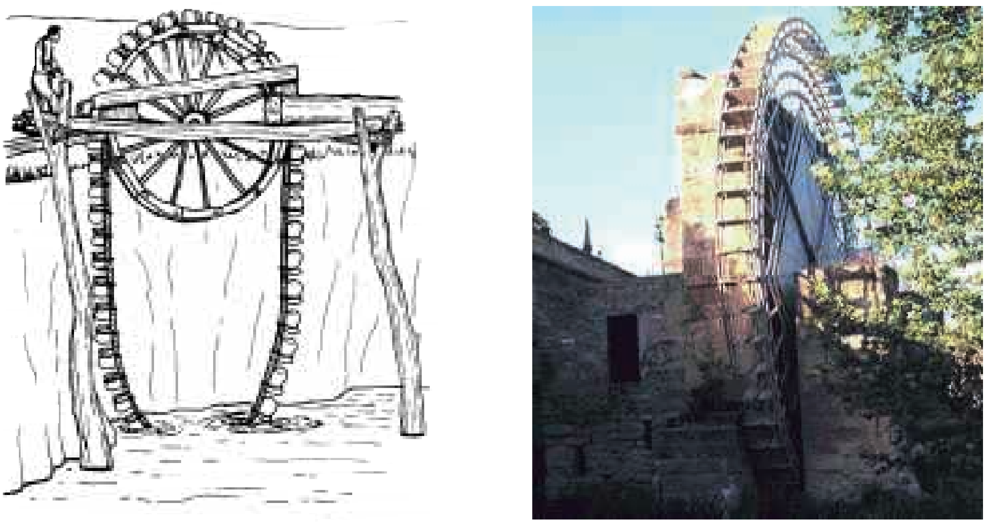
Virtually all water lifting devices can best be characterized for practical purposes by measuring their output at different heads and speeds. Normally the performance of a pump is presented on a graph of head versus flow (an H-Q graph, as in Figure 3.43) and in most cases curves can be defined for the relationship between H and Q at different speeds of operation. Invariably there is a certain head, flow and speed of operation that represents the optimum efficiency of the device, i.e. where the output is maximized in relation to the power input. Some devices and pumps are more sensitive to variations in these factors than others; i.e. some only function well close to a certain design condition of speed, flow and head, while others can tolerate a wide range of operating conditions with little loss of efficiency. For example, the centrifugal pump characteristic given in Fig. 3.43 shows an optimum efficiency exceeding 80% is only possible for speeds of about 2000 rpm.

FIGURE 3.42 - Typical curves showing relationship between head, flow, speed, and efficiency (example for a centrifugal pump).



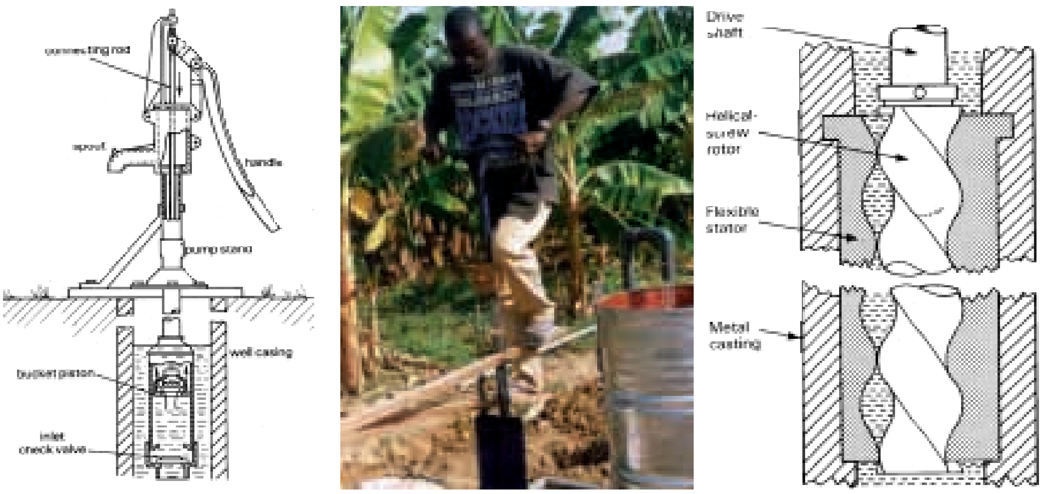
A. Direct-lift devices. These are all variations on the theme of the bucket and are the earliest artificial method for lifting and carrying water. It generally improves both efficiency and hence productivity if the water lifting element can move on a steady circular path. An obvious improvement to the simple rope and bucket is to fit numerous small buckets around the periphery of an endless belt to form a continuos bucket elevator. The original version of this, which is ancient in origin but still widely used, was known as a "Persian wheel". The water powered Noria, a water wheel with pots, is similar in principle.

FIGURE 3.43 - Scheme of a Persian wheel and photograph of a Noria.



B. Displacement pumps. The most common and well-known form of reciprocating/cyclic are the piston-type pumps and of rotary/continuous are the Archimedean screw-types. In the piston pump, water is sucked into the cylinder through a check valve on the up-stroke, and the piston valve is held closed by the weight of water above it; simultaneously, the water above the piston is propelled out of the pump. On the down-stroke, the lower check valve is held closed by both its weight and water pressure, while the similar valve in the piston is forced open as the traped water is displaced through the piston ready for the next up-stroke. The rotary positive displacement pumps have their origins among the Archimedean screw. Modern concepts have appeared such as the progressive cavity pump (also called “mono” pump), yet they all have a number of similarities. The principle is that water is picked up by the submerged end of the helix each time it dips below the surface and, as it rotates, a pool of water gets trapped in the enclosed space between the casing and the lower part of each turn. The progressive cavity (mono) pump is ready to fit in down boreholes and it is of great advantage because positive displacement pumps can cope much more effectively than centrifugal pumps with variations in pumping head. Therefore, any situation where the water level may change significantly with the seasons makes the progressive cavity pump an attractive option.

FIGURE 3.44 - Left: Scheme of a hand pump with single acting bucket piston (piston valve shown open as on the down-stroke, and inlet valve is closed). Center: A peadle piston-type pump. Right: Scheme of a progressive cavity or "mono" pump.



C. Velocity pumps. Their mechanism is based on the principle that when water is propelled to a high speed, the momentum can be used either to create a flow or to create a pressure. The reciprocating/cyclic ones are rarely used while the rotary/continuous ones are highly widespread. The latter are called rotodynamic pumps and their mechanism is based on propelling water using a spinning impeller or rotor.

Since any single rotodynamic pump is quite limited in its operating conditions, manufacturers produce a range of pumps, usually incorporating many components, to cover a wider range of heads and lows. Where high flows at low heads are required (which is common in irrigation pumps), the most efficient impeller is an axial-flow one (this is similar to a propeller in a pipe). Conversely, for high heads and low flows a centrifugal (radial-flow) impeller is needed.

Where a higher head is needed than can be achieved with a single pump, two pumps can be connected in series. Similarly, if a greater discharge is needed, two centrifugal pumps may be connected in parallel.

FIGURE 3.45 - Rotodynamic pumps: (a) radial or centrifugal pump and (b) axial pump.

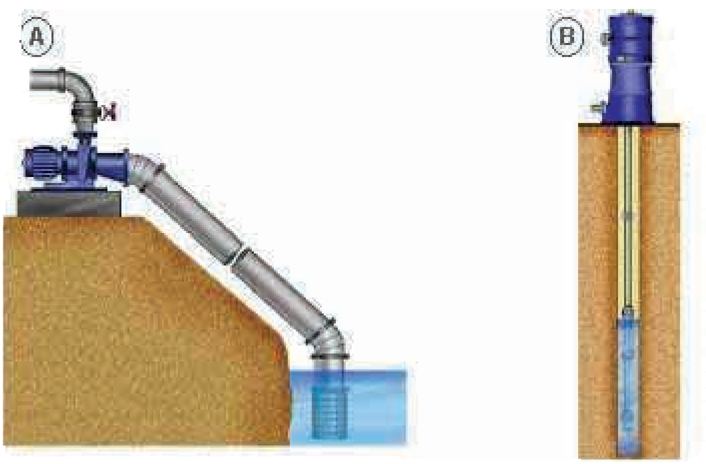
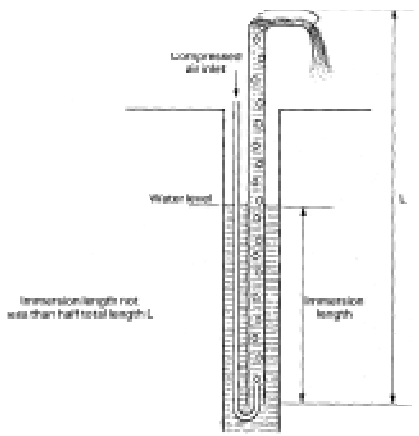


FIGURE 3.46 - Left: a rotodynamic pump powered by a tractor. Right: a pumping unit with rotodynamic pumps in parallel.

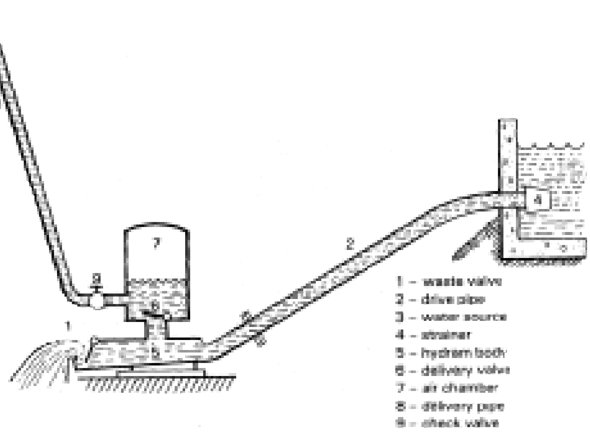
D. Air-lift pumps. A rising main, which is submerged in a well so that more of it is below the water level than above it, has compressed air blown into it at its lowest point. The compressed air produces a froth of air and water, which has a lower density than water and consequently rises to the surface. The compressed air is usually produced by an engine driven air compressor. The main advantage of the air-lift pump is that there are no mechanical below-ground components to wear out, so it is essentially simple, reliable, virtually maintenance-free and can easily handle sandy or gritty water. The disadvantages are rather severe: first it is inefficient as a pump, probably no better than 20-30% in terms of compressed air energy to hydraulic output energy and this is this is compounded by the fact that air compressors are also generall inefficient. Second, it usually requires a borehole to be drilled considerably deeper (more than twice the depth of the static water level) than otherwise would be necessary.

FIGURE 3.47 - Scheme of an air-lift pump.



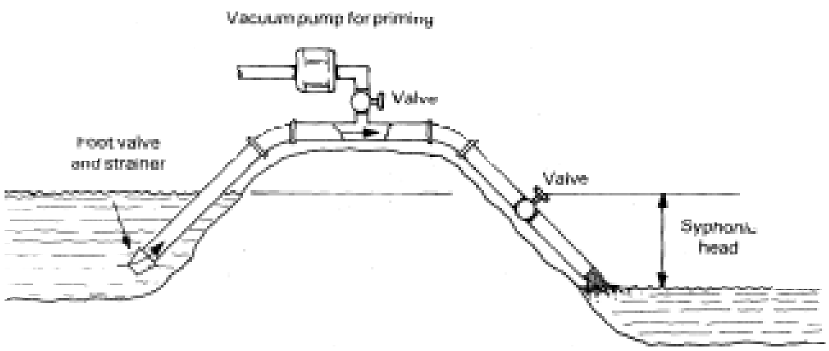
E. Impulse (water hammer) pumps. These devices apply the energy of falling water to lift a fraction of the flow to a higher level than the source. The principle they work by is to let the water from the source flow down a pipe and then to create sudden pressure rises by intermittently letting a valve in the pipe slam shut. This causes a "water hammer" effect which results in a sudden sharp rise in water pressure sufficient to carry a small proportion of the supply to a considerably higher level. They therefore are applicable mainly in hilly regions in situations where there is a stream or river flowing quite steeply down a valley floor, and areas that could be irrigated which are above that level that can be commanded by small channels contoured to provide a gravity supply. A practical example of this pumps is the hydraulic ram pump or "hydram". The main virtue of the hydram is that it has no substantial moving parts, and is therefore mechanically extremely simple, which results in very high reliability, minimal maintenance requirements and a long operational life. However, in most cases the output is rather small (in the region of 1-3 litre/sec) and they are therefore best suited for irrigating small-holdings.

FIGURE 3.48 - Schematic diagram of hydram installation.



F. Gravity devices. Syphons are the most common device of this type, though strictly speaking they they are not water-lifting devices, since, after flowing through a syphon, water finishes at a lower level than it started. However syphons can lift water over obstructions at a higher level than the source and they are therefore potentially useful in irrigation. Syphons are limited to lifts about 5m at sea level for exactly the same reasons related to suction lifts for pumps. The main problem with syphons is that due to the low pressure at the uppermost point, air can come out of solution and form a bubble, which initially causes an obstruction and reduces the flow of water, and which can grow sufficiently to form an airlock which stops the flow. Therefore, the syphon pipe, which is entirely at a sub-atmospheric pressure, must be completely air-tight.

FIGURE 3.49 - A syphon arrangement.



Calculation of the power requirements (P)?

The power requirements are calculated as:

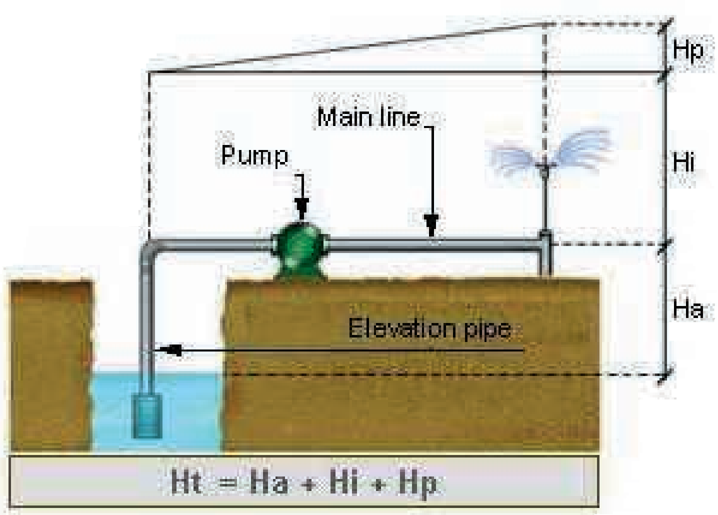
$$P(HP) = \frac{Q(l/s) \times Ht(m)}{75 \times e1 \times e2}$$

$$P(kw) = \frac{Q(l/s) \times Ht(m)}{102 \times e1 \times e2}$$

where:
Ht is the total head;
e1 is the pump efficiency (fraction in the order of 0.5-0.8); and
e2 is the driving efficiency (fraction of 0.7-0.9 for electric motors and 0.5-0.75 for diesel engines).

The total head (Ht) required for the normal operation of the system is the sum of the following pressures:

FIGURE 3.50 - Ht is the total head, Ha is the elevation head, Hi is the emitter operation head and Hp is the friction losses head (sum of friction losses in the main line, submains, manifolds, laterals, valves, pipe fittings and minor losses).



ANNEX: Equipment for open canal/surface irrigation systems

1 **Water Control devices.** In open canals, water flow is controlled with different kind of devices. The most common one are gates. Gates are used in canal turnouts. A special type are the downstream constant level gates, commonly known as Neyrpics.

FIGURE 3.51 - Left: a gate for a farm turnout. Right: a Neyrpic gate.

2 **Flow measurement devices.** Discharges can be measured with weirs or flumes. Weirs are sharp-crested, overflow structures that are built across open canals. The water level upstream of the structure is measured using a measuring gauge. The discharge corresponding to that water level is then read from a table which is specific for the size and type of weir being used. Flumes consist of a narrowed canal section with a particular, well-defined shape. Like measurements with weirs, the water level upstream of the flume is a measure of the discharge trough the flume, and when the head has been measured the discharge can be obtained by reading the value on a diagram which is specific for the flume being used.

FIGURE 3.52 - Left: Scheme of a "V" notch weir. Right: Photograph of a "V" notch weir installed in a furrow.

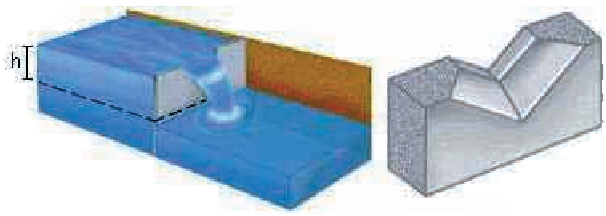


FIGURE 3.53 - A Parshall-type flume.

❸ **Water application devices.** Syphons and gated pipes are commonly used in surface irrigation. A syphon is a curved pipe filled with water and laid over the channel bank at every irrigation. Gated pipes are used to control the water applied to individual furrows.

FIGURE 3.54 - Left: Syphons. Rigth: A gated pipe.

CHAPTER 4: System design

INTRODUCTION

The engineering design is the second stage in irrigation planning. The first stage is the consideration of the crop water requirements, the type of soil, the climate, the water quality and the irrigation scheduling. The water supply conditions, the availability of electricity and the field topography also need to be considered. The economic considerations, the labour and the know-how also need to be taken into account. The irrigation system is selected after a thorough evaluation of the above data and the computation of the system's flow, the irrigation dose, the duration of application and the irrigation interval.

Once the design has been completed, a detailed list of all the equipment needed for the installation of the system must be prepared with full descriptions, standards and specifications for every item.

SYSTEM DESIGN

The engineering and hydraulic design procedure is almost the same in all kinds of pressurized irrigation systems. It consists of a series of interlinked calculations. The various stages are outline below.

Selection of the water emitter (sprinkler, dripper, minisprinkler, bubbler, hose, etc.) according to the crop, irrigation method and requirements:

- type, flow rate, operating pressure, diameter coverage;
- spacing and number per lateral line.

DESIGN OF THE LATERALS

- length, direction, spacing and total number of lateral lines (in solid systems) or lateral positions (in semi-permanent installations);
- flow of the lateral = number of emitters per lateral x emitter flow rate;
- number of laterals operating simultaneously = system flow/flow of lateral;
- number of shifts to complete one irrigation = total number of lateral lines or positions ÷ number of laterals operating simultaneously;

- Duration of application = irrigation dose in millimetres ÷ application rate in millimetres per hour, or irrigation dose in cubic metres per hour ÷ system flow in cubic metres per hour.

DETERMINATION OF THE SIZE OF THE PIPELINES

Lateral lines

It is important to understand the water emitter's functions and principle of operation before commencing the design process. One of the main characteristics of all types of emitters is the relationship between flow rate and operating pressure, which is usually expressed by the empirical formula:

q = k d H *

where q is the emitter discharge, k and d are coefficients (constants), H is the pressure at the emitter and * is an exponent characterized by the emitter flow regime and the flow rate curve as a function of the pressure.

The lower the value of *, the less the influence of pressure variations on the emitter flow rate along the lateral line. Most of the water emitter flow regime is fully turbulent with an exponent value equal to 0.5. Thus, the difference in discharge is half the difference in pressure, when the ratio of the two different pressures is < 1.3/1.0.

In order to ensure a high uniformity of water application over the field, the differences in the discharge of the emitters should be kept to the minimum possible and in no case exceed 10 percent. These criteria were established by J. Christiansen for sprinklers and are now applied in all pressurized systems. As a general rule, the maximum permissible difference in pressure between any two emitters in operation should be no more than 20 percent. The lateral lines with emitters must be of a size that does not allow a loss of head (pressure) due to friction of more than 20 percent.

The loss of head due to friction (friction losses) in lateral pipes is taken from a graph or a table. The reading is usually given as loss of head of water in metres or feet per 100 m or 100 ft of pipe. For example, in a 50-mm quick coupling sprinkler lateral pipe with a 15 m_/h flow, the friction losses are 7 percent. If the length of the lateral is 120 m, the friction losses are: 7/100 x 120 = 8.4 m. However, this figure is for the total flow of 15 m_/h running the whole length of lateral. Thus, it is not the true figure as the flow is distributed en route through the emitters. In order to compute the actual losses the above figure is multiplied by

Christiansen's reduction coefficient, F, to compensate for the water delivered along the lateral line. The F values depend on the number of the outlets uniformly spaced along the pipeline (Table 5).

Three different series of F values exist corresponding to the Q exponent (m) of the three main friction loss formulas: Hazen Williams, 1.85; Scobey, 1.9; and Darcy Weisbach, 2.0. Moreover, lower values are taken if the distance of the first outlet is half the spacing of the outlets, etc. However, the differences between the various F values are almost negligible.

TABLE 5 - F factor for multiple outlets

Number of outlets	F value (m = 2.0)	Number of outlets	F value (m = 2.0)
1	1.0	12	0.376
2	0.62	15	0.367
3	0.52	20	0.360
4	0.47	24	0.355
5	0.44	28	0.351
6	0.42	30	0.350
7	0.41	40	0.345
8	0.40	50	0.343
9	0.39	100	0.338
10	0.385	>	0.333

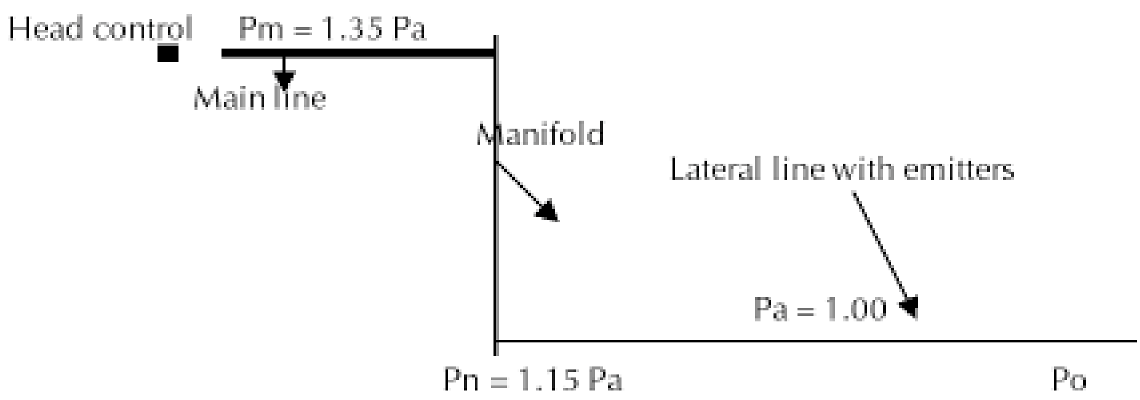
Assuming that in the above example there are ten emitters (in this case sprinklers) on the lateral, the F value is 0.4. Then, in a 50-mm quick coupling lateral, 120 m long, with a flow of 15 m_/h, with 10 sprinklers of 1.5 m_/h at 2.0 bars, the friction losses are: 7/100 x 120 x 0.4 = 3.36 m head of water. This figure must not exceed the maximum permissible, which is 20 percent of the emitter's average operating pressure, i.e. 2.0 bars x 0.20 = 0.4 bars (4 m) on level ground. Where the lateral slopes downwards, the difference in elevation is added to the maximum permissible loss of pressure. Similarly, it is deducted where the lateral slopes upwards.

Due to the multiplicity of emitters with variable flow regimes and other factors affecting the pressure/discharge relation along the laterals in the field, such as local minor losses that occur at the connection of the emitters on small-sized pipes and temperature fluctuations, the manufacturers should always provide charts for the optimum length of emitter laterals, based on the size of pipe, emitter spacing, operating pressure, flow rate and slope.

Manifolds, submain and main pipelines

On the manifolds, whether these pipelines are the submains or the mains as well, a number of laterals are fed simultaneously. The flow of the line is distributed en route, as in the laterals with the emitters. Consequently, when computing the friction losses, Christiansen's reduction coefficient, F, is also considered. Example: 120 m of 75-mm HDPE, 6 bars, manifold line, 16.3 m_/h, 6 laterals operating simultaneously; the friction loss under full flow is 3.3 percent, i.e. 4.0 m x 0.42 = 1.7 m approximately.

The mains, submains and all hydrants are selected in such sizes that the friction losses do not exceed approximately 15 percent of the total dynamic head required at the beginning of the system's piped network. On level ground, these friction losses amount to about 20 percent of the emitter's fixed operating pressure. This is a practical rule for all pressurized systems to achieve uniform pressure conditions and water distribution at any point of the systems. The above figure should not be confused with or related in any way to the maximum permissible friction losses along the laterals.



In the above figure, Pa is the average emitter pressure, or fixed pressure taken from the catalogue; Pn is the lateral inlet pressure; Po = 0.95 Pa is the distal end emitter pressure; and Pm is the pressure at the inlet of the main line.

Pn - Po = 0.20 Pa;
Po = Pn ÷ 1.21;
Pn = 1.15 Pa;
Pm = 1.35 Pa.

The friction loss in a lateral with emitters is very high at the beginning and drops rapidly after the first few outlets and then more gradually toward the end of the line. In the upper one-fourth of the lateral the friction loss is approximately 75 percent of the total.

Another important element is the flow velocity in the mains, submains and hydrants. This value should always be kept below 1.7 m/s_ in plastic tubes and a maximum of 2 m/s_ in other pipes (steel, aluminium, etc.). From the flow velocity formula, V = Q/A, the pipe inside diameter is determined for a given flow: diameter (mm) = Q (m_/h) ÷ V (m/s_) x 0.0028.

HEAD CONTROL

The component parts of the head control and their size are in accordance with the system requirements. In micro-irrigation systems the units are complete with filters and fertilizer injectors, while in sprinkler and hose irrigation systems the head controls are simple with the minimum of equipment. The friction losses in the various component parts vary accordingly from 3 to 10 m.

The friction loss formulas are empirical and include many variables and correction factors. In calculating the pipe friction losses from equations, extensive practical experience is needed. In view of the fact that great accuracy is not possible due to the unpredictable changes in pipe roughness, water viscosity, nozzle wear, clogging, etc., the use of friction loss tables and nomographs is recommended.

TOTAL DYNAMIC HEAD OF THE SYSTEM

The total pressure head or dynamic head required for the normal operation of the system is the sum of the following pressures:

Pressure at the emitter	Metres head
Friction losses in the lateral line	Metres head
Friction losses in the manifold	Metres head
Friction losses in the submains and in the main line	Metres head
Friction losses in the valves and pipe fittings and minor losses (usually up to 15 percent of the total losses in the pipes)	Metres head
Difference in elevation (plus or minus)	Metres head
Loss of pressure in the head control	*Metres head*
Total pressure head of system	Metres head

TOTAL DYNAMIC HEAD OF THE PUMPING UNIT

This is the sum of the system's total head plus the pumping lift. The brake horsepower formula is:

BHP = Q x TDH ÷ 270 x e1 x e2

where Q is the flow capacity in cubic metres per hour, TDH is expressed in metres, e1 is the pump efficiency (fraction), e2 is the driving efficiency (fraction), and 270 is a constant for metric units.

- Pump efficiency: 0.5-0.8;
- Electric motor efficiency: 0.7-0.9;
- Diesel engine efficiency: 0.5-0.75.

The overall pumping efficiency under field conditions ranges accordingly from 0.35 in engine driven units to 0.50 in motor driven pumps. Higher efficiencies are not realistic.

CHAPTER 5: Equipment, standards and tenders for supply

With the completion of the design, a detailed list of all the equipment needed (bill of quantities) for the installation of the system must be prepared with full descriptions, standards and specifications for every item. The preparation of this list is of great importance. In addition to the quantities, it is imperative to determine and specify:

- size and name (2-in ball valve, 50-mm pipe, etc.);
- kind of material (brass, uPVC, etc.);
- pressure rating (PN 16 bars, 6 bars, etc.);
- type of joints (screw, solvent welded, etc.);
- standards complied with (ISO 161, 3606, BS 21, ISO 7, etc.).

Three different lists may be prepared: one for the mains, submains and manifolds with the hydrants; one for the laterals with the emitters; and one for the head control. Sizes will have already been decided on during the design stage.

WORKING PRESSURE OF THE EQUIPMENT

A closed pipe pressurized system installation consists of pipes of different working pressures according to the location. The main pipelines are subjected to higher pressures than the submains, manifolds and laterals, therefore the main lines should be stronger than the other pipelines. The working pressure of the pipes to be installed should always be higher than the system's operating pressure. For example, in a micro-jet (minisprinkler) installation the approximate operating pressure is 2.3-2.5 bars in the laterals, 2.5-2.7 bars in the manifolds and 2.7-3.0 bars in the mains. A pipe working pressure of 4.0 bars seems to meet the requirements of the system. However, although the low to medium pressure systems are not subjected to the very high pressures created by water hammer, it is advisable to use 6.0-bar pipes for the main line and 4.0 bars for the other pipelines.

MAIN, SUBMAIN AND MANIFOLD PIPELINES, AND HYDRANTS

The most widely used kinds of pipes for these lines are rigid PVC, HDPE, LDPE and quick coupling light steel or aluminium. The following must be determined:

- total length and pieces of the pipelines (about 5 percent should be added to the total);
- quantities of pipe connector fittings (bends, tees, end plugs, reducers, etc.) of the same type of connection to be used with the above pipes;
- number of bends, tee outlets and clamp saddles, which have two different types of connections, e.g. tee 90 mm x 90 mm x 2 in (internal threaded), bend 110 mm x 3 in (flanged);
- quantity of adaptors (starters). These fittings have one end threaded or flanged and the other end arranged in the same type of connection as the pipes. They are used at the starting point of the pipelines and at any other point where valves are fitted;
- number of shut-off and air valves on the distribution network. The air valves are fitted on riser pipes connected with clamp saddles on the mains;
- quantities of the riser pipes for the hydrants, if the mains are buried, and of the shut-off valves or the special hydrant valves. If the mains are not buried, then the fittings for connecting clamp saddles with the shut-off valves must be determined. The number of these fittings is equal to the number of the hydrants.

LATERALS

Quick coupling and LDPE pipes are used as surface laterals in the majority of the systems. The following must be determined:

- total length of pipes required;
- quantities of adaptors, tees, bends, end plugs and line filters;
- total number of emitters and their connector fittings if any, e.g. minisprinkler complete with plunger, connecting flexible tube and plastic wedge, or specify in terms of set, e.g. minisprinkler complete set.

HEAD CONTROL

All the components of the head control of the system must be determined, i.e. shut-off valves, check valve, air valve, fertilizer injector, filters, pressure regulators, etc. In addition, all the auxiliary fittings must be included, such as the pipe pieces, hoses and fittings needed to assemble the unit, and the pressure gauges and other small devices required.

PUMPING UNIT

A full and detailed description of the pumping unit must be given, including the following:

- the average BHP calculated of the driving force and the type (engine or motor);
- the kind of pump (centrifugal single or multi-stage, turbine, electro-submersible), the inlet and outlet diameter, and the type and number of stages;
- the capacity and output of the pumping unit, i.e. the water delivery versus the dynamic head.

STANDARDS

All pipes, pipe fittings and other irrigation equipment are manufactured according to various standards applied in the countries of origin. These standards, although equivalent to each other, vary in terms of the dimensioning, the class rating, the safety factor and the nomenclature. Much technical engineering effort has been devoted by the International Standards Organization (ISO) to the establishing of international standards and specifications so that all national and regional standards are in broad conformity. However, at present the variety of standards causes small farmers a great deal of confusion regarding thermoplastic irrigation equipment. Below is an example of a 4-in rigid PVC pipe, 6.0 bars, in two different national standards

	to DIN 8062	**to ASTM D2241 (SDR 4.1)**
Nominal diameter	110.0 mm	4 in
Outside diameter	110.0 mm	114.3 mm
Inside diameter	103.6 mm	108.7 mm
Wall thickness	3.2 mm	2.8 mm
Working pressure	6.0 bars	6.8 bars (100 psi)

The description of the equipment should be as clear and simple as possible. An example with the minimum specifications required for two items is as follows:

Item 1: Black LDPE pipe, PN 4.0 bars, to DIN 8072 or equivalent standards in compliance with ISO standards, supplied in coils of 200 m:
a. 32 mm DN, 1 800 m;
b. 25 mm DN, 3 200 m.

Item 2: Polypropylene connector fittings manufactured to ISO metric dimensions. Quick release, compression type and/or threaded (screw-type) ends male or female, to ISO 7 or BS 21, PN 10 bars for use with the above PE pipes:

a. 63 mm x 2 in (male) adaptor, 7 pieces;
b. 63 mm x 2 in (female) clamp saddle, 2 pieces;
c. 50 mm x _ (male) adaptor, 2 pieces.

Should the equipment not comply with any standard, due to many reasons, a full technical description should be given of the material it is made of, the working pressure and the use. The latter is important because the fittings should be made of material recommended for use with the particular pipe.

Most of the irrigation equipment should meet the appropriate material, dimensional, and quality requirements recommended in the specifications in Table 6.

TABLE 6 - Equipment specifications

Standard name:	Standard description:
ASAE EP419	Evaluation of furrow irrigation systems.
ASAE S435	Drip/trickle polyethylene pipe used for irrigation laterals.
ASAE S447	Procedure for testing and reporting pressure losses in irrigation valves.
ASAE EP458	Field evaluation of micro-irrigation systems.
ASTM D-2235	Standard specification for solvent cement for ABS plastic pipes and fittings.
ASTM D-2464	Standard specification for threaded PVC plastic pipe fittings, Schedule 80.
ASTM D-2466	Standard specification for threaded PVC plastic pipe fittings, Schedule 40.
ASTM D-2467	Standard specifications for socket-type PVC plastic pipe fittings, Schedule 80.
ASTM D-2468	Standard specification for ABS plastic pipe fittings, Schedule 40.
ASTM D-2469	Standard specifications for socket-type ABS plastic pipe fittings, Schedule 40.
ASTM D-2609	Standard specifications for plastic insert fittings for polyethylene (PE) plastic pipes.
ASTM D-2683	Standard specification for socket-type PE fittings for outside diameter controlled PE pipe.
ASTM D-2855	Standard practice for making solvent cemented joints with PVC pipe and fittings.
ASTM D-3036	Standard specifications for socket-type PVC plastic line couplings.
ASTM D-3139	Standard specifications for joints for plastic pressure pipes using flexible elastometric seals.
ASTM D-3261	Standard specifications for butt heat -fusion PE plastic fittings for PE plastic pipe tubing.
ISO 7714: 1995	Agricultural irrigation equipment - volumetric valves - general requirements and test methods.
ISO 7749-1: 1995	Agricultural irrigation equipment - rotating sprinklers - Part 1: design and operational requirements.
ISO 7749 —2: 1990	Irrigation equipment - rotating sprinklers - Part 2: uniformity of distribution and test methods.
ISO 8026: 1995	Agricultural irrigation equipment - sprayers - general requirements and test methods.
ISO/TR 8059: 1986	Irrigation equipment - automatic irrigation systems - hydraulic control.
ISO 8224—1: 1985	Traveller irrigation machines - Part 1: laboratory and field test methods.
ISO 8224—2: 1991	Traveller irrigation machines - Part 2: softwall hose and couplings - test methods.
ISO 8779: 1992	PE pipes for irrigation laterals - specifications.
ISO 8796: 1989	PE 25 pipes for irrigation laterals - susceptibility to environmental stress-cracking induced by insert-type fittings - test. method and specification
ISO 9260: 1991	Agricultural irrigation equipment - emitters - specification and test methods.
ISO 9261: 1991	Agricultural irrigation equipment - emitting pipe systems - specification and test methods.
ISO 9625: 1993	Mechanical joint fittings for use with PE pressure pipes for irrigation purposes.
ISO 9635: 1990	Irrigation equipment - hydraulically operated irrigation valves.
ISO 9644: 1993	Agricultural irrigation equipment - pressure losses in irrigation valves - test methods.
ISO 9911: 1993	Agricultural irrigation equipment - manually operated small plastic valves.
ISO/DIS 9912—1	Agricultural irrigation equipment - filters - Part 1: classification.

TABLE 6 - Equipment specifications (cont'd)

Standard name:	Standard description:
ISO 9912—2: 1992	Agricultural irrigation equipment - filters - Part 2: strainer-type filters.
ISO 9912—3: 1992	Agricultural irrigation equipment - filters - Part 3: automatic self-cleaning strainer-type filters.
ISO 9952: 1993	Agricultural irrigation equipment - check valves.
ISO 10522: 1993	Agricultural irrigation equipment - direct-acting pressure-regulating valves.
ISO 11419: 1997	Agricultural irrigation equipment - float-type air release valves.
ISO 11545: 1995	Agricultural irrigation equipment - centre-pivot and moving lateral irrigation machines with sprayer or sprinkler nozzle. — Determination uniformity of water distribution
ISO 11678: 1996	Agricultural irrigation equipment - aluminium irrigation tubes.
ISO/DIS 11738	Agricultural irrigation equipment - head controls.
ISO 12347: 1995	Agricultural irrigation - wiring and equipment for electrically driven or controlled irrigation machines.
ISO/DIS 13457	Agricultural irrigation equipment - water driven chemical injector pumps.
ISO/DIS 13460	Agricultural irrigation equipment - plastic saddles for PE pressure pipes.
ISO 161-1: 1996	Thermoplastics pipes for fluid conveyance - nominal outside diameters and nominal pressures - Part 1: metric series.
ISO 161-2: 1996	Thermoplastics pipes for fluid conveyance - nominal outside diameters and nominal pressures - Part 2: inch-based. series
ISO 4065: 1996	Thermoplastics pipes - universal wall thickness table.
ISO 3606: 1976	Unplasticized PVC pipes - tolerances on outside diameters and wall thickness.
ISO 3607:1977	PE pipes - tolerances on outside diameters and wall thickness.
ISO 7-1: 1994	Pipe threads - pressure-tight joints are made on threads - Part 1.
ISO 49: 1994	Malleable cast iron fittings threaded to ISO 7-1.
BS 21:1985	Specification for pipe threads for tubes and fittings - pressure-tight joints on threads (ISO 7/1, 7/2: 1982).
BS 143 &1256: 1986	Specification for malleable cast iron and cast copper alloy threaded pipe fittings.
BS 1387:1985(1990)	Specification for screwed/socketed steel tubes and for plain steel tubes suitable for welding or for screwing to BS 21. pipe threads
BS 3867: 1987	Method of specifying outside diameters and pressure ratings for thermoplastic pipes (inch series) (ISO 161/2).
BS 4346:Part 1,2,3	Joints and fittings for use with unplasticized PVC pressure pipes.
BS 5556:1978(1986)	Specification for dimensions and pressure ratings for thermoplastic pipes (metric) (ISO 161/1).
DIN2999(1,2,3,4,5,6	Pipe threads for tubes and fittings.
DIN 2440/41/42	Steel tubes (medium-weight) suitable for screwing.
DIN 8161 (1994)	Unplasticized PVC pipes - general quality requirements and testing.
DIN 8062 (1988)	Unplasticized uPVC, PVC-HI pipes, dimensions.
DIN 8072 (1972)	LDPE pipes, dimensions.
DIN 8074 (1987)	HDPE pipes, dimensions.
ASAE S263	Minimum standards for aluminium sprinkler irrigation tubing.
ASAE S330	Procedure for sprinkler distribution testing for research purposes.
ASAE S376	Design, installation and performance of underground, thermoplastic irrigation pipelines.
ASAE S398	Procedure for sprinkler testing and performance reporting.
ASAE EP405	Design and installation of micro-irrigation systems.
ASAE EP409	Safety devices for chemigation.

ASAE: Society for Engineering in Agriculture, Food, and Biological Systems (former American Society of Agricultural Engineers).
ASTM: American Society for Testing Material.
BS: British Standards.
DIN: (Deutsches Institut für Normung) German standards.
ISO: International Standards Organization.

TENDERS

The purchasing of irrigation equipment or execution of services, such as the installation, operation and maintenance of irrigation networks and or pumps, should be subject to public tender.

For equipment and services up to a value of US$500, the purchase can be effected through 'quotations', i.e. written quotations may be asked from a representative number (2-3) of suppliers. Where the value of the equipment exceeds a certain amount, e.g. US$600, their purchase should be effected through tender. This is done in accordance with the 'stores regulations' applied in the project or the country concerned.

Wide publicity should be given to every 'notice inviting tenders' (invitation for tenders). This must include the name of the buyer, a brief description of the items for which tenders are invited, the address for delivery of equipment, and the closing date and time of the tenders. Moreover, it should include a statement that the buyer is not bound to accept the lowest or any other tender, and also state to whom the bidders must apply for full particulars.

In the case of 'local tenders' for the purchase of relatively limited quantities, the tender document that must be available and given to prospective bidders on request should include only the general conditions of the tender and the technical specifications of goods. It is important that all required conditions be clearly stated in detail in the tender document, including the time and method of delivery, i.e. FOB, CIF, ex-stock; method of payment, i.e. letter of credit, cash against documents, payment on delivery, etc.; and other related information. For tenders over US$3 000, bidders should furnish a bank guarantee or cheque equal to 10 percent of the value of the tender price. An example of this kind of tender is given below.

In the case of 'international bids', the contract documents must include, in detail, the following:

- invitation for bids (as described above);
- instructions to bidders (source of funds, eligible bidders, goods and services, cost, content of bidding documents, preparation and submission of bids, opening and evaluation, award of contract, etc.);
- general conditions of contract (definitions, country of origin and standards, performance, security, inspection and tests, insurance, transportation, warranty, payment, amendments, delays, force majeure, etc.);
- special conditions;
- technical specifications (general, materials and workmanship, schedules of requirements/bill of quantities, and particular technical requirements/specifications);
- bid form and price schedules;
- contract form, bid security and performance security.

EXAMPLE

Tenders for the supply of irrigation equipment

Tenders are hereby invited for the supply of irrigation equipment required for a private farm in the Project area, as per attached quantities, description and specification.

General conditions of tenders

1. **Price:** Bidders to quote prices per unit and total, CIF nearest port, Republic of …, full liner terms, including bank charges on the attached price schedules. Prices to be firm for at least 90 calendar days from the closing date of tender.

2. **Delivery:** Date of delivery in the project site should not exceed 60 days from the time of awarding the tender.

3. The tenders should be sealed and addressed to the General Manager, Irrigation Project, P.O. Box 5564. Tenders should be marked 'TENDER FOR THE SUPPLY OF IRRIGATION EQUIPMENT FOR PRIVATE FARM' on the envelope and should reach Project main offices not later than 31 December 1999.

4. The bidder shall be prepared to accept the prices tendered by him. The tender shall become binding and be carried into effect upon being accepted by the Project. Should the bidder delay execution of the tender or refuse to execute the tender, the bidder shall be liable for any expenses incurred by the Project.

5. **Payment:** The Project shall make all necessary arrangements towards the opening of the letter of credit in US dollars for goods to be supplied in its name and on behalf of the supplier within seven days after receiving the import licence. The Project shall make a first payment of 50 percent of the value of the tender upon submission of all the necessary shipping documents. Such documents shall reach the Project at least one month before the scheduled date of arrival of goods into the port of entry. A second payment of 50 percent of the value of contract shall be paid to the supplier after receipt of goods at Project's store and issuing certificate of acceptance in accordance with the technical specifications.

6. Insurance to cover all the risks for the CIF value, plus 10 percent from warehouse up to the Project's stores.

7. Bidders to quote the country of origin. It is imperative to quote for the items according to the specifications and standards as per the attached list. Otherwise, full details are required.

8. Bidders should provide a guarantee of excellent workmanship and against faulty material of not less than 12 months.

9. Selected candidates should confirm by fax without delay their receipt of the invitation to tender.

10. Tenders shall not be considered unless all the above conditions have been strictly observed.

11. Tenders to be submitted in duplicate.

12. The Project does not bind itself to accept the lowest or any tender.

Bill of quantities

Item	Description	Unit	Quantity	Rate (US$)	Amount (US$)
1.	HDPE pipe ø 75 mm	m	300		
2.	HDPE pipe ø 63 mm	m	650		
3.	HDPE pipe ø 50 mm	m	100		
4.	LDPE pipe ø 25 mm	m	3 600		
5.	LDPE pipe ø 16 mm	m	1 400		
6.	Clamp saddle ø 75 mm x 2 in (F)	pcs	8		
7.	Clamp saddle ø 63 mm x _ in (F)	pcs	70		
8.	Clamp saddle ø 50 mm x _ in (F)	pcs	10		
9.	Adaptor (starter) ø 75 mm x 3 in (M)	pcs	1		
10.	Adaptor (starter) ø 63 mm x 2 in (M)	pcs	7		
11.	Adaptor (starter) ø 50 mm x 2 in (M)	pcs	1		
12.	Adaptor (starter) ø 25 mm x _ in (M)	pcs	240		
13.	Adaptor (starter) ø 16 mm x _ in (M)	pcs	150		
14.	Coupling ø 75 mm	pcs	2		
15.	Coupling ø 63 mm	pcs	4		
16.	Coupling ø 50 mm	pcs	1		
17.	Coupling ø 25 mm	pcs	30		
18.	Coupling ø 16 mm	pcs	10		
19.	Tee ø 50 x 50 x 50 mm	pcs	1		
20.	Tee ø 25 x 25 x 25 mm	pcs	10		
21.	Tee ø 25 mm x _ in (M)	pcs	10		
22.	Tee ø 25 mm x _ in (F)	pcs	150		
23.	Cross ø 2″	pcs	1		
24.	Nipple hexagon ø 2 in	pcs	8		
25.	Nipple hexagon ø _ in	pcs	80		
26.	End plug ø 75 mm	pcs	1		
27.	End plug ø 63 mm	pcs	10		
28.	End plug ø 50 mm	pcs	1		
29.	Ball valve ø 2 in	pcs	8		
30.	Ball valve ø _ in	pcs	80		
31.	Filter strainer ø 3 in	pcs	1		
32.	Dripper emitter 24 litres/h	pcs	5 000		
33.	Sprinkler pop-up full circle	pcs	4		
34.	Air valve _ in	pcs	2		
35.	Valve box	pcs	8		
36.	Excavation of trench and backfill	m	1 050		

Equipment specification

Item number	Equipment specification
1,2,3	Black HDPE pipes, PN 6.0 bars, in accordance with CYS104: Part 1: 1985 or equivalent other national standards in compliance with ISO. Supplied in 100 and 60 m rolls.
4,5	Black LDPE pipes, PN 4.0 bars, in accordance with CYS106: Part 1, Part 2: 1985 or equivalent other national standards in compliance with ISO. Supplied in 200 m rolls.
6-28	Polypropylene connector fittings for use with PE Pipes to CYS and ISO dimensions, quick release compression type and/or screw ends to BS 21, or ISO 7, PN 10 bars.
29,30	Ball valves, quarter-turn, on-off operation, made of brass, PN 16 bars to BS 5154, threaded to BS 21, or ISO 7.
31	Filter (strainer), screen type, or grooved disks, 120 mesh/130 micron, epoxy coated metal body, or other high quality material, PN 10, complete with pressure inspection valves, wash-out drain valve, threaded connection to BS 21.
32	On-line, point-source dripper emitters, turbulence flow made of high quality plastic material, 24 litres/h discharge, 1.0 bar operating pressure, cv < 7%, filtration requirements 120 mesh/130 micron.
33	Pop-up sprinkler rotary gear driven full circle, 0.7-0.8 m3/h discharge at 2-2.5 bars operating pressure, radius 7 m, interchangeable nozzle, c/with small strainer, drain mechanism and plastic cover, threaded (F) connection _ in to BS 21.
35	Valve boxes, made of reinforced plastic or any other material, with cutout openings for pipe on opposite sides of the open bottom, c/with tight-fitting lids or covers on the top. Approximate dimensions: 33 cm x 45 cm (base) x 30 cm height.
36	The trench should be as uniform and level as possible, free of large stones and any other sharp-edged materials. Where required it must be filled with embedment material such as grained soil or sand to a depth of 10 cm. Trench dimensions should be 60 cm minimum depth for the 75-mm pipe and 50 cm for the 63 and 50-mm pipes, and 35 cm minimum width in all cases.

CHAPTER 6:
Irrigation scheduling

Irrigation scheduling is one of the factors that influence the agronomic and economic viability of small farms. It is important for both water savings and improved crop yields. The irrigation water is applied to the cultivation according to predetermined schedules based upon the monitoring of:

- the soil water status;
- the crop water requirements.

The type of soil and climatic conditions have a significant effect on the main practical aspects of irrigation, which are the determination of how much water should be applied and when it should be applied to a given crop.

In addition to the basic factors relevant to the preparation of irrigation schedules examined below, other important elements should also be considered, such as crop tolerance and sensitivity to water deficit at various growth stages, and optimum water use.

SOIL-WATER RELATIONSHIP

Table 7 presents a summary table of soil physical properties.

TABLE 7 - Soil physical properties (average values)

Type of soil	Light (coarse) texture	Medium texture	Heavy (fine) texture
Saturation capacity (SC) % weight	25-35%	35-45%	55-65%
Field capacity (FC) % weight	8-10%	18-26%	32-42%
Wilting point (WP) % weight	4-5%	10-14%	20-24%
SC/FC	2/1	2/1	2/1
FC/WC	2/1	1.85/1	1.75/1
Bulk density(volume weight)	1.4-1.6 g/cm_	1.2-1.4 g/cm_	1.0-1.2 g/cm_
Soil available water (moisture) by volume (FC-WP x bulk density)	6%	12%	16-20%
Available moisture (Sa) in mm per metre soil depth (FC-WP x bulk density x 10)	60 mm	120 mm	160-200 mm
Soil water tension in bars:			
• at field capacity	0.1	0.2	0.3
• at wilting point	15.0	15.0	15.0
Time required from saturation to field capacity	18-24 h	24-36 h	36-89 h
Infiltration rate	25-75 mm/h	8-16 mm/h	2-6 mm/h

Example:
The field capacity (FC) of a 45-cm layer of soil is 18 percent. How much water in cubic metres per hectare does this layer hold?

Answer:
FC = 18%, WP = FC ÷ 1.85 = 9.7%, Sa = 18-9.7 = 8.3%;
Bulk density = 1.2 g/cm_;
Sa mm/m = 8.3 x 1.2 x 10 = 99.6, Sa mm/45 cm = 8.3 x 1.2 x 10 x 0.45 = 44.8 mm;
m_/ha = 0.0996 ÷ 1 x 0.45 x 10 000 (1 ha) = 448.2, or
m_/ha = Sa (mm/m) x depth of layer (m) x 10.
Therefore, the answer is 448.2 m_/ha.

EFFECTIVE ROOT DEPTH

This is the soil depth from which the plants take nearly 80 percent of their water needs, mostly from the upper part where the root system is denser. The rooting depths depend on the plant physiology, the type of soil, and the water availability (kind of irrigation). Indicative figures are presented in FAO Irrigation and Drainage Paper No. 24, Table 39.

In general, vegetables (beans, tomatoes, potatoes, onions, peanuts, cucumbers, etc.) are shallow rooted, about 50-60 cm; fruit trees, cotton and some other plants have medium root depths, 80-120 cm. Alfalfa, sorghum, and maize have deeper roots (Table 8). Moreover, rooting depths vary according to age.

TABLE 8 - Example of rooting depth (metres) during the growing season

	August	September	October	November	December	January
Maize	-	0.4	0.9	1.2	1.2	-
Cotton	0.4	0.8	1.0	1.0	1.0	-
Tomato	-	-	0.3	0.7	0.9	0.9

PERMISSIBLE DEFICIT OR DEPLETION OF SOIL AVAILABLE WATER

The fraction of moisture in the soil which amounts to 20-70 percent of the total available moisture (Sa) and is easily absorbed by the plants (without any stress that results in yield reduction) is called readily available moisture. It is a product of Sa multiplied by p, which represents the maximum permissible depletion of available water (moisture). The p value differs according to the kind of plant, the root depth, the climatic conditions and the irrigation techniques. Values for p are given in FAO Irrigation and Drainage Paper No. 33, Tables 19 and 20, and vary from

0.25 in shallow rooted sensitive crops to 0.70 in deep rooted tolerant crops. Table 23 of the same paper provides information on the sensitive growth periods of different crops.

Field observations have shown that the lower the soil moisture depletion (p), the better the crop development and yield. Hence, the recommended p values are:

- 0.20-0.30 for shallow rooted seasonal crops;
- 0.40-0.60 for deep rooted field crops and mature trees.

NET IRRIGATION APPLICATION DEPTH

Irrigation takes place when the permissible percentage (p) of available water (Sa) is depleted from the root depth, i.e. to replenish the depleted water. Therefore:

Net depth of irrigation dose (d) (mm) = (Sa x p) D

where Sa is the available water in millimetres per metre, p is the permissible depletion (fraction), and D is the root depth (m).

Example:
Where Sa = 99 mm/m, p = 0.5, D = 0.4 m, what is the net irrigation dose (d) in millimetres to replenish the moisture deficit?

d = 99 x 0.5 x 0.4 = 19.8 mm.

CROP WATER REQUIREMENTS

The amount of water which evaporates from wet soils and plant surfaces together with the plant transpiration is called evapotranspiration (ET). Its value is largely determined by climate factors, such as solar radiation, temperature, humidity and wind, and by the environment. Out of the total evapotranspiration, evaporation accounts for about 10 percent and plant transpiration for the remaining 90 percent. Crop water requirements encompass the total amount of water used in evapotranspiration.

Alternative approaches for estimating the evapotranspiration, such as the radiation, Penman and pan methods, are presented in FAO Irrigation and Drainage Papers Nos. 24 and 33. Reference evapotranspiration (ETo) represents the rate of evapotranspiration of green grass under ideal conditions, 8-15 cm tall, with extensive vegetative cover completely shading the ground. It is expressed as a mean value in millimetres per day over a period of 10-30 d.

The most practical method for determining ETo is the pan evaporation method. This approach combines the effects of temperature, humidity, wind speed and sunshine. The best known pans are the Class A evaporation pan (circular) and the Colorado sunken pan (square).

The evaporation from the pan is very near to the evapotranspiration of grass that is taken as an index of ETo for calculation purposes. The pan direct readings (Epan) are related to the ETo with the aid of the pan coefficient (kpan), which depends on the type of pan, its location (surroundings with or without ground cover vegetation) and the climate (humidity and wind speed). Hence, ETo = Epan x kpan.

The kpan values for both types of pans are given in FAO Irrigation and Drainage Paper No. 24, Tables 18 and 19. For the Class A pan the average kpan is 0.70 and for the Colorado sunken pan it is 0.80.

Example:

Estimate of ETo in millimetres per day in the Wadi Tuban Delta

Month	June	July	August	September	October	November	December
Epan	9.0	8.8	8.8	8.2	8.0	6.5	5.7
kpan			average	0.70			
ETo	6.3	6.2	6.2	5.7	5.6	4.5	4.0

In order to relate ETo to crop water requirements (ETc), the specific crop coefficient (kc) must be determined: ETc = ETo x kc.

The crop coefficient (kc) depends on the crop leaf area and its roughness, the stage of growth, the growing season and the prevailing weather conditions. Tables 9 and 10 list the kc values for different crops at various growth stages.

Example:

Cotton, growing season August-December

	August	September	October	November	December
ETo mm/d	6.2	5.7	5.6	4.5	4.0
Cotton kc	0.4	0.7	1.1	1.0	0.8
Cotton ET cmm/d	2.5	4.0	6.2	4.5	3.2
Cotton ET cmm/month	78	120	192	135	99

Total net water requirement approximately 580 mm
(December taken as half)

TABLE 9 - Crop factor (kc) for seasonal crops (average figures)

Crop	Initial	Crop development	Mid-season	Late and harvest
Bean (green)	0.35	0.70	1.0	0.9
Bean (dry)	0.35	0.75	1.1	0.5
Cabbage	0.45	0.75	1.05	0.9
Carrot	0.45	0.75	1.05	0.9
Cotton	0.45	0.75	1.15	0.75
Cucumber	0.45	0.70	0.90	0.75
Eggplant	0.45	0.75	1.15	0.80
Groundnut	0.45	0.75	1.0	0.75
Lettuce	0.45	0.60	1.0	0.90
Maize (sweet)	0.40	0.80	1.15	1.0
Maize (grain)	0.40	0.75	1.15	0.70
Melon	0.45	0.75	1.0	0.75
Onion (green)	0.50	0.70	1.0	1.0
Onion (dry)	0.50	0.75	1.05	0.85
Pea (fresh)	0.45	0.80	1.15	1.05
Pepper	0.35	0.75	1.05	0.90
Potato	0.45	0.75	1.15	0.75
Spinach	0.45	0.60	1.0	0.90
Squash	0.45	0.70	0.90	0.75
Sorghum	0.35	0.75	1.10	0.65
Sugar beet	0.45	0.80	1.15	0.80
Sugar cane	0.45	0.85	1.15	0.65
Sunflower	0.35	0.75	1.15	0.55
Tomato	0.45	0.75	1.15	0.80

TABLE 10 - Crop factor (kc) for permanent crops

Crop	Young	Mature
Banana	0.50	1.10
Citrus	0.30	0.65
Apple, cherry, walnut	0.45	0.85
Almond, apricot, pear, peach, pecan, plum	0.40	0.75
Grape, palm tree	0.70	0.70
Kiwi	0.90	0.90
Olive	0.55	0.55
Alfalfa	0.35	1.1

EFFECTIVE RAINFALL

In many areas, seasonal rain precipitation (P) might provide part of the water requirements during the irrigation season. The amount of rainwater retained in the root zone is called effective rainfall (Pe) and should be deducted from the total irrigation water requirements calculated. It can be roughly estimated as:

Pe = 0.8 P where P > 75 mm/month;
Pe = 0.6 P where P < 75 mm/month.

GROUND COVER

Another element to consider when estimating crop water requirements is the percentage of the field area (ground) covered by the cultivation. A reduction factor, expressed as kr, is applied to the conventional ET crop calculations. This factor is slightly higher, by about 15 percent, than the actual ground covered by the crop. For example, if the actual ground cover is 70 percent, kr = 0.70 x 1.15 = 0.80.

IRRIGATION INTERVAL OR FREQUENCY

This is the number of days between two consecutive irrigations, i = d ÷ ETc, where d is the net depth of irrigation application (dose) in millimetres and ETc is the daily crop evapotranspiration in millimetres per day.

Example:
Where d is 19.8 mm, and ETc is 2.5 mm/d, then
i = 19.8 ÷ 2.5 = 8 days.

IRRIGATION APPLICATION EFFICIENCY

The amount of water to be stored in the root zone is estimated as the net irrigation dose (d). However, during the irrigation process, considerable water loss occurs through evaporation, seepage, deep percolation, etc. The amount lost depends on the efficiency of the system (Table 11). Irrigation field application efficiency is expressed as:

Ea = water stored in the root zone (d)/water applied x 100

Example:
The net irrigation dose (d) for an area of 1 ha is 19.8 mm, i.e. 198 m^3. The water delivered during irrigation is 280 m^3. What is the application efficiency?

Answer:
Ea = 198 x 100 ÷ 280 = 70.7%, or expressed as a fraction, 0.70.
The remaining 30 percent of water applied is lost.

TABLE 11 - Approximate application efficiency of various on-farm irrigation systems and methods

System/method	Ea %
Earth canal network surface methods	40-50
Lined canal network surface methods	50-60
Pressure piped network surface methods	65-75
Hose irrigation systems	70-80
Low-medium pressure sprinkler systems	75
Microsprinklers, micro-jets, minisprinklers	75-85
Drip irrigation	80-90

GROSS IRRIGATION APPLICATION DEPTH

Given the irrigation efficiency as a fraction, i.e. Ea = 0.60 (60 percent), the gross depth of irrigation application or gross irrigation dose (dg) is calculated as follows:

$dg = d \div Ea$ (fraction)

LEACHING REQUIREMENTS

The salinity level in the root zone is related directly to the water quality, the amount of fertilizers and the irrigation application depth. A high salt content in the soil is controlled by leaching. An excess amount of water, 10-15 percent, is applied during the irrigation where necessary for leaching purposes. In this way a portion of the water percolates through and below the root zone carrying with it a portion of the accumulated soluble salts. The leaching requirements (LR) are considered for the calculation of the gross irrigation application (d).

SYSTEM FLOW (SYSTEM CAPACITY)

The minimum flow capacity of any irrigation system should be the one that can meet the water requirements of the area under irrigation at peak demand:

minimum $Q = 10\ A \times dg \div it$

where Q is the system flow in cubic metres per hour, A is the area in hectares, dg is the gross irrigation application depth (irrigation dose) in millimetres, i is the interval in days between two irrigations at peak demand, t is the operating hours per day, and 10 is a constant for hectares. However, the minimum flow of the system should be the one that enables the completion of irrigation at least two days before the next irrigation. This allows time to repair any damage to the system or pumping unit. Therefore, the value of i in the above formula should be reduced by two days.

The duration of application per irrigation is determined as:

$T = 10\ A \times dg \div Q$

where T is the total operating hours of the system.

GENERAL EXAMPLE

In the following example the effective rainfall (Pe), the ground cover (kr) and the leaching requirements (LR) are not considered. However, these elements are important in localized micro-irrigation systems.

Crop: Cotton
Area: 1.5 ha. Location: Tuban Delta. Growing season: August-December.
Irrigation method: Pressure piped surface method.
Irrigation efficiency: 70 percent.
Soil of medium texture, Sa = 99 mm/m.

	August	September	October	November	December
Soil available water Sa mm/m	99	99	99	99	99
Depletion of available water p	0.5	0.6	0.6	0.6	0.6
Cotton root depth D m	0.4	0.7	1.0	1.0	1.0
Net irrigation application d mm	19.8	41.6	59.4	59.4	59.4
Epan mm/d	8.8	8.2	8.0	6.5	5.7
kpan	0.7	0.7	0.7	0.7	0.7
ETo mm/d	6.2	5.7	5.6	4.5	4.0
Cotton kc	0.4	0.7	1.1	1.0	0.8
Cotton ETc mm/d	2.5	4.0	6.2	4.5	3.2
Irrigation interval i days	8	10.5	9.6	13	18.5
Gross irrigation dose dg mm	28.3	59.4	85.0	85.0	85.0
Gross irrigation dose dg m^3/h	425	891	1 275	1 275	1 275

The peak demand is in October when ETc is 6.2 mm/d and the irrigation frequency (interval) is 8 days. If the number of operating hours per day is seven, the system flow should be:

Minimum Q = 10 x 1.5 x 85 ÷ (9 days - 2 days) x 7 = 26 m^3/h.

The duration of application per irrigation would be as follows:

August: T = 10 x 1.5 x 28.3 ÷ 26 = 16.3 hours, i.e. 2 days;
September: T = 10 x 1.5 x 59.4 ÷ 26 = 34.3 hours, i.e. 5 days;
October: T = 10 x 1.5 x 85.0 ÷ 26 = 49.0 hours, i.e. 7 days;
November: T = 10 x 1.5 x 85.0 ÷ 26 = 49.0 hours, i.e. 7 days;
December: T = 10 x 1.5 x 85.0 ÷ 26 = 49.0 hours, i.e. 7 days.

Irrigation programme		
End of July	**pre-sowing irrigation to wet 0.6 m soil depth**	**1 273 m^3_**
Beginning of August	crop establishment	
8 August	irrigation	425 m^3
16 August	irrigation	425 m^3
24 August	irrigation	425 m^3
1 September	irrigation	891 m^3
11 September	irrigation	891 m^3
22 September	irrigation	891 m^3
2 October	irrigation	1 275 m^3
11 October	irrigation	1 275 m^3
21 October	irrigation	1 275 m^3
31 October	irrigation	1 275 m^3
13 November	irrigation	1 275 m^3
26 November	irrigation	1 275 m^3

The last irrigation on 26 November can last up to 9 December, i.e. until harvest. The total amount of water that must be applied to this crop on an area of 1.5 ha is: 11 598 m3 plus 1 273 m3 as the minimum amount for pre-irrigation, for a total of 12 871 m3.

CHAPTER 7: Water quality for irrigation

INTRODUCTION

Salinity is a common problem facing farmers who irrigate in arid climates. This is because all irrigation waters contain soluble salts. Whether derived from springs, diverted from streams, or pumped from wells, the waters contain appreciable quantities of chemical substances in solution, dissolved from the geological strata through and over which the waters have flowed. Waters with a high salt content may have moved from a saline water table. In areas with intensive agriculture, fertilization is a major cause of aquifer salinization.

COMPOSITION AND CONCENTRATION OF SOLUBLE SALTS

The composition of salts in water varies according to the source and properties of the constituent chemical compounds. These salts include substances such as gypsum (calcium sulphate, $CaSO_4.2H_2O$), table salt (sodium chloride NaCl) and baking soda (sodium bicarbonate $NaHCO_3$). When dissolved in water, salts separate into ions; e.g. sodium chloride breaks down into sodium and chloride ions. Thus, it is customary to refer to ions rather than salts. The principle ions in irrigation water and their characteristics are listed in Table 12.

TABLE 12 - Principle ions present in irrigation water

Ions	Chemical symbol	Equivalent weight
Anions (acidic ions)		
Chloride	Cl^-	35.5
Sulphate	SO_4^{--}	48
Carbonate	CO_3^{--}	30
Bicarbonate	HCO_3^-	61
Nitrate	NO_3^-	62
Cations (basic ions)		
Sodium	Na+	23
Potassium	K+	39.1
Calcium	Ca++	20
Magnesium	Mg++	12.2

All ions are expressed in the form of milligrams per litre (mg/litre or ppm) and milliequivalents per litre (meq/litre). The latter unit is preferable because water quality criteria involve milliequivalents per litre calculations.

The conversion formula is:

meq/litre = mg/litre ÷ equivalent weight

Boron is also present in irrigation waters as un-ionized boric acid expressed as boron element (B) in milligrams per litre. The salt concentration in most irrigation waters ranges from 200 to 4000 mg/litre total dissolved solids (TDS). The pH of the water is also an indicator of its quality and it normally ranges from 6.5 to 8.4.

The common method for evaluating the total salts content in water is by measuring the electrical conductivity of water (ECw) at 25°C. Electrical conductivity is expressed in deciSiemens per metre. There is a relation between the electrical conductivity and the concentration of salts in milliequivalents per litre and in milligrams per litre when the ECw is in the range of 1-5 dS/m. Thus, every 10 meq/litre of salts (cation concentration) create 1 dS/m ECw. The relationship between electrical conductivity and total dissolved salts (TDS) is:

ECw (dS/m) x 640 = TDS (mg/litre)

The sum of cations should equal the sum of anions. The accuracy of the chemical water analyses should be checked on the basis of the above relationships.

EFFECT OF SOLUBLE SALTS ON PLANTS

The application of irrigation water to the soil introduces salts into the root zone. Plant roots take in water but absorb very little salt from the soil solution. Similarly, water evaporates from the soil surface but salts remain behind. Both processes result in the gradual accumulation of salts in the root zone, even with low salinity water. This situation may affect the plants in two ways: a) by creating salinity hazards and water deficiency; and b) by causing toxicity and other problems.

Salinity hazards and water deficiency

The build-up of salinity in the root zone increases the osmotic pressure of the soil solution and causes a reduction in both the rate of water absorption by the plants and the soil water availability. Thus, a continuous water deficiency may exist even though the field is heavily irrigated. Plant wilting symptoms may not become apparent, but growth and yield are depressed. Under such circumstances it is not possible to maintain good crop development conditions and obtain high yields. Instead, plant growth is delayed and there is a considerable reduction in yield. Seed germination is also affected by the presence of salts. It is usually delayed and in some cases does not occur.

The level of salinity build-up depends on both the concentration and the composition of salts in the water. Chloride is highly soluble and remains in the soil solution, while sulphate and bicarbonate combine with calcium and magnesium, where present, to form calcium sulphate and calcium carbonate, which are sparingly soluble compounds.

Toxicity hazards

Many fruit trees and other cultivations are susceptible to injury from salt toxicity. Chloride, sodium and boron are absorbed by the roots and transported to the leaves where they accumulate. In harmful amounts, they result in leaf burn and leaf necrosis. Moreover, direct contact during sprinkling of water drops with a high chloride content may cause leaf burn in high evaporation conditions. To some extent, bicarbonate is also toxic. Other symptoms of toxicity include premature leaf drop, reduced growth and reduced yield. In most cases, plants do not show clear toxicity problems until it is too late to remedy the situation.

Chloride and sodium ions are both present in the solution. Thus, it is difficult to determine whether the damage caused is due to the one or to the other. Chloride ions in high concentrations are known to be harmful to citrus and many woody and leafy field crops. A chloride content exceeding 10 meq/litre may cause severe problems to crops. The effect of sodium toxicity is not very clear. However, it has been found that it may cause some direct or indirect damage to many plants.

Boron is an essential element to the plants. However, where present in excessive amounts, it is extremely toxic, even at relatively very low concentrations of 0.6 mg/litre. Toxicity occurs with the uptake of boron from the soil solution. The boron tends to accumulate in the leaves until it becomes toxic to the leaf tissue and results in the death of the plant. In arid regions, boron is considered the most harmful element in irrigation water.

Other problems

In addition to the moisture availability effect and the toxicity problems to which the soluble salts contribute, certain salt constituents may interfere with the normal nutrition of various crops. Bicarbonate ions in high concentrations may affect the uptake of mineral nutrients and their metabolism in the plant. Chlorotic symptoms in sensitive plants may be due to the direct or indirect effects of bicarbonate, e.g. an increase in soil pH.

Excessive nitrate contents, higher than 100 mg/litre, may affect transplants and sensitive crops at the initial growth stage. However, no negative effects have been reported in the last three decades from fertigation with pure nitrogen concentrations in irrigation water of about 200 ppm. Although there is no doubt about the problem's existence, it seems that the main concern should be the nitrate content in the irrigation water, when calculating the total nitrogen application, NO_3 equals 0.226 N (pure nitrogen).

EFFECTS OF SOLUBLE SALTS ON SOIL

Sodium hazard

A soil permeability problem occurs with a high sodium content in the irrigation water. Sodium has a larger concentration than any other cation in saline water, its salts being very soluble. Positively charged, it is attracted by negatively charged soil particles, replacing the dominant calcium and magnesium cations. The replacement of the calcium ions with sodium ions causes the dispersion of the soil aggregates and the deterioration of its structure, thus rendering the soil impermeable to water and air. The increase in the concentration of exchangeable sodium may cause an increase in the soil pH to above 8.5 and reduce the availability of some micronutrients, e.g. iron and phosphorus.

The degree of absorption to the clay particles of the sodium depends on its concentration in the water and the concentration of the calcium and magnesium ions. This reaction is called cation exchange and it is a reversible process. The capacity of soil to adsorb and exchange cations is limited. The percentage of the capacity that sodium takes up is known as the exchangeable sodium percentage (ESP). Soils with ESP > 15 are seriously affected by adsorbed sodium.

The sodium problem is reduced if the amount of calcium plus magnesium is high compared with the amount of sodium. This relation is called the sodium adsorption ratio (SAR) and it is a calculated value from the formula:

SAR = Na (meq/litre) ÷ v Ca (meq/litre) + Mg (meq/litre) ÷ 2

The use of water with a high SAR value and low to moderate salinity may be hazardous and reduce the soil infiltration rate. The SAR of irrigation water indicates the approximate ESP of a soil with water.

Residual sodium carbonate (RSC)

This is defined as the difference in milliequivalents per litre between the bicarbonate ions and those of calcium and magnesium. Calcium and magnesium may react with bicarbonate and precipitate as carbonates. The relative sodium concentration in the exchangeable complex increases resulting in the dispersion of soil. When the RSC value is lower than 1.25 meq/litre, the water is considered good quality, while if the RSC value exceeds 2.5 meq/litre, the water is considered harmful.

CROP TOLERANCE TO SALINITY

Crop tolerance is the degree to which a crop can grow and yield satisfactorily in saline soil. Different crops vary widely in their response to salinity. Some can tolerate less than 2 dS/m and others up to and above 8 dS/m. Salt tolerance also depends considerably upon cultural conditions and irrigation management practices. Many other factors such as plant, soil, water and climate interact to influence the salt tolerance of a crop.

Relative salt tolerance data have been developed for many crops and are used as general guidelines. The following data are related to the expected decline in yield. The ECe is the soil salinity in terms of electrical conductivity measured from the soil saturation extract, with a value of 1.5 EC for irrigation water (ECiw). Tables 13-18 (taken from Maas, 1990) give two important parameters for expressing a plant's salt tolerance:

- Threshold - the maximum allowable salinity of soil saturation extract (ECe).
- Slope - the percent yield decrease per unit increase in salinity.

The rating of plants according to their sensitivity/tolerance to salts is even more important as it provides vital information at first sight for the evaluation of and diagnosis for potential salinity problems.

TABLE 13 - Relative salt tolerance of herbaceous crops - vegetables and fruit crops

Common name	Botanical name	Threshold dS/m	Slope % per dS/m	Rating
Artichoke	*cynara scolymus*	-	-	MT*
Asparagus	*asparagus officinalis*	4.1	2.0	T
Bean	*phaseolus vulgaris*	1.0	19.0	S
Bean, mung	*vigna radiata*	1.8	20.7	S
Beet, red	*beta vulgaris*	4.0	9.0	MT
Broccoli	*brassica oleracea botrytis*	2.8	9.2	MS
Brussels sprouts	*b. oleracea gemmifera*	-	-	MS*
Cabbage	*b. oleracea capitata*	1.8	9.7	MS
Carrot	*daucus carota*	1.0	14.0	S
Cauliflower	*brassica oleraca botrytis*	-	-	MS*
Celery	*apium graveolens*	1.8	6.2	MS
Corn, sweet	*zea mays*	1.7	12.0	MS
Cucumber	*cucumis sativa*	2.5	13.0	MS
Eggplant	*solanum melongena esculentum*	1.1	6.9	MS
Kale	*brassica oleracea acephala*	-	-	MS*
Kohlrabi	*b. oleracea gongylode*	-	-	MS*
Lettuce	*lactuca sativa*	1.3	13.0	MS
Muskmelon	*cucumis melo*	-	-	MS
Okra	*abelmoschus esculentus*	-	-	S
Onion	*akkium cepa*	1.2	16.0	S
Parsnip	*pastinaca sativa*	-	-	S*
Pea	*pisum sativa*	-	-	S*
Pepper	*capsicum annuum*	1.5	14.0	MS
Potato	*solanum tuberosum*	1.7	12.0	MS
Pumpkin	*cucurbita pepo pepo*	-	-	MS*
Radish	*raphanus sativus*	1.2	13.0	MS
Spinach	*spinacia oleracea*	2.0	7.6	MS
Squash scallop	*curcubita melo melopepo*	3.2	16.0	MS
Squash zucchini	*curcubita melo melopepo*	4.7	9.4	MT
Strawberry	*fragaria sp.*	1.0	33.0	S
Sweet potato	*ipomoea batatas*	1.5	11.0	MS
Tomato	*lycopersicon lycopersicum*	2.5	9.9	MS
Tomato cherry	*l.esculentum var cerasiforme*	1.7	9.1	MS
Turnip	*brassica rapa*	0.9	9.0	MS
Watermelon	*citrullus lanatus*	-	-	MS*

Notes: S sensitive, MS moderately sensitive, MT moderately tolerant, T tolerant. The above data serve only as a guideline to relative tolerance among crops. Absolute tolerance varies, depending upon climate, soil conditions, and cultural practices.

In gypsipherus soils, plants will tolerate an ECe about 2 dS/m higher than indicated.

***:** *Ratings are estimates.*

TABLE 14 - Relative salt tolerance of herbaceous crops - woody crops

Common name	Botanical name	Threshold dS/m	Slope % per dS/m	Rating
Almond **	*prunus duclis*	1.5	19.0	S
Apple	*malus sylvestris*	--	--	S
Apricot **	*prunus americana*	1.6	24.0	S
Avocado **	*persea americana*	--	--	S
Blackberry	*rubus sp*	1.5	22.0	S
Boysenberry	*rubus ursinus*	1.2	22.0	S
Castor seed	*ricinus communus*	--	--	MS *
Cherimoya	*annona cherimola*	--	--	S *
Cherry, sweet	*prunus avium*	--	--	S *
Cherry, sand	*prunus besseyi*	--	--	S *
Currant	*ribes sp.*	--	--	S *
Date palm	*phoenix dactylifera*	4.0	3.6	T
Fig	*ficus carica*	--	--	MT *
Gooseberry	*ribes sp.*	--	--	S *
Grape **	*vitis sp.*	1.5	9.6	MS
Grapefruit **	*citrus paradisi*	1.8	16.0	S
Guayule	*parthenium argentantum*	15.0	13.0	T
Jojoba **	*simmondsia chinensis*	--	--	T
Jujube	*ziziphus jujuba*	--	--	MT *
Lemon **	*citrus limon*	--	--	S
Lime	*citrus aurantiifolia*	--	--	S *
Loquat	*eriobotrya japonica*	--	--	S *
Mango	*mangifera indica*	--	--	S *
Olive	*olea europea*	--	--	MT
Orange	*citrus sinensis*	1.7	16.0	S
Papaya **	*carica papaya*	--	--	MT
Passion fruit	*passiflora edulis*	--	--	S *
Peach	*prunus persica*	1.7	21.0	S
Pear	*pyrus communis*	--	--	S *
Persimmon	*diospyros virginiana*	--	--	S *
Pineapple	*ananas comosus*	--	--	MT *
Plum, prune **	*prunus domestica*	1.5	18.0	S
Pomegranate	*punica granatum*	--	--	MT *
Pummelo	*citrus maxima*	--	--	S *
Raspberry	*rubus idaeus*	--	--	S
Rose apple	*syzygium jambos*	--	--	S *
Sapote, white	*casimiroa edulis*	--	--	S *
Tangerine	*citrus reticulata*	--	--	S *

Notes. Data applicable when rootstocks are used that do not accumulate Na or Cl rapidly, or when these ions do not predominate in the soil. In gypsipherus soils, plants will tolerate an ECe about 2 dS/m higher than indicated.

***:** *Ratings are estimates.*
****:** *Tolerance is based on growth rather than yield*

TABLE 15 - Relative salt tolerance of herbaceous crops - grasses and forage crops

Common name	Botanical name	Threshold dS/m	Slope % per dS/m	Rating
Vetch, common	*vicia angustifolia*	3.0	11.0	MS
Rescuegrass	*bromus unioloides*	--	--	MT*
Rhodesgrass	*chloris gayana*	--	--	MT
Rye (forage)	*secale sereale*	--	--	MS*
Ryegrass, Italian	*lolium italicum multiflorum*	--	--	MT*
Ryegrass, perennial	*l. perenne*	5.6	7.6	MT
Saltgrass, desert	*distichlis stricta*	--	--	T*
Sesbania	*sesbania exaltata*	2.3	7.0	MS
Sirato	*macroptilium atropurpureum*	--	--	MS
Sphaerophysa	*sphaerophysa salsula*	2.2	7.0	MS
Sudangrass	*sorghum sudanense*	2.8	4.3	MT
Timothy	*phleum pratense*	--	--	MS*
Trefoil, big	*lotus uliginosus*	2.3	19.0	MS
Wheat (forage)	*triticum aestivum*	4.5	2.6	MT
Wheat, durum (forage)	*t. turgidum*	2.1	2.5	MT
Wheatgrass, standard	*agropyron sibiricum*	3.5	4.0	MT
Wheatgrass, fairway	*a. cristatum*	7.5	6.9	T
Wheatgrass, intermediate	*a. intermedium*	--	--	MT*
Wheatgrass, slender	*a. trachycaulum*	--	--	MT
Wheatgrass, tall	*a. elongatum*	7.5	4.2	T
Wheatgrass, western	*a.smithii*	--	--	MT*
Wildrye, Altai	*elymus angustus*	--	--	T
Wildrye, beardless	*e. triticoides*	2.7	6.0	MT
Wildrye, Canadian	*e. canadensis*	--	--	MT*
Wildrye, Russian	*e. junceus*	--	--	T
Trefoil, narrowleaf	*l. corniculatus tenuifolium*	5.0	10.0	MT
Trefoil, broadleaf	*l. corniculatus arvenis*	--	--	MT
Panicgrass, blue	*panicum antidotale*	--	--	MT*
Rape	*brassica napus*	--	--	MT*
Alfalfa	*medicago sativa*	2.0	7.3	MS
Alkaligrass, Nuttal	*puccinellia airoides*	--	--	T*
Alkali sacaton	*sporobolus airoides*	--	--	T*
Barley (forage)	*hordeum vulgare*	6.0	7.1	MT
Bentgrass	*agrostis stolonifera palustris*	--	--	MS
Bermudagrass	*cynodon dactylon*	6.9	6.4	T
Bluestem, Angleton	*dichanthium aristatum*	--	--	MS*
Brome, mountain	*bromus marginatus*	--	--	MT*
Brome, smooth	*b. inermis*	--	--	MS
Buffelgrass	*cenchrus ciliaris*	--	--	MS*
Barnet	*poterium sanguisorba*	--	--	MS*
Canarygrass, reed	*phalaris arundinacea*	--	--	MT
Clover, alsike	*trifolium hybridum*	1.5	12.0	MS
Clover, Berseem	*trifolium alexandrinum*	1.5	5.7	MS
Clover, Hubam	*melitotus alba*	--	--	MT*
Clover, ladino	*trifolium repens*	1.5	12.0	MS
Clover, red	*trifolium pratense*	1.5	12.0	MS
Clover, strawberry	*melitotus*	--	--	MT*
Clover, white Dutch	*trifolium repens*	--	--	MS*
Corn (forage)	*zea mays*	1.8	7.4	MS
Cowpea (forage)	*vigna unguiculata*	2.5	11.0	MS
Dallisgrass	*paspalum dilatatum*	--	--	MS*
Fescue, tall	*festuca elatior*	3.9	5.3	MT

TABLE 15 - Relative salt tolerance of herbaceous crops - grasses and forage crops (cont'd)

Common name	Botanical name	Threshold dS/m	Slope % per dS/m	Rating
Fescue, meadow	*f. pratensis*	--	--	MT*
Foxtail, meadow	*alopecurus pratensis*	1.5	9.6	MS
Grama, blue	*bouteloua gracilis*	--	--	MS*
Hardinggrass	*phalaris tuberosa*	4.6	7.6	MT
Kallargrass	*diplachne fusca*	--	--	T*
Lovergrass	*eragrostis sp.*	2.0	8.4	MS
Milkvetch, Cicer	*astragalus cicer*	--	--	MS*
Oatgrass, tall	*arrhenatherum danthonia*	--	--	MS*
Oats (forage)	*avena sativa*	--	--	MS*
Orchardgrass	*dactylis glomerata*	1.5	6.2	MS

Notes. The above data serve only as a guideline to relative tolerance among crops. Absolute tolerance varies, depending upon climate, soil conditions, and cultural practices.

In gypsipherus soils, plants will tolerate an ECe about 2 dS/m higher than indicated.

TABLE 16 - Boron tolerance limits for agricultural crops

Common name	Botanical name	Threshold ** mg/litre	Slope % per mg/litre
Very sensitive			
Lemon*	*Citrus limon*	--	--
Blackberry	*Rubus sp.*	--	--
Sensitive			
Avocado	*persea american*	0.5-0.75	--
Grapefruit*	*citrus paradisi*	0.5-0.75	--
Orange*	*c. sinensis*	0.5-0.75	--
Apricot*	*prunus americana*	0.5-0.75	--
Peach*	*p. persica*	0.5-0.75	--
Cherry*	*p. avium*	0.5-0.75	--
Plum*	*p. domestica*	0.5-0.75	--
Persimmon*	*diospyros kaki*	0.5-0.75	--
Fig, kadota*	*ficus carica*	0.5-0.75	--
Grape*	*vitis vinifera*	0.5-0.75	--
Walnut*	*juglans regia*	0.5-0.75	--
Pecan*	*carya illinoienis*	0.5-0.75	--
Onion	*allium cepa*	0.5-0.75	--
Garlic	*allium sativum*	0.75-1.0	--
Sweet potato	*ipomea batatas*	0.75-1.0	--
Wheat	*triticum aestivum*	0.75-1.0	0.33
Sunflower	*helianthus annuus*	0.75-1.0	--
Bean, mung*	*vigna radiata*	0.75-1.0	--
Sesame*	*sesamum indicum*	0.75-1.0	--
Lupine*	*lipinus hartwegii*	0.75-1.0	--
Strawberry*	*fragaria ap.*	0.75-1.0	--
Artichoke, Jerusalem*	*helianthus tuberosus*	0.75-1.0	--
Bean, kidney*	*phaseolus vulgaris*	0.75-1.0	--
Bean, limab	*p. lunatus*	0.75-1.0	--
Peanut	*arachis hypogaea*	0.75-1.0	--

***:** *Ratings are estimates.*

TABLE 16 - Boron tolerance limits for agricultural crops (cont'd)

Common name	Botanical name	Threshold ** mg/litre	Slope % per mg/litre
Moderately sensitive			
Broccoli	*brassica oleracea botrytis*	1.0	1.8
Pepper, red	*capsicum annuum*	1.0-2.0	--
Pea*	*pisum sativa*	1.0-2.0	--
Carrot	*daucus carota*	1.0-2.0	--
Radish	*raphsnus sativus*	1.0-2.0	1.4
Potato	*solanum tuberosum*	1.0-2.0	--
Cucumber	*cucumis sativus*	1.0-2.0	--
Moderately tolerant			
Cabbage*	*brassica oleracea capitata*	2.0-4.0	--
Turnip	*b. rapa*	2.0-4.0	--
Bluegrass, Kentucky*	*poa pratensis*	2.0-4.0	--
Barley	*hordeum vulgare*	3.4	4.4
Cowpea	*vigna unguigulata*	2.5	12
Oats	*avena sativa*	2.0-4.0	--
Corn	*zea mays*	2.0-4.0	--
Artichoke*	*cynara scolymus*	2.0-4.0	--
Tobacco*	*nicotiana tabacum*	2.0-4.0	--
Mustard*	*brassica juncea*	2.0-4.0	--
Clover, sweet*	*melitotus indica*	2.0-4.0	--
Squash	*cucurbita pepo*	2.0-4.0	--
Muskmelon*	*cucmis melo*	2.0-4.0	--
Cauliflower	*b. oleracea botrytis*	2.0-4.0	1.9
Tolerant			
Alfalfa*	*medicago sativa*	4.6-6.0	--
Vetch, purple*	*vicia bengalensis*	4.6-6.0	--
Parsley*	*petroselinum crispum*	4.6-6.0	--
Beet, red	*beta vulgaris*	4.6-6.0	--
Sugar beet	*b. vulgaris*	4.9	4.1
Tomato	*lycopersicum*	5.7	3.4
Very tolerant			
Sorghum	*sorhgum bicolor*	7.4	4.7
Cotton	*gossypium hirsutum*	6.0-10.0	--
Celery*	*apium graveolens*	9.8	3.2
Asparagus*	*asparagus officinalis*	10.0-15.0	--

***:** *Tolerance based on reduction in vegetative growth*
****:** *Maximum permissible concentration in soil water without reduction in yield. Boron tolerances may vary, depending upon climate, soil conditions, and crop varieties.*

TABLE 17 - Salt tolerance of ornamental shrubs, trees and ground cover (cont'd)

Common name	Botanical name	Max. permissible ECe dS/m
Very sensitive		
Star jasmine	Trachelospermum jasminoides	1-2
Pyrenees cotoneaster	Cotoneaster congestus	1-2
Oregon grape	Mahonia aquifolium	1-2
Photinia	Photinia fraseri	1-2
Sensitive		
Pineapple guava	feijoa sellowiana	2-3
Chinese holly, cv. Burford	Ilex cornuta	2-3
Rose cv. Grenoble	Rosa sp.	2-3
Glossy abelia	Abelia grandiflora	2-3
Southern yew	Podocarpus macrophyllus	2-3
Tulip tree	Liriodendron tulipifera	2-3
Algerian ivy	Hedera canariensis	3-4
Japanese pittosporum	Pittosporum tobira	3-4
Heavenly bamboo	Nandina domestica	3-4
Chinese hibiscus	Hibiscus rosa sinensis	3-4
Laurustinus cv. Robustum	Viburnum tinusm	3-4
Strawberry tree, cv compact	Arbutus unedo	3-4
Grape myrtle	Lagerstroemia indica	3-4
Moderately sensitive		
Glossy privet	Ligustrum lugidum	4-6
Yellow sage	Lantana camara	4-6
Orchid tree	Bauhinia purpurea	4-6
Southern magnolia	Magnolia grandiflora	4-6
Japanese boxwood	Buxus microphylla var. japonica	4-6
Xylosma	Xylosma congestum	4-6
Japanese black pine	Pinus thunbergiana	4-6
Indian hawthorn	Raphiolepis indica	4-6
Dodonaea, cv. atropurpurea	Dodonaea viscosa	4-6
Oriental arborvitae	Platycladus orientalis	4-6
Thorny elaeagnus	Elaeagnus pungens	4-6
Spreading juniper	Uniperus chinensis	4-6
Pyracantha, cv. Graberi	Pyracantha fortuneana	4-6
Cherry plum	Prunus cerasifera	4-6
Moderately tolerant		
Weeping bottlebrush	Callistemon viminalis	6-8
Oleander	Nerium oleander	6-8
European fan palm	Chamerops humilis	6-8
Blue dracaena	Cordiline indivisa	6-8
Rosemary	Rosmarinus officinalis	6-8
Aleppo pine	Pinus halepensis	6-8
Sweet gum	Liquidamabar styraciflua	6-8
Tolerant		
Brush cherry	Syzygium paniculatum	> 8
Ceniza	Leucophyllum frutescens	> 8
Natal plum	Carssa grandiflora	> 8
Evergreen pear	Pyrus Kawakamii	> 8
Bougainvillaea	Bougainvillaea spectabilis	> 8
Italian stone pine	Pinus pinea	> 8
Very tolerant		> 10
White iceplant	Delosperma alba	> 10
Rosea iceplant	Drosanthemum hispidum	> 10
Purple iceplant	Labranthus productus	> 10
Croceum iceplant	Hymenocyclus croceus	> 10

Note: Salinities exceeding the maximum permissible ECe may cause leaf burn, loss of leaves and/or excessive stunting.

TABLE 18 - Boron tolerance limits for ornamentals

Common name	Botanical name	Threshold mg/litre
Very sensitive		
Oregon grape	*Mahonia aquifolium*	
Photinia	*Photinia x fraseri*	
Xylosma	*Xylosma congestum*	
Thorny elaeagnus	*Elaeagnus pungens*	
Laurustinus	*Viburnum tinus*	
Wax-leaf privet	*Ligustrum japonicum*	
Pineapple guava	*Feijoa sellowiana*	
Spindle tree	*Euonymu japonica*	
Japanese pittosporum	*Pittosporum tobira*	
Chinese holly	*Ilex cornuta*	
Juniper	*Juniperus chinensis*	
Yellow sage	*Lantana camara*	
American elm	*Ulmus americana*	
Sensitive		
Zinnia	*Zinnia elaeagnus*	0.5-1.0
Pansy	*Viola tricolor*	0.5-1.0
Violet	*Viola odorata*	0.5-1.0
Larkspur	*Delphinum sp.*	0.5-1.0
Glossy abelia	*Abelia x grandiflora*	0.5-1.0
Rosemary	*Rosmarinus officinalis*	0.5-1.0
Oriental arborvitae	*Platycladus orientalis*	0.5-1.0
Geranium	*Pelargoium x hortorum*	0.5-1.0
Moderately sensitive		
Gladiolus	*Gladiolus sp.*	1.0-2.0
Marigold	*Calendula officinalis*	1.0-2.0
Poinsettia	*Euphorbia pulcherrima*	1.0-2.0
China aster	*Callistephus chinensis*	1.0-2.0
Gardenia	*Gardenia sp.*	1.0-2.0
Southern yew	*Podocarpus macrophyllus*	1.0-2.0
Brush cherry	*Syzygium paniculatum*	1.0-2.0
Blue dracaena	*Cordyline indivisa*	1.0-2.0
Ceniza	*Leucophyllus frutenscens*	1.0-2.0
Moderately tolerant		
Bottlebrush	*Callistemon citrinus*	2.0-4.0
California poppy	*Eschscholzia californica*	2.0-4.0
Japanese boxwood	*Buxus microphylla*	2.0-4.0
Oleander	*Nerium oleander*	2.0-4.0
Chinese hibiscus	*Hibiscus rosa-senensis*	2.0-4.0
Sweet pea	*Lathyrus odoratus*	2.0-4.0
Carnation	*Dianthus caryophyllus*	2.0-4.0
Tolerant		
Indian hawthorn	*Raphiolepis indica*	6.0-8.0
Natal plum	*Carissa grandiflora*	6.0-8.0
Oxalis	*Oxalis bowiei*	6.0-8.0

Notes: Species listed in order of increasing tolerance based on appearance as well as growth reductions. Boron concentration exceeding threshold may cause leaf burn and leaf loss.

WATER QUALITY CRITERIA

There have been calls to establish standards as a guide for judging the suitability of water for irrigation. Any classification should be based on the total concentration and the composition of salts. However, the suitability of water for irrigation also depends on other associated factors, such as the crop, soil, climate and management practices. The classification adopted by FAO in 1985 (after Maas), and proposed as an initial guide, has proved most practical and useful in assessing water quality for on-farm water use. The principal parameters for water classification (crop response to salinity, sodium hazard and toxicity) are quite clear and understood by both the extension engineers and the farmers themselves for proper irrigation management and follow-up purposes.

With the FAO assessment method, the parameters taken into consideration are the four presented below.

Total salinity

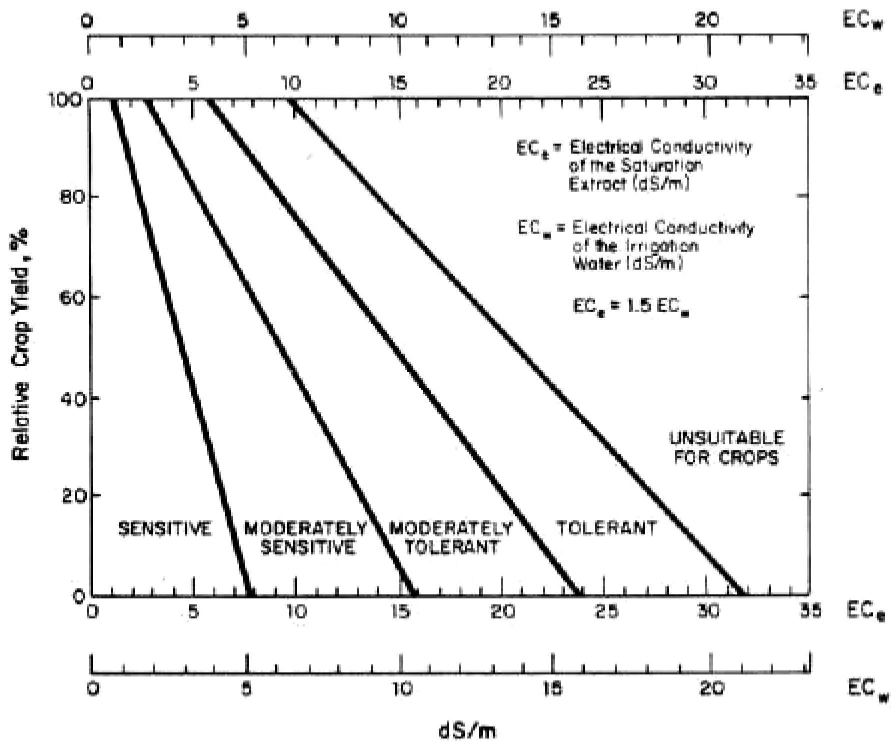
TABLE 19 - Water classification by salinity

	EC dS/m	TDS mg/litre
Non-saline water	< 0.7	< 500
Saline water	0.7-42	500-30 000
Slightly saline	0.7-3.0	500-2 000
Medium saline	3.0-6.0	2 000-4 000
Highly saline	> 6.0	> 4 000
Very saline	> 14.0	> 9 000
Brine	> 42	> 30 000

Crop response to salinity

The figure below shows the expected yield reduction for each crop in accordance with its sensibility/tolerance to salt. This graph enables a quick assessment of the two main parameters for the water suitability.

FIGURE 7.1 - Divisions for relative salt tolerance ratings of agricultural crops (Maas, 1984)



Sodium hazard

The sodium adsorption ratio is commonly used as an index of the sodium hazard of soils and waters, and as a substitute soil ESP. The SAR (Sodium Absorption Ratio) of a given water determines, to a certain extent, the relative amount of sodium that may be adsorbed by the soil. The effect of sodium ions in the irrigation water in reducing the infiltration rate and soil permeability is dependent on the total salt concentration, as shown in Table 20.

TABLE 20 - Potential infiltration problem due to sodium in irrigation water

Salinity levels of irrigation water dS/m	No reduction	Slight reduction	Medium reduction	Severe reduction
	SAR	SAR	SAR	SAR
ECw = 0.7	< 1	1-5	5-11	> 11
ECw = 0.7-3.0	< 10	10-15	15-23	> 23
ECw = 3.0-6.0	< 25	> 25	No effect	No effect
ECw = 6.0-14.0	< 35	> 35	No effect	No effect
ECw = >14.0	No effect	No effect	No effect	No effect

Based on Rhoades, Oster and Schroer.

Toxicity problems

Toxicity problems may be created by excess chloride, sodium, boron, bicarbonate, nitrates and an abnormal pH. The evaluation of the water quality for irrigation should include these and a few other parameters in association with all the other factors involved.

SALINITY CONTROL

The salts that accumulate in the soil can be effectively removed only by leaching. For this to occur, enough water must enter the surface to produce downward percolation and outflow of drainage water from the root zone. The extra amount of this water in addition to the irrigation dose is called the leaching requirement (LR), and can be estimated exactly with the use of the equation:

$$LR = ECw \div 5\ (ECe) - ECw$$

where LR is the leaching requirements as a fraction of the irrigation dose, and ECe is the permissible level of salinity in the soil solution primarily related to the salt tolerance of the crop grown at a 100 percent yield potential. The average value usually taken for ECe is 1.5 ECw. In this case, LR = 0.15.

Leaching is especially necessary as a soil preparation for crops with high plant density, such as carrots, onions and groundnuts. The salinity over the entire area should be the same with no difference between the wetted and the non-wetted parts of the field during the preceding season. The leaching of the salts in the top layer is particularly important because crops are sensitive to salinity during the first stages of their growth.

For the control of the salinity level in the root zone, frequent observations should be conducted with soil sampling for the laboratory determination of the soil extract EC. The use of soil solutions, extractors and portable metering devices on the spot enables the continuous monitoring, for immediate action, of any significant change in the EC of the soil solution, the chloride and nitrate content, and the soil pH as a result of irrigation and fertilization.

MICRO-IRRIGATION AND SALINITY CONTROL

In drip irrigation, the distribution of dissolved salts in the soil profile follows the pattern of the water flux with the tendency for accumulation at the periphery of the wetted soil mass. Most of the wetted zone below the emitter, where most of the roots concentrate and function, remains free from salts during the irrigation season with low to medium salinity values. Near the surface, due to evaporation, the salt accumulation is five times greater than in the deeper layers and increases with distance from the emitters. This, in combination with the use of poor quality irrigation water and the application of fertilizers through the system, will cause a salinity build-up, which might become a problem in areas where the annual rainfall does not exceed 250 mm. In these cases, it is essential to flood the total area once a year, at the end of the season, with adequate amounts of water in order to leach the salts beyond the rooting depth.

The salinity level in the root zone is related to the water quality, the amount of fertilizers and the irrigation dose. The salt accumulation in the vicinity of the emitters is less than half that between the emitter lines. The EC value of the saturation extract beyond the emitter is 2-3 times the ECw, and between the lines it is six to ten times higher. This high salt content can be controlled only by leaching or by reducing the amount of fertilizer during the growing season. In no case should the fertilizer concentration in the irrigation water exceed EC 0.5 dS/m, that is added to the total salinity of the irrigation water.

In drip irrigation, extra leaching with increased quantities of water every application during the irrigation season is not recommended unless salt accumulation reaches hazardous levels. Leaching should take place after the crop harvest, between irrigation seasons, where the salt content is excessive and the rainfall is not sufficient. It is done either by flooding the area or by low precipitation sprinklers with very fine drops.

Example analyses
Case 1

Water chemical analysis data sheet

Submitted by: Andreas Christoforou	Date: 11.9.97
Locality: Potamia	Laboratory No.: W-76/97
Analysis requested: Full ionic plus boron	Borehole No.: N332
Remarks: Planning cropping patterns - fruit trees, vegetables	
LABORATORY RESULTS	Analyst: N. Antoniou Date: 19.9.97
Electrical conductivity ECw dS/m: 3.6	**pH:** 7.1

Anions	mg/litre	meq/litre	Cations	mg/litre	meq/litre
Chloride (Cl^-)	429	2.09	**Sodium (Na+)**	480	20.8
Sulphate (SO_4	552	11.50	**Potassium (K+)**	19	0.5
Carbonate (CO_3^{--})	Nil	Nil	**Calcium (Ca++)**	160	8.0
Bicarbonate (HCO_3^-)	480	7.90	**Magnesium (Mg++)**	60	5.0
Nitrate (NO_3^-)	180	2.90	**Boron (B)**	1.5	------
Total	1 641	34.3		719	34.3
TDS:	2 360				

Evaluation and remarks: SAR = 8, RSC = Nil
Medium saline water - High in sodium and boron content at toxic levels for most fruit trees (citrus, deciduous, etc.) grapes, strawberries and some vegetables (onion, garlic, beans) - there is no sodium hazard - under proper management, on light soil with good infiltration and internal drainage and no impermeable layer, it can be used for irrigation of crops tolerant to salinity and boron, such as olives, pomegranates, pistachio, date palms, most of the vegetables, watermelons, potatoes, etc. and forage crops - some delay in crop development and certain yield reduction should be expected - any problems from bicarbonates can be solved easily - due to high nitrate content, which is equal to 40 g of net nitrogen per cubic metre of water, the application of nitrogen fertilizer should be reduced by 66 percent for fruit trees and 20-30 percent for vegetables accordingly - frequent irrigation is recommended - LR 0.15.

Signature: ____________________

Case 2

Water chemical analysis data sheet

Submitted by: N. Papas	**Date:** 2.10.1997
Locality: Orini	**Laboratory No.:** W/400/97
Analysis requested: Full ionic plus boron	**Borehole No.:** N335
Remarks: Irrigation use	
LABORATORY RESULTS	**Analyst:** A.Magnetis **Date:** 9.10.1997
Electrical conductivity ECw dS/m: 2.1	**pH:** 8.35

Anions	**mg/litre**	**meq/litre**	**Cations**	**mg/litre**	**meq/litre**
Chloride (Cl^-)	215	6.05	**Sodium (Na+)**	320	13.9
Sulphate (SO_4	244	5.10	**Potassium (K+)**	2	--
Carbonate (CO_3^{--})	Nil	Nil	**Calcium (Ca++)**	48	2.4
Bicarbonate (HCO_3^-)	432	7.11	**Magnesium (Mg++)**	31	2.6
Nitrate (NO_3^-)	41	0.66	**Boron (B)**	0.56	
Total	932	18.9		401	18.9
TDS:	1 333				

Evaluation and remarks: SAR = 9, RSC = 2.11
Slightly saline water - no sodium hazard or any severe toxicity problem - under proper management and on light soils with good structure and internal drainage it is suitable for use in the majority of the crops - bicarbonate may cause some micronutrient deficiency problems that can be overcome.

Signature: ____________________

Case 3

Water chemical analysis data sheet

Submitted by: G. Demosthenous | **Date:** 3.11.97

Locality: Limassol | **Laboratory No.:**

Analysis requested: Full ionic plus boron | **Borehole No.:**

Remarks: Irrigation of olives and other field crops

LABORATORY RESULTS | **Analyst:** E. Iasonos **Date:** 10.11.97

Electrical conductivity ECw dS/m: 2.3 | **pH:** 8.7

Anions	**mg/litre**	**meq/litre**	**Cations**	**mg/litre**	**meq/litre**
Chloride (Cl^-)	107	3.02	**Sodium (Na+)**	410	17.80
Sulphate (SO_4	278	5.80	**Potassium (K+)**	6	0.10
Carbonate ($CO_3^{-\,-}$)	14	0.48	**Calcium (Ca++)**	8	0.40
Bicarbonate (HCO_3^-)	624	10.27	**Magnesium (Mg++)**	14	1.20
Nitrate (NO_3^-)	Nil	Nil	**Boron (B)**	2.88	
Total	1 023	19.5		438	19.5
TDS:	1 461				

Evaluation and remarks: SAR = 20, RSC = 8.67
Slightly saline water, however problematic - boron content at toxic levels for the majority of fruit trees and most herbaceous agricultural crops - danger of severe soil infiltration and permeability problem from the use of this water - excess bicarbonate salts could cause chlorosis to some plants - pH is higher than normal and may result in imbalanced nutrition - usage of this water should be done with caution, very good management, on light soils with high infiltration rate and permeability, and selected crops tolerant to boron toxicity, such as date palms, cabbage, cauliflower, squash, parsley, tomato, celery, asparagus, corn, alfalfa, sugar beet - the existing olive trees may be irrigated reservedly - soil improvement additives (washed manure, gypsum, etc.) should be applied occasionally - frequent irrigation is preferable - a follow-up based on a schedule is essential.

Signature: ______________________________

CHAPTER 8: Hose-move sprinkler irrigation

INTRODUCTION

In recent decades various sprinkler irrigation methods and installations, both solid and portable, have been developed to meet farmers' needs. The most widely adopted and least expensive system for irrigating small to medium-sized farms is the piped hand-move system with a low to medium operating pressure (2.0-3.5 bars). The sprinklers are mounted at equal spacings (6-12 m) on the lateral pipelines laid across the field at predetermined intervals (called lateral positions) of 6-18 m so that the irrigation water is sprinkled uniformly over the area covered.

To avoid lateral movement and to reduce labour requirements, the hose-move sprinkler system has been developed. It is an improvement on the conventional piped hand-move system and combines some features of semi-permanent installations with those of permanent ones. In this system the sprinkler lateral lines are placed permanently at a wide spacing up to 60 m apart. The sprinklers, mounted on tripod stands, are not fitted directly to the lateral pipes, but connected to them via flexible PE hoses which are 20-25 mm in diameter and up to 30 m in length. The hoses with the sprinklers can be moved laterally on either side to cover a number of lateral positions.

As the sprinklers are of low to medium pressure, this system can be classed as a low or medium pressure, semi-permanent, hand-move installation. It is recommended for the irrigation of full coverage crops such as alfalfa, maize, cotton, potatoes, carrots and groundnuts. It should be noted that hose-move systems are different from the drag-hose system. The latter is used only for under-tree sprinkling and the sprinklers are fitted on small skids which can be easily dragged backwards from a distance.

SYSTEM LAYOUT AND COMPONENT PARTS

The layout of the system is the standard one consisting of a head control, a pipe distribution network (mains, submains and manifolds, where needed), hydrants, laterals and a number of hoses (one per sprinkler).

The head control is simple and includes only the regulating valves (shut-off, non-return, air, etc.). The main and submain pipelines are usually buried 90-150-mm rigid PVC pipes, or 75-110-mm HDPE pipes laid on the surface. The hydrants (2-3 in) are located along the manifolds (mains or submains) at the same wide spacing as the sprinkler laterals. The manifolds and the sprinkler laterals can be either HDPE or quick coupling light steel/aluminium pipes (63-75 mm). The flexible hoses are soft 20-25-mm LDPE pipes. The tripod stands for the sprinklers can be made of 8-mm iron rods.

SPRINKLERS

The water discharged through the sprinkler devices is shot into the air and falls to the ground in a circular pattern around the sprinkler. Most of the agricultural sprinklers have a hammer-drive slow-rotating or revolving mechanism (hammer wedge and spring, or hammer and rocker weight) and use a low to medium operating pressure (2.0-3.5 bars). They are equipped with two nozzles for discharging the water: the range and the spreader. The range nozzle, larger in diameter, shoots a water jet and covers the area distant from the sprinkler, activating the rotating mechanism at the same time. The spreader nozzle sprays the water in the vicinity of the sprinkler. The nozzles are interchangeable to allow variability in performance according to requirements. The sprinklers are made of brass or heavy-duty plastic. Most of them have several parts made of brass and others of plastic. The axle and the spring are made of stainless steel. The main performance characteristics of the sprinklers used in hose-move systems are:

- two nozzles: 3.0-6.0 mm (range) x 2.5-4.2 mm (spreader);
- low to medium operating pressure: 1.8-3.5 bars;
- water discharge: 1.1- 3.0 m_/h;
- diameter coverage (wetted): 18-35 m;
- jet angle: 20¡-30¡ (except where low angle jet is needed, e.g. strong wind, treated water);
- type of connection: threaded internal or external _-1 in.

To ensure satisfactory sprinkling with impact rotating conventional sprinklers, the minimum operating pressure should be at least 2.0 bars.

DESIGN CRITERIA AND CONSIDERATIONS

The water discharged from a single sprinkler is not uniformly distributed over the entire area; a greater quantity falls near the sprinkler and less in the periphery. To ensure a uniform precipitation over the entire area under irrigation, the sprinklers are always placed so that they overlap each other from both directions. This setting is termed sprinkler spacing. The spacing of the sprinklers along the lateral lines is known as SL, and the spacing between two lines as Sm. The spacing pattern is square, rectangular or triangular, with SL = Sm.

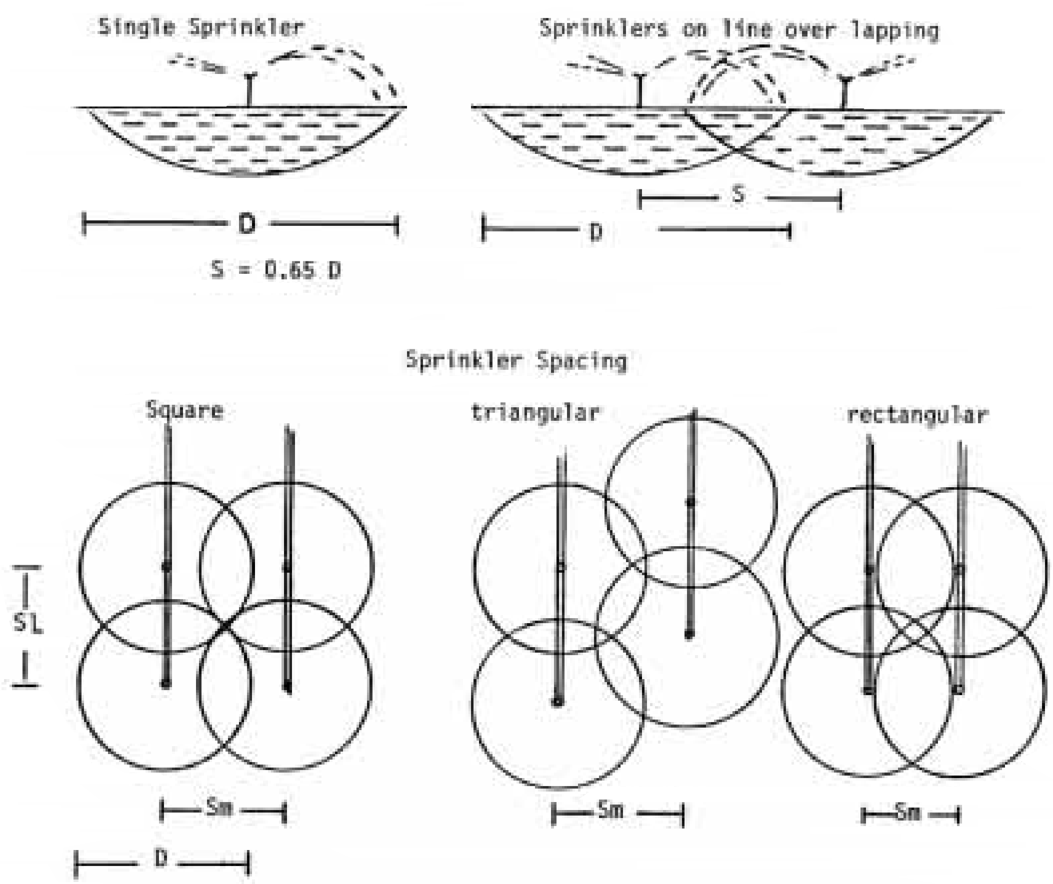
In order to obtain good distribution uniformity by overlapping, the sprinkler spacing (Sm) should not exceed 65 percent of the sprinkler diameter coverage under light to moderate wind conditions in the square and rectangular patterns. In the triangular pattern, the spacing can be extended up to 70 percent of the diameter coverage. In strong wind conditions, the spacing should be 50 percent of the diameter coverage with the lateral direction perpendicular to the wind direction. With a wind strength of over 3.5 m/s, sprinkling is not recommended.

The average application (precipitation) rate is a function of the sprinkler discharge and the spacing of the sprinklers:

Precipitation rate (mm/h) = sprinkler discharge (litres/h) ÷ SL x Sm (m)

The rate of precipitation should not exceed the soil intake (infiltration) rate (25 mm/h in light soils, 8-16 mm/h in loams and 2-8 mm/h in clays).

Profile of wetted soil under sprinklers



D = Diameter Coverage, SL = spacing along the line, Sm = spacing between the lines. Under normal wind conditions (wind speed 2m/sec) S=0.60D. In strong wind (2.5-3.5 m/sec) S=0.50D.

The common sprinkler spacing in low-medium pressure systems is 6, 9, or12 m along the laterals and 12 or 18 m between the laterals. Initially, these spacings were convenient given the standard length of the quick coupling pipe (6 m). However, they have proved most practical as the close spacing, low discharge and precipitation rates of 8-14 mm/h give better results. The height of the sprinklers above ground should be a minimum of 60 cm for low-growing crops. For high-growing crops, the height should be adjusted accordingly.

The light portable quick coupling pipes (steel or aluminium) can be used not only as sprinkler lateral lines but also as water conveyance and distribution lines. These pipes maintain their value for a considerable length of time. There are cases where farmers have sold many of these pipes at a profit even after extensive use.

The design procedure is the same as for the pipe-move sprinkler systems. The sprinkler laterals are laid across the field perpendicular to the manifold line (mains or submains) on lateral positions in accordance with the designed Sm spacing, every 6, 12 or 18 m. The number of laterals operating simultaneously, capable of delivering the flow of the system, is called the set of lateral lines; these lines are fewer in number than their positions. Therefore, after the completion of their operation at one position, the set of laterals is moved to the next position and so on. The number of lateral positions should be a multiple of the number of lateral lines per set. The quotient of the two numbers is the number of movements or shifts per irrigation cycle.

In hose-move sprinkler systems, the sprinklers can be extended on both sides of the lateral line to cover a distance of up to 60 m, which corresponds to six lateral positions at 12-m Sm spacing. Instead of the lateral positions and movements, there are sprinkler positions and movements (shifts). Thus, one lateral line may cover up to six sprinkler positions. Two sets of complete lateral lines with their hoses and sprinklers, one in operation and one on stand-by, can cover an entire field area just by moving the sprinklers from one position to another.

The maximum permissible length of the lateral lines is a function of the size of the pipe, the number of the sprinklers (the spacing) and their discharge. The loss of pressure due to friction in the lateral line should not exceed 20 percent of the pressure at its entrance. Based on this assumption, some indicative figures for quick coupling light steel or aluminium laterals are presented in Table 21.

TABLE 21 - Maximum number of low-medium pressure sprinklers on quick coupling lateral pipes

		50 mm		70 mm		89 mm	
Sprinkler pressure bars	Sprinkler discharge m_/h	6 m	12 m	SL spacing 6 m	12 m	6 m	12 m
2.5	1.5						
3.0	1.65	12	10	23	18	36	28
3.5	1.8						
2.5	2.0						
3.0	2.2	10	8	19	15	30	23
3.5	2.3						

IRRIGATION SCHEDULING PROGRAMME

With sprinkler irrigation, the whole area is wetted and, thus, a larger volume of soil is wetted. This allows a relatively lower water content in the soil to be maintained than is the case with localized methods, thereby increasing the irrigation interval. The larger the volume of wetted soil, the later the crop goes into deficit. The preparation of the irrigation programme follows the standard procedure, i.e. taking into consideration the soil moisture holding capacity, the plant physiology (root depth, growing stages, crop coefficient, etc.) and the climate. The irrigation efficiency is about 75 percent. In general, the irrigation dosage application depth for deep rooted field crops under sprinkling ranges from 40 to 100 mm. With a precipitation rate of about 14 mm/h, the operating time at each position is approximately 3-7 hours. Irrigation intervals of two weeks are common in sprinkler irrigation.

COST

The total cost for the installation of the system in 2.0 ha (as in the example design) is US$1 790.00, or less than US$1 000/ha. A cost analysis shows that the head control costs about US$70. The major cost items are the plastic pipes, PVC and PE tubes, for the system's network which amount to US$1 177, 65.7 percent of the total cost. Imported sophisticated equipment, such as the sprinklers, rarely exceeds 10 percent of the total cost.

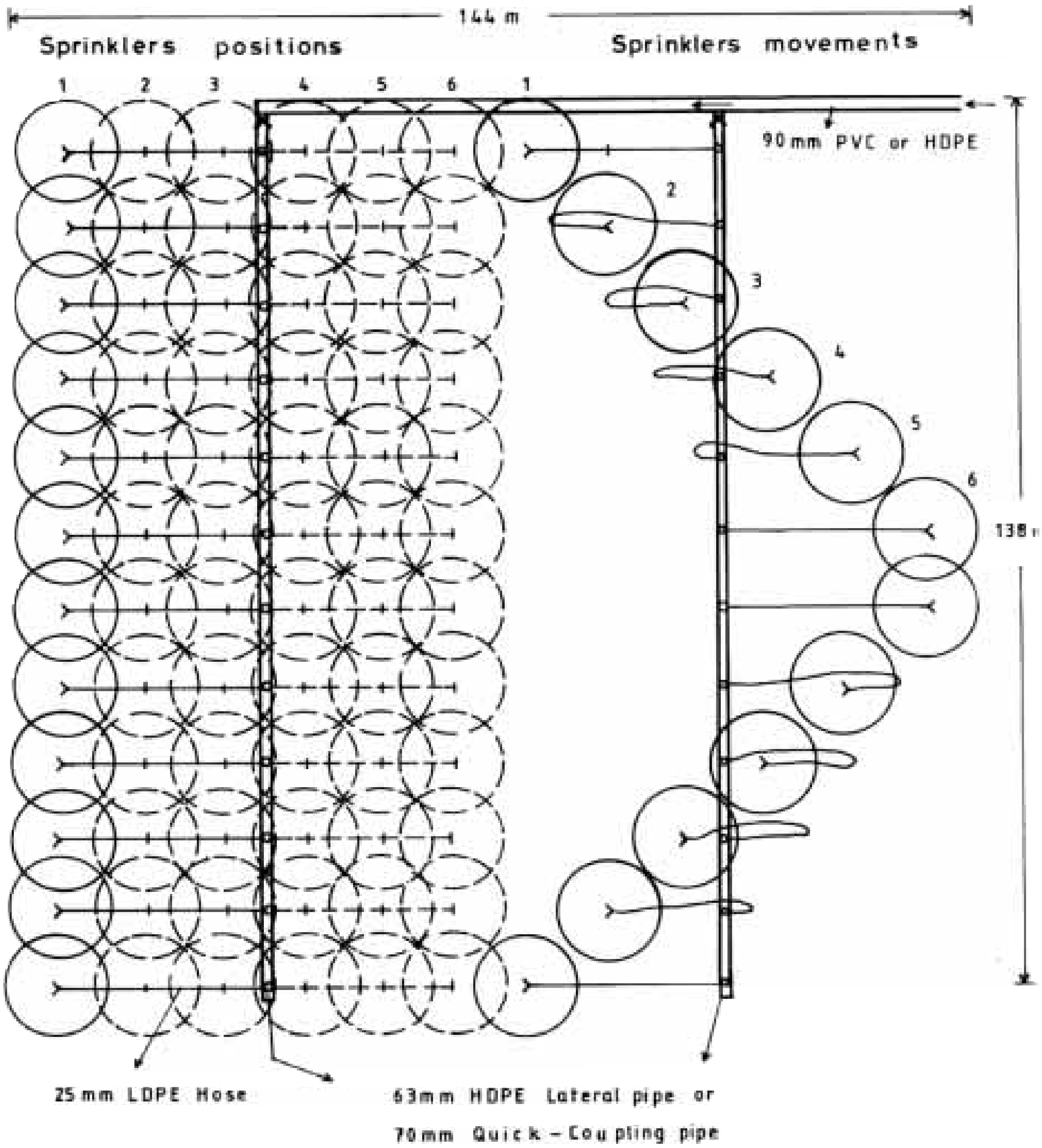
ADVANTAGES

- High irrigation application efficiency - 75 percent.
- Easy design, simple installation and operation.
- Adaptability for all types of soils, many kinds of field crops and small irregular plots.
- Less expensive than many other modern irrigation systems.
- Involves unskilled labour.

DISADVANTAGES

- Moving the hoses with the sprinklers is heavy and unpleasant work.
- Long duration for the irrigation cycle.

Hose move sprinkler irrigation
(Sample design) 2.0 ha



EXAMPLE DESIGN

Hose-move sprinkler for cotton

Area and crop: An area of approximately 2.0 ha planted with cotton at the beginning of August. The field is square and level.

Soil, water and climate: Medium texture soil of good structure, with good infiltration and internal drainage. The soil available moisture (Sa) is 110 mm/m depth. The water is of good quality with no salinity or toxicity hazards; the source is a tube-well equipped with a pumping unit delivering 36 m3/h. The peak irrigation demand is in October, at the mid-season growth stage of the crop.

Crop water requirements and irrigation scheduling: The pan average readings in October are 5.6 mm/d. This figure multiplied by 0.66 (pan correction factor) gives an ETo of 3.7 mm/d. The crop factor kc for cotton at this stage is taken as 1.05, the root depth 1.0 m and the moisture depletion 50 percent. Then, ETc cotton = 3.7 x 1.05 = 3.88 mm/d. The net application depth is Sa 110 mm x root depth 1.0 m x depletion 0.5 = 55 mm. The maximum permissible irrigation interval in October is 55 mm ÷ 3.88 mm/d = 14 days. The irrigation frequency depends on many factors and in no case should exceed the maximum permissible irrigation interval. The system's application efficiency is 75 percent, therefore, the gross application depth at peak is: 55 mm ÷ 0.75 = 73.3 mm. The gross irrigation dose is: 73.3 mm x 10 x 2.0 ha = 1 466 m^3.

System layout, performance and hydraulics

A 90-mm rigid PVC main pipeline is buried along the northern boundary of the field. Two 63-mm HDPE lateral pipelines are placed perpendicular to the mains, from north to south, 60 m apart and connected with the mains through offtake surface hydrants. On the lateral lines and at a regular spacing of 12 m, 25-mm flexible PE hoses 30 m long are fitted and extended on the sides. At the other end of the hoses are sprinklers on tripod stands.

- sprinkler characteristics and performance: low pressure, two-nozzle sprinklers, discharge = 1.5 m_/h at 2.5 bars operating pressure, diameter coverage = 26 m;
- sprinkler spacing: 12 x 12 m;
- precipitation rate: 10.4 mm/h;
- number of sprinklers per lateral: 12;
- number of laterals: 2;

- total number of sprinklers: 24 (operating simultaneously);
- lateral discharge: 18 m_/h;
- system discharge: 36 m_/h;
- number of (lateral) sprinklers positions (shifts): 6;
- duration of application per shift: 73.3 mm ÷ 10.4 = 7 hours;
- duration of irrigation cycle: 42 hours.

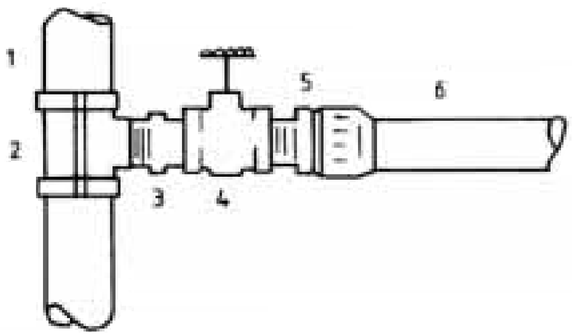
	bars
Pressure required at sprinkler	2.50
Friction losses in the 25-mm LDPE sprinkler hose, 30 m	0.33
Friction losses along the 63-mm HDPE lateral line	0.47
Friction losses along the 90-mm PVC main line	0.15
Minor local and other losses	**0.25**
Total dynamic head required	3.70

List of the equipment required for the hose-move sprinkler system installation (bill of quantities)

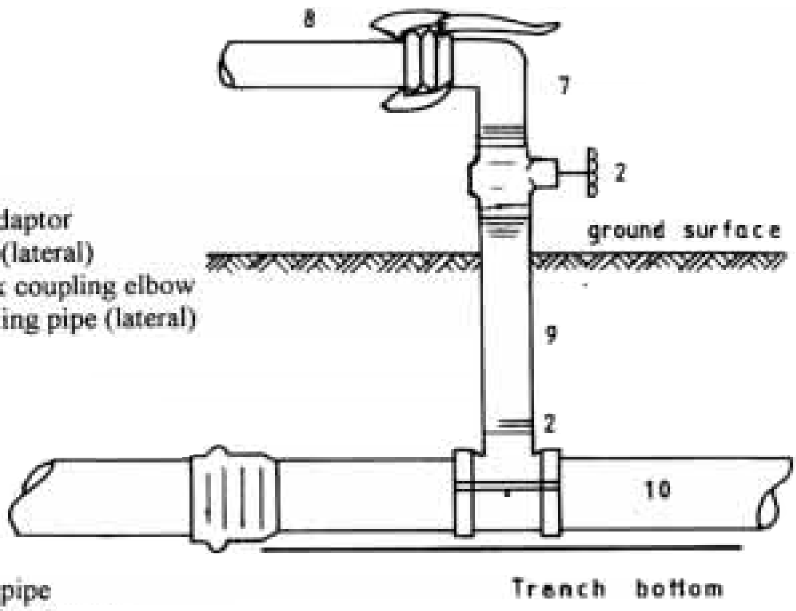
List of the equipment required for the hose-move sprinkler system installation (bill of quantities)

Item	Description	Quantity	Unit price US$	Total price US$
	System distribution network			
1.	90-mm rigid PVC pipe, 6 bars	110 m	2.50	275.00
2.	63-mm HDPE pipe, 6 bars	280 m	1.80	504.00
3.	3-in x 90-mm PP adaptor	1 pc	10.00	10.00
4.	2_-in x 63-mm PP adaptor	2 pcs	5.00	10.00
5.	90-mm PP end plug	1 pc	10.00	10.00
6.	63-mm PP end plug	2 pcs	5.00	10.00
7.	90-mm x 2_-in PP clamp saddle	2 pcs	3.00	6.00
8.	63-mm x _-in PP clamp saddle	24 pcs	1.30	31.20
9.	_-in x 25-mm PP adaptor	48 pcs	1.00	48.00
10.	2_-in threaded riser pipe, 60 cm	2 pcs	4.00	8.00
11.	2_-in gate valve	2 pcs	13.00	26.00
12.	2_-in nipple	2 pcs	1.00	2.00
13.	Tripod sprinkler stand	24 pcs	8.00	192.00
14.	Sprinkler two nozzle, 1.5 m_/h at 2.5 bars	24 pcs	8.00	192.00
15.	25-mm LDPE hose, 4 bars	720 m	0.40	288.00
	Trench excavation and backfilling	110 m	1.00	110.00
				1722.20
	Head control			
16.	2_-in brass check valve	1 pc	15.00	15.00
17.	2_-in brass shut-off valve	2 pcs	13.00	26.00
18.	2_-in tee (galvanized iron, or PVC)	3 pcs	3.50	10.50
19.	2_-in nipple	4 pcs	1.00	4.00
20.	1-in single air valve	1 pc	12.00	12.00
				67.50
			Total cost	**1789.70**

HOSE - Move sprinkler jointing techniques

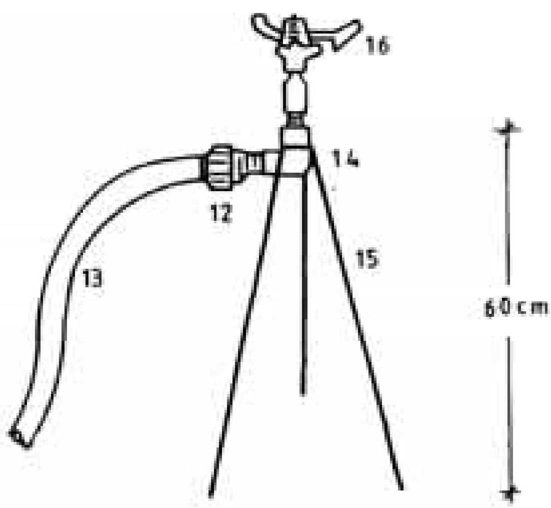


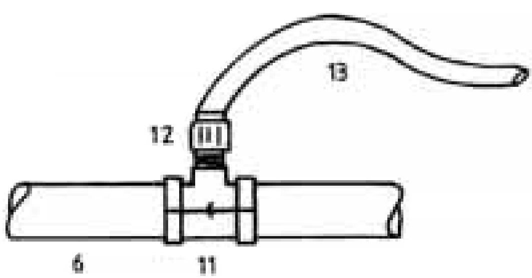
1. 90 mm HDPE Pipe (main)
2. 90 mm x 2½" PP Clamp saddle
3. 2½" Nipple



4. 2½" Gate valve
5. 2½" x 63 mm PP Adaptor
6. 63 mm HDPE Pipe (lateral)
7. 2½" x 70 mm Quick coupling elbow
8. 70 mm Quick coupling pipe (lateral)

9. 2½" Threaded riser pipe
10. 90 mm rigid PVC pipe (buried)
11. 63 mm x ¾" PP Clamp saddle
12. ¾" x 25 mm PP Adaptor
13. 25 mm LDPE hose
14. ¾" G. I. Elbow
15. Tripod stand
16. Sprinkler (two nozzle)





CHAPTER 9: Microsprinklers

INTRODUCTION

Microsprinklers are low capacity water emitters, sprinkler in type, but smaller in size than the conventional sprinklers and with flow rates up to 250 litres/h. They are placed on a relatively close rectangular or triangular spacing for the maximum overlap to irrigate potatoes, carrots, leafy vegetables, groundnuts and other densely planted field crops. This method is reliable, highly efficient, and easy to apply, operate and handle.

The system is a seasonal, low pressure, micro-irrigation solid installation which can be easily placed in the field and quickly removed (collected) at the end of the season.

SYSTEM LAYOUT AND COMPONENTS

The layout of the system consists of a head control equipped only with the regulating valves (shut-off, non-return, air) and a filter of about 40-60 mesh (200-300 microns). No injectors are needed as fertigation through this system is not a common practice among farmers.

The arrangement of the main and submain lines, hydrants and manifolds is the same as in other micro-irrigation piping networks.

The size of the manifold feeder lines should be 50-63 mm and in no case exceed 75 mm. Pipelines of 50-63 mm are recommended for flows of approximately 12-18 m_/h when the water is distributed en route continuously.

The pipes used for the system's distribution network are mainly in rigid PVC (buried) or black HDPE (normally laid on the surface). Other kind of pipes are used also, such as layflat hoses and quick coupling galvanized light steel pipes.

The laterals are soft PE pipes, 20, 25 or 32 mm in diameter, according to the length, PN 4.0 bars, laid permanently on the surface. The microsprinklers are placed along the laterals at a spacing of 5-7 m, fixed 70-80 cm above the surface on iron rods inserted into the ground. They are connected to the laterals through a small flexible PVC tube 7-9 mm in diameter and 1 m long.

MICROSPRINKLER EMITTERS

These emitters are low capacity rotary sprinklers designed for low discharges uniformly distributed over the irrigated area in a rainfall pattern. Made of durable plastic, they have various operating mechanisms, and are usually compact without external moving parts. They have one low trajectory (jet angle above nozzle), quick rotating, 1.5-2.0-mm nozzle.

The main performance characteristics are:

- operating pressure: 2.0 bars;
- flow rate (discharge): 130-250 litres/h (recommended 160-180 litres/h);
- wetting diameter (coverage): 12 m average;
- precipitation rate: 4-7 mm/h (recommended);
- filtration requirements: 40-60 mesh (300-250 microns) approximately.

A complete set consists of: a) the sprinkler emitter compact head; b) a 6-mm iron rod 1 m long; and c) a 7-9-mm flexible PVC tube with a barbed plunger for connection with the PE lateral line.

IRRIGATION SCHEDULING PROGRAMME

This system enables a high degree of control of both when to apply and how much irrigation water to apply. The restrictions imposed by the system are limited. Thus, there are more timing options in the irrigation scheduling programme. The vegetables are mostly shallow rooted crops, so the selected option is generally that of fixed depletion irrigation.

A gross application depth of 20-30 mm is common for potatoes and vegetables. The gross water requirements of a vegetable or a potato plantation vary from 300 to 400 mm in terms of depth. Thus, the total number of irrigations required is about 12-15, at intervals based on the cumulative evaporation.

DESIGN CRITERIA AND CONSIDERATIONS

In addition to the standard design criteria, such as area, crop, water supply, soil and climate, it is important to examine the system's special features and characteristics as these parameters influence the final decision.

Microsprinklers deliver the water in low application rates and in fine drops. Such drops easily drift in the air, even under low to moderate wind conditions. In order to ensure a high uniformity of application, the sprinkler spacing should be decreased and not exceed 50 percent of the diameter coverage, i.e. the sprinkler spacing along the laterals and between the laterals should range from 5 to 7 m. Hence, common spacings are 5 x 5 m, 5 x 6 m, 5 x 7 m and 6 x 7 m. Furthermore, to mitigate the adverse effects of the wind, a relatively large number of sprinklers per unit area should be operated simultaneously. The operation shifts should be arranged so that the area irrigated at the same time is as compact as possible.

The system laterals are made of LDPE. Experience has shown that the optimum size of these pipes for this system is 32 mm as such pipes are easy to handle on site, to place, to remove, etc. Larger diameters are not recommended.

The maximum permissible length of various size laterals on level ground depending on the number of the sprinklers, the spacing and the flow rate is as follows:

Lateral size and spacing		160 litres/h		180 litres/h	
		No. of sprinklers	Lateral length m	No. of sprinklers	Lateral length m
20 mm	5 m	8	40	7	35
20 mm	6 m	7	42	6	36
20 mm	7 m	7	49	6	42
20 mm	8 m	7	56	6	48
25 mm	5 m	12	60	11	55
25 mm	6 m	11	66	10	60
25 mm	7 m	10	70	10	70
25 mm	8 m	10	80	9	72
32 mm	5 m	21	105	18	90
32 mm	6 m	20	120	17	102
32 mm	7 m	18	126	16	102
32 mm	8 m	18	144	15	120

All pipes LDPE 4.0 bars to DIN 8072 (inside diameter 16.0, 20.2 and 27.2 mm respectively).

COST

The cost for a complete installation of this system is approximately US$3 300/ha. The head control unit accounts for 8-10 percent of the total cost of the system; the plastic pipes (tubes), exactly 50 percent; and the low capacity sprinklers, nearly 35 percent.

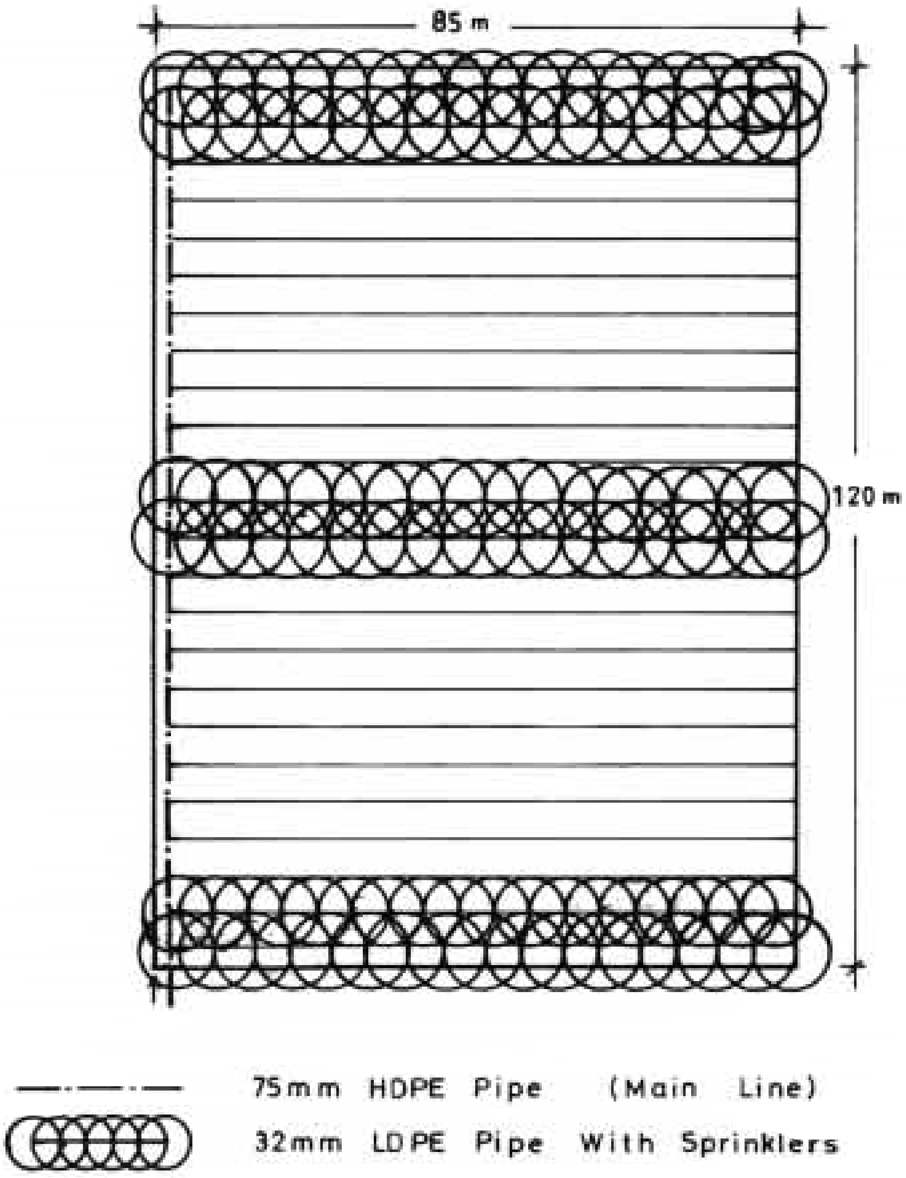
ADVANTAGES

- Low labour O&M requirements.
- Flexibility and adaptability: the technology is simple and easy to adopt and manage. The safe transition from traditional surface methods to advanced micro-irrigation can be successfully accomplished through the installation of this kind of system.
- High irrigation application efficiency.

DISADVANTAGES

- High initial purchase cost.

Low capacity sprinkler irrigation in potatoes (solid system)
(Sample design)



EXAMPLE DESIGN

Microsprinklers with potatoes

Area and crop: The plot dimensions are 120 x 85 m (1.0 ha) planted with spring potatoes.

Soil, water and climate: Fine texture soil of good structure with a permeability of approximately 11 mm/h, and a high water holding capacity (200 mm/m). The water is supplied from a properly treated reservoir; it is clean, but slightly saline. The spring potato season is from January to May. In April the average pan readings are 3.3 mm/d; multiplied by the pan correction factor (0.66), this gives ETo = 2.18 mm/d.

Crop water requirements and irrigation schedule: Peak demand is in April and the kc value is 0.9. Then, ETc = 2.18 x 0.9 = 1.96 mm/d (net water requirements at peak). The system's application efficiency is 75 percent. In addition, an extra amount of about 15 percent should be applied for leaching salts. The peak gross irrigation requirements are:

1.96 mm/d x 100/75 = 2.61 mm/d x 100/85 = 3.1 mm/d x 10 x 1.0 ha = 31 m_/day

The soil available moisture is 200 mm/m depth, the effective root depth is 0.35-m, and the maximum recommended moisture depletion is 40 percent. The maximum irrigation interval in April is:

200 x 0.35 x 0.4/1.96 = 14 days

The irrigation scheduling programme is arranged at a fixed depletion of about 20 mm (cumulative evaporation). Thus, the interval in April is: 20 ÷ 1.96 = 10 days. The gross irrigation application is 31.4 mm, which gives a gross amount of 314 m_/ha per irrigation.

System layout: The system is a solid installation with all the sprinkler laterals permanently laid on the field. The head control unit is equipped with regulating valves and a screen filter of 60 mesh. There is only the main line, 75-mm HDPE, 6.0 bars, laid along the side of the field serving also as a manifold, feeding the laterals. The sprinkler laterals are 32-mm LDPE, 4.0 bars, connected with the mains through _-in hydrants.

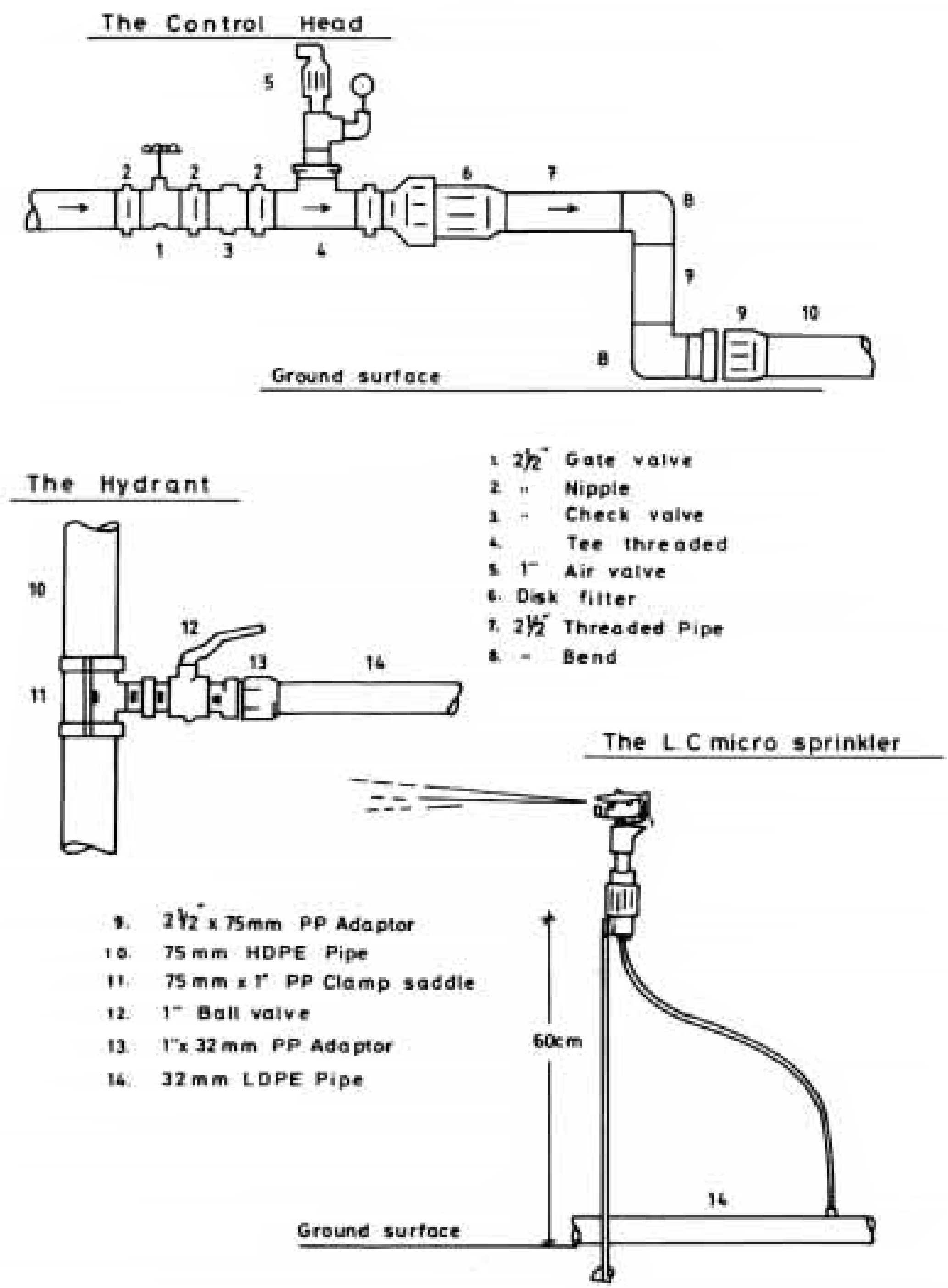
Sprinklers: 160 litres/h at 2.0 bars, full circle, wetting diameter (coverage) 11 m. Spacing: 5 m along the lateral x 5 m between the laterals. Precipitation rate: 6.4 mm/h. Number of sprinklers per lateral: 17.

Lateral line discharge: 2 720 litres/h. Total number of laterals: 24. Number of laterals operating simultaneously (per shift): 6. System discharge: 16.3 m_/h. Number of shifts per irrigation: 4. Duration of application per shift: 4.9 h (4 h 50 min). Time required for one irrigation: 19.5 h (all shifts).

System's operating pressure:

	bars
Pressure required at the sprinkler head:	2.00
Friction losses in the lateral:	0.20
Friction losses in the main line:	0.35
Friction losses in the head control:	0.50
Minor local losses:	0.20
Total dynamic head	3.05

Low capacity (micro) sprinkler system



List of equipment needed for the installation

Item	Description	Quantity	Unit price US$	Total price US$
	System distribution network			
1.	75-mm black HDPE, 6.0 bars	120 m	2.60	312.00
2.	32-mm black LDPE, 4.0 bars	2040 m	0.65	1326.00
3.	75-mm x 2_-in PP adaptor	1 pc	9.00	9.00
4.	32-mm x 1-in PP adaptor	24 pcs	1.25	30.00
5.	75-mm PP end plug	1 pc	9.00	9.00
6.	32-mm PP end plug	24 pcs	1.25	30.00
7.	75-mm x 1-in PP clamp saddle	24 pcs	1.80	43.20
8.	1-in brass shut-off valve	24 pcs	3.50	84.00
9.	1-in nipple	24 pcs	0.40	9.60
10.	Low capacity sprinklers, full circle, 160 litres/h at 2.0 bars, 11 m wetted diameter, complete with supporting stake and connector tube	408 pcs	2.80	1142.40
				2995.20
	Head control			
11.	2_-in brass check valve	1 pc	15.00	15.00
12.	2_-in brass shut-off valve	2 pcs	13.00	26.00
13.	2_-in tee (galvanized iron or PVC)	3 pcs	3.50	10.50
14.	2_-in nipple	4 pcs	1.00	4.00
15.	1-in air valve (single automatic)	1 pc	12.00	12.00
16.	2_-in filter screen type 60 mesh	1 pc	180.00	**180.00**
				247.00
			Total cost	**3242.20**

CHAPTER 10: Minisprinklers

INTRODUCTION

With this method a single minisprinkler emitter is placed for each tree. The emitter sprays water in a circular pattern under the foliage at low rates over a limited area around the tree. This approach combines the principles and advantages of both sprinkler and localized drip irrigation.

Minisprinkler irrigation is a localized micro-irrigation approach which uses a low pressure system in a solid permanent or seasonal installation.

SYSTEM LAYOUT AND COMPONENTS

The control station can be as simple as possible. However, a filtering device is necessary as in all micro-irrigation installations. The fertilizer injector is not always needed, as many farmers prefer to apply fertilizer manually. Nonetheless, the arrangement of the equipment should be one which will enable the installation of a fertilizer injector at a later stage.

The mains and the submains can be of any kind of permanently assembled pipes, either on the surface or buried, with hydrants (2-3 in) rising on the surface, or protected in valve boxes where buried.

The manifold (feeder) pipelines can be either surface-laid HDPE or buried rigid PVC pipes. Other kinds of pipes can also be used, such as layflat hose or quick coupling light steel pipes.

The laterals with the minisprinklers are laid along the rows of the trees near the trunks, one line at each row, with one minisprinkler per tree.

The lateral pipelines are generally (soft) 16, 20, 25 and 32-mm LDPE pipes, 4.0 bars PN. Buried small-diameter PVC pipes can also be used for the laterals, with longer connecting small plastic tubes, rising on the surface.

THE MINISPRINKLER EMITTER

The microsprayers used in tree orchards, called minisprinklers, spitters or micro-jets, are small plastic emitters of the static sprinkler type with a low-angle small water discharge in the form of fine drops which is uniformly distributed around the trees in a full or part circle pattern.

They can be of various mechanisms (capped with a rotating needle, non-capped with a swivel spreader, or with a deflector) with a wide range of flow rates and water diameters. All kinds have rather small flow sectional areas (nozzle diameter 1-1.7 mm approximately). The irrigation water needs to be filtered before it enters the system.

The main performance characteristics of the minisprinklers are:

- operating pressure: 1.5-2.0 bars;
- flow rate: 35-250 litres/h (generally 150 litres/h);
- wetting diameter: 3-6 m;
- precipitation rate: 2-20 mm/h (generally 4-8 mm/h);
- filtration requirements: 60-80 mesh (250-200 microns).

The minisprinkler heads are fixed to small plastic wedges or metallic rods 20-30 cm above the ground and they are connected to the PE laterals with 7-9-mm flexible plastic tubes 60-120 cm long and a barbed plunger. Thus, a complete minisprinkler emitter consists of the head, support wedge and connecting tube with plunger. All component parts are press-fit, interchangeable and easily assembled and dismantled.

Minisprinklers with trees

IRRIGATION SCHEDULING

As in all localized micro-irrigation methods, the amount of water stored in the root zone is restricted as a result of the limited wetted soil volume. However, with this method the wetted volume of soil exceeds 65 percent of the total volume, there thus being no urgent need for very frequent irrigations unless the soil water holding capacity is very low.

The common practice is to irrigate at a fixed interval on a weekly basis and to apply the accumulated water requirements in the preceding days. With young trees, the irrigation interval is shorter, twice a week. Farmers in most arid and semi-arid zones apply water to their tree crops (citrus, guavas, avocado, etc.) as per Table 22.

TABLE22 - Minisprinkler irrigation scheduling

Age of trees years	Litres per tree per day	Irrigation interval (days)	Average irrigation dosage per tree (litres)	Average operation time (hours)
1-2	8-15	4-6	60	0.5
3-4	20-40	6-7	200	1.6
4-6	50-60	7	380	3.0
7 plus	80-120	7-10	900	7.5

DESIGN CRITERIA AND CONSIDERATIONS

Minisprinklers are mainly used with intensively irrigated fruit trees. They can also be used with rainfed trees for supplementary irrigation. One emitter per tree is sufficient; therefore, the emitter spacings are identical to the tree spacings. The distance between the minisprinklers and the tree trunks is 30-50 cm depending on the age and size of the tree. For young trees, the minisprinkler heads can be mounted upside down to reduce the wetting diameter.

The emitter flow rate should be one which matches the existing conditions of water availability; the area; the number, age and size of the trees; and the number of irrigation shifts (irrigation programme). This is not a difficult task, considering the large range of minisprinkler flow rates available.

The minisprinkler emitters are short-path nozzle-orifice emitters with fully turbulent flow. Therefore, the variation in minisprinkler discharge is half the variation in the operating pressure; e.g. a 20-percent difference in pressure results in a 10-percent difference in discharge, which is considered the maximum permissible. Table 23 is based on this principle.

TABLE 23 - Maximum number of minisprinklers on the lateral and length of lateral on level ground. Minisprinkler flow rate at 2.0 bars

	70 litres/h		120 litres/h		150 litres/h	
Lateral size and spacing (metres)	Max. no. of mini-sprinklers	Lateral length (metres)	Max. no. of mini-sprinklers	Lateral length (metres)	Max. no. of mini-sprinklers	Lateral length (metres)
16 mm 3	10	30	7	21	6	18
4	9	36	6	24	6	24
5	8	40	6	30	5	25
6	8	42	5	30	5	30
8	7	56	5	40	4	32
20 mm 3	16	48	11	33	9	27
4	15	60	10	40	9	36
5	14	70	9	45	8	40
6	13	78	9	54	8	48
8	11	88	8	64	7	56
25 mm 3	25	75	18	54	15	45
4	22	88	16	64	14	56
5	20	100	15	75	13	65
6	19	114	14	84	12	72
7	18	144	12	96	11	88

Note: All pipes are LDPE, 4.0 bars, to DIN 8072.

Minisprinklers with trees

COST

The total cost for the installation of the system on 1.0 ha, as in the example design, is US$1 634. A cost analysis shows that the head control unit costs US$470, i.e. 26 percent of the total. The same unit can serve an area of at least 3.0 ha. The most important cost item is the PE pipes (tubes), i.e. the system network, at US$864. This is 55 percent of the total cost for a 1.0-ha system. For a 3.0-ha complete installation, the pipes represent about 65 percent of the total cost.

ADVANTAGES

- High irrigation application efficiency. The amount of water is precisely controlled and only a partial area is wetted. No losses occur due to evaporation, deep percolation or runoff.
- Salinity control. The water movement through the soil profile is vertical downwards and the accumulated salts in the root zone can easily be leached to deeper layers.
- Flexibility and adaptability. It is the most flexible micro-irrigation system and is easily adopted and managed by farmers. The technology is simple and the range of equipment relatively low.
- Low labour requirements.

DISADVANTAGES

- High initial purchase cost.

EXAMPLE DESIGN

Minisprinkler with citrus lemon trees

Area and crop: The plot is 85 x 120 m, i.e. about 1 ha, planted with mature (12-year-old) citrus lemon trees in rows at a spacing of 6 x 6 m. There are 20 rows with 14 trees in each row for a total of 280 trees. The slope of the plot is 0.5 percent from west to east and from north to south.

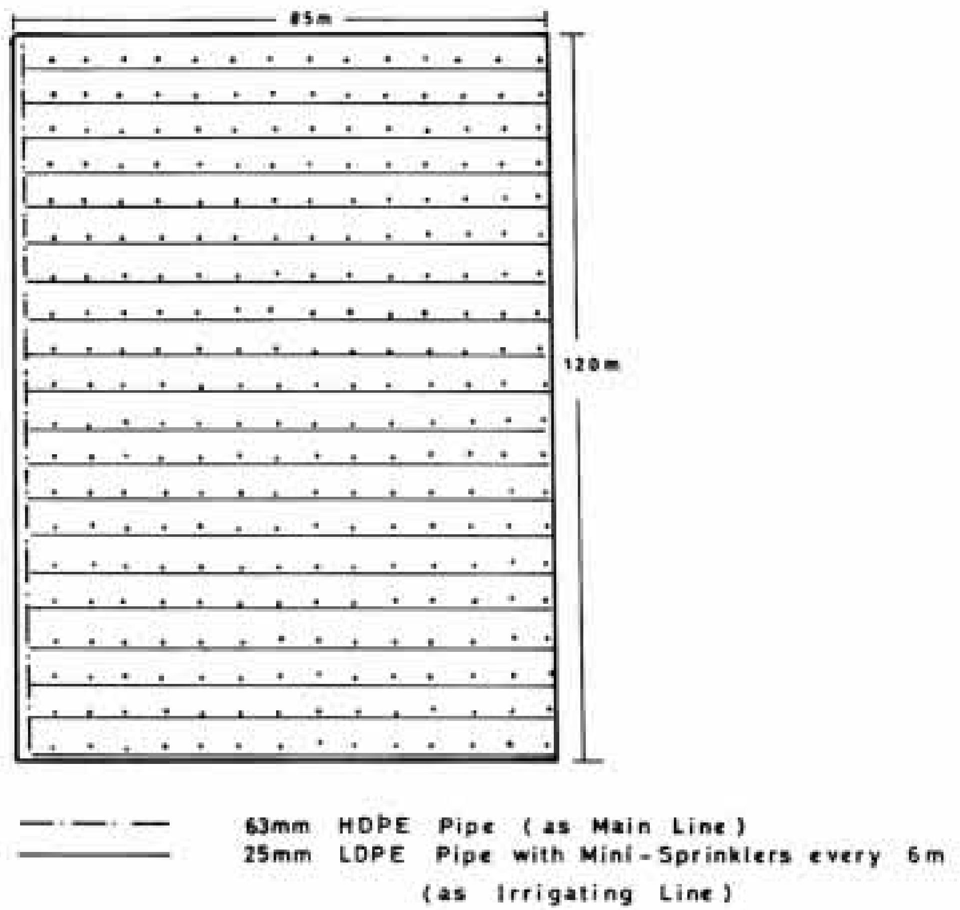
Soil, water and climate: The soil is of medium texture with a permeability of approximately 4 mm/h, a water holding capacity of 22 percent, and soil available moisture of 150 mm/m depth. There are no salinity or toxicity hazards. The source of water is an existing tube-well with a safe output of 5 litres/s (18 m^3/h). The water is of good quality with the electrical conductivity of the irrigation water ECw = 1.5 dS/m total salinity. The evaporation pan average readings in mid-July are 7.0 mm/d. The irrigation season is from April to October.

Crop water requirements and irrigation schedule: A pan reading of 7.0 mm/d multiplied by 0.66 (pan correction factor) gives an ETo of 4.65 mm/d. The crop factor kc is 0.65. Thus, ETc = 4.65 x 0.65 = 3.0 mm/d. The area shaded by the tree canopy is 70 percent and for calculation purposes it is taken as 82 percent. Therefore, the daily water requirements are: 3.0 x 0.82 = 2.48 mm/d net. With a system application efficiency of 80 percent, the gross daily irrigation requirements are: 2.48 x 100 ÷ 80 = 3.1 mm (31 m^3). If irrigation takes place every 10 days, the gross irrigation dosage is: 10 x 31 = 310 m^3.

The maximum permissible irrigation interval in July with a 50-percent moisture depletion for a tree root depth of 0.6 m is: 150 x 0.6 x 0.5 ÷ 3.0 = 15 days. The irrigation frequency depends on many factors and in no case should exceed the maximum permissible irrigation interval.

However, as mentioned, the common practice is to irrigate every seven days. The seven-day interval accumulates gross irrigation requirements of 217 m^3, i.e. the irrigation dosage at peak demand in July.

Mini sprinkler irrigation in fruit trees. (Sample design)

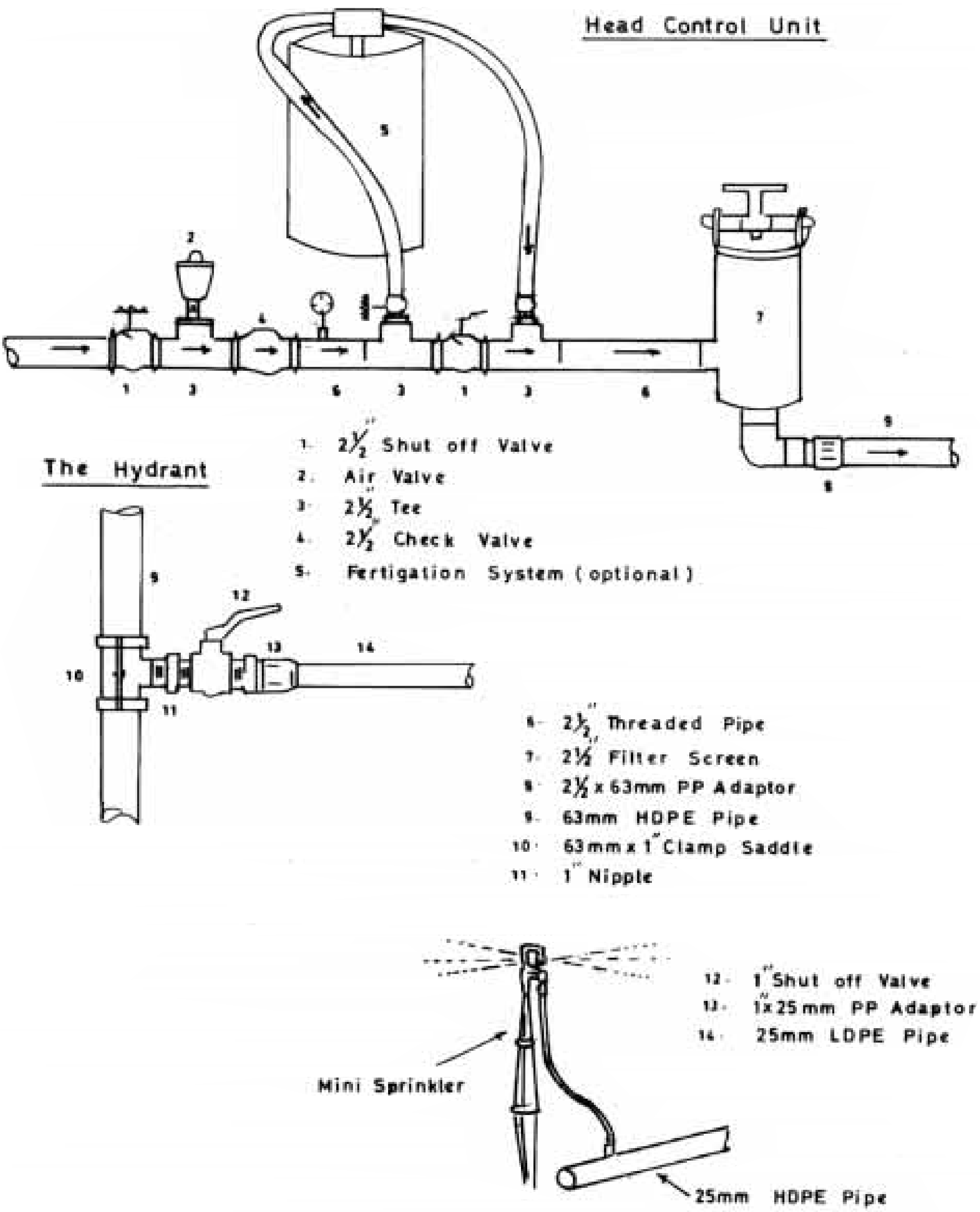


SYSTEM LAYOUT, PERFORMANCE AND HYDRAULICS:

- One lateral irrigating line of 25-mm LDPE pipe, 81 m long, is laid along each row of trees, with one minisprinkler per tree, i.e. 14 minisprinklers per line. The laterals lines are connected directly to the main line, a 63-mm HDPE pipe laid along the plot boundaries, which also serves as a manifold.
- Minisprinkler performance: 120 litres/h flow rate full circle, 2.0 bars, 60 mesh, filtration required.
- Number of minisprinklers per lateral line: 14
- Lateral discharge: 1 680 litres/h
- System discharge: 7-18 m/h
- Total number of laterals: 20
- Maximum number of laterals operating simultaneously: 10
- Number of shifts per irrigation: 2
- Duration of irrigation application per shift: 6.2 hours approximately.

	bars
Pressure required for minisprinkler operation	2.00
Friction losses along the lateral line	0.35
Friction losses along the main line	0.25
Friction losses in the head control unit	0.50
Minor local losses	0.20
	3.30
Difference in elevation	0.15
Total dynamic head	3.15

Mini sprinkler system



Equipment required for the system installation

Item	Description	Quantity	Unit price US$	Total price US$
	System distribution network			
1.	63-mm black HDPE pipe, 6.0 bars	120 m	1.80	216.00
2.	25-mm black LDPE pipe, 4.0 bars	1620 m	0.40	648.00
3.	63-mm x 2_-in PP adaptor	1 pc	6.00	6.00
4.	25-mm x _-in PP adaptor	20 pcs	1.00	20.00
5.	63-mm PP end plug	1 pc	6.00	6.00
6.	63-mm x _-in PP clamp saddle	20 pcs	1.30	26.00
7.	_-in brass shut-off valve	20 pcs	2.30	46.00
8.	Minisprinkler full circle, 120 litres/h, 2.0 bars	280 pcs	0.70	**196.00**
				1164.00
	Head control			
9.	2_-in brass check valve	1 pc	15.00	15.00
10.	2_-in brass shut-off valve	2 pcs	13.00	26.00
11.	_-in brass shut-off valve	2 pcs	2.30	4.60
12.	2_-in galvanized iron nipple	2 pcs	1.00	2.00
13.	_-in galvanized iron nipple	2 pcs	0.25	0.50
14.	2_-in galvanized iron tee	3 pcs	3.50	10.50
15.	1-in air valve automatic single	1 pc	12.00	12.00
16.	2_-in filter (screen or disk type) 60 mesh	1 pc	180.00	**180.00**
				250 60
			Total cost	**1415.00**

CHAPTER 11: Bubbler irrigation of trees

INTRODUCTION

Bubbler irrigation is a localized, low pressure, solid permanent installation system used in tree groves. Each tree has a round or square basin which is flooded with water during irrigation. The water infiltrates into the soil and wets the root zone. The water is applied through bubblers. These are small emitters placed in the basins which discharge water at flow rates of 100-250 litres/h. Each basin can have one or two bubblers as required.

SYSTEM LAYOUT AND COMPONENTS

The system layout is the typical one of all pressurized systems. It consists of a simple head control unit without filters and fertilizer apparatus. The mains and the submains are usually buried rigid PVC pipes, with hydrants rising on surface. The manifolds and laterals are also often buried rigid PVC pipes. The bubblers are placed above ground, supported on a stake, and connected to the laterals with a small flexible tube rising on the surface, or they can be fitted on small PVC risers connected to the buried laterals.

The difference between bubbler systems and other micro-irrigation installations is that whereas in the other installations the lateral lines are small (12-32 mm), the bubblers are usually 50 mm (due to the lateral high discharge). This is why the laterals need to be underground.

BUBBLER EMITTERS

The bubblers are small plastic head emitters with a threaded joint. They were originally designed for use on risers above ground for flood irrigation of small ornamental areas. In recent decades they have been used successfully in several countries for the irrigation of fruit trees. They perform well under a wide range of pressures delivering water in the form of a fountain, small stream or tiny umbrella in the vicinity of the emitter.

The main performance characteristics are:

- Operating pressure: 1.0-3.0 bars;
- Flow rate (discharge): 100-250 litres/h (adjustable);
- No filtration is required.

There is a wide range of flow rates up to 800 litres/h; this paper presents only low discharge bubblers.

IRRIGATION SCHEDULING

With bubbler irrigation the percentage of the root soil volume wetted is about 80 percent. Thus, there are no restrictions on the way the irrigation programme is prepared. This can be either fixed depletion or fixed interval, taking into consideration the soil water holding capacity, the availability of the irrigation water, the size of flow, etc.

DESIGN CRITERIA AND CONSIDERATIONS

Bubbler irrigation is mainly applied in fruit tree orchards. The most important criteria, apart from the routine design criteria, are the system's special features and characteristics.

Bubbler emitters discharge water on the same spot of ground at high rates. Thus, for a uniform distribution over the basin area, a minimum of land preparation is needed. In sandy soils, the water infiltrates at the point of application and high losses occur due to deep percolation. In fine soils with low infiltration rates, the water ponds and evaporation occurs.

Mature trees always take two bubbler emitters, one on each side, in order to ensure an acceptable uniformity of application. The flow rate per tree is relatively high compared with other micro-irrigation techniques at about 500 litres/h. Thus, the diameter of an 80-m-long lateral for a single row of 13 trees spaced at 6-m intervals should be 50 mm.

The common practice is to have one lateral per two rows of trees with small flexible tubes extended on both sides and connected to the bubblers. In this way, the same size of lateral pipe (50 mm), placed (buried) between two rows can serve 12 trees on each side (24 trees in total) spaced at 6-m intervals with 48 bubbler emitters.

The size of the equipment for the installation should always be able to accommodate the flows required for mature trees.

For longer laterals, pressure compensated bubblers can be used, though this involves higher energy consumption and more expensive higher pressure pipes.

COST

The cost for a complete permanent installation of this system is about US$3 900/ha, of which US$70 are needed for the head control unit, i.e. less than 2 percent. The cost of the pipes (all rigid PVC) is US$1 250 plus US$970 for the trench (excavation and backfilling), i.e. approximately 56 percent of the total cost. The bubblers with the connecting small flexible tubes cost US$980, or 25 percent of the total cost of the system. The cost per tree of the laterals with the bubblers is about US$6.60.

ADVANTAGES

- High irrigation application efficiency, up to 75 percent, resulting in considerable water savings, with absolute control of the irrigation water from the source to the tree basin.
- All the piping network is buried, so there are no field operations problems.
- The technology is simple and no highly sophisticated equipment is used. The system can be operated by unskilled farmers and labourers. No filters or fertilizer injectors are needed.

DISADVANTAGES

- High initial purchase cost.
- Small water flows cannot be used as in other micro-irrigation systems.
- In sandy soils with high infiltration rates, it is difficult to achieve a uniform water distribution over the tree basins.

EXAMPLE DESIGN

Bubbler irrigation with fruit trees

Area and crop: The plot dimensions are 120 x 85 m (1.0 ha) with mature guava trees in rows at a spacing of 6 x 6 m. There are 20 rows with 14 trees in each row for a total 280 trees. The slope of the plot is 0.5 percent from west to east and from north to south.

Soil, water and climate: Medium texture soil with an infiltration rate of approximately 8 mm/h and a soil available moisture of 150 mm/m depth. The source of water is an existing tube-well with a safe output of 25 m^3/h of suitable quality. The evaporation pan average readings in July are 7 mm/d.

Crop water requirements and irrigation scheduling: The pan reading of 7.0 mm/d multiplied by 0.66 (pan correction factor) gives an ETo of 4.65 mm/d. The crop factor kc is 0.65, thus ETc = 4.65 x 0.65 = 3.0 mm/d. The area shaded by the tree canopy is 70 percent and for calculation purposes it is taken as 82 percent. Therefore, the daily water requirements are: 3.0 x 0.82 = 2.48 mm/d net. With a system application efficiency of 75 percent, the gross daily irrigation requirements are: 2.48 x 100 ÷ 75 = 3.3 mm (33 m^3). If irrigation takes place every ten days, the gross irrigation dosage is: 10 x 33 = 330 m^3.

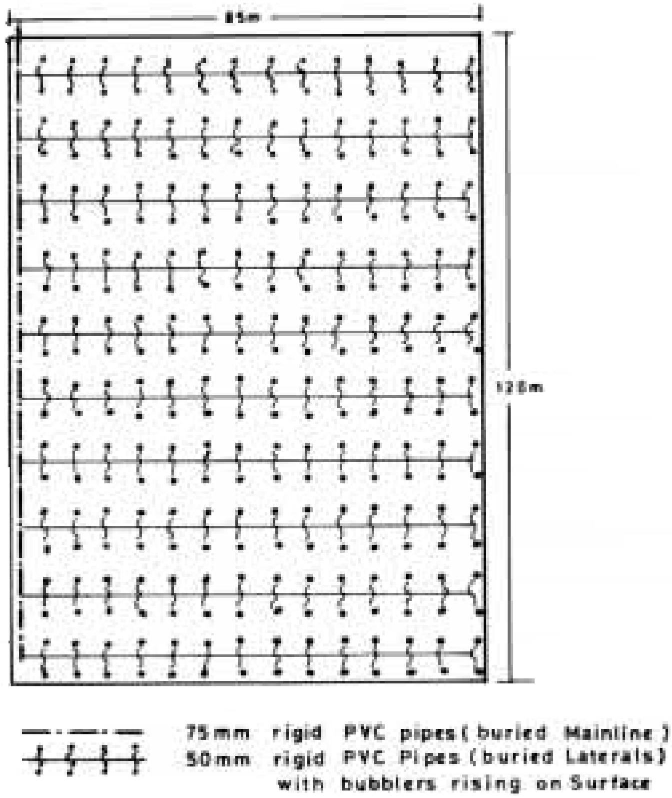
The maximum permissible irrigation interval in July on a 50-percent moisture depletion for a tree root depth of 0.6 m is: 150 x 0.6 x 0.5 ÷ 3.0 = 15 days. The irrigation frequency depends on many factors and in no case should exceed the maximum permissible irrigation interval.

System layout, performance and hydraulics: The main line also serves as a manifold (feeder) line. The laterals are buried 50-mm rigid PVC pipes laid between every other row of trees with 12-mm flexible tubes rising on both sides and extended to the tree basins with two bubblers in each tree basin. The main characteristics of the bubblers are:

- flow rate: 225 litres/h at 2.0 bars;
- number of bubblers per lateral: 56 (each lateral irrigates two rows of trees, i.e. 28 trees);
- lateral discharge: 12 600 litres/h (12.6 m3/h);
- total number of laterals: 10;
- system discharge: 25 m_/h;
- number of laterals operating simultaneously: 2;
- number of shifts per irrigation: 5;
- operating hours per shift: 2.64 h (3 h 26 min);
- time to complete one irrigation: 13.2 h (13 h 15 min);

Pressure at the bubbler	**bars 2.00**
Friction losses in the lateral	0.34
Friction losses in the main line	0.60
Friction losses in the head control unit	0.20
Minor local losses	0.20
	3.34
Difference in elevation	0.10
Total dynamic head	3.24

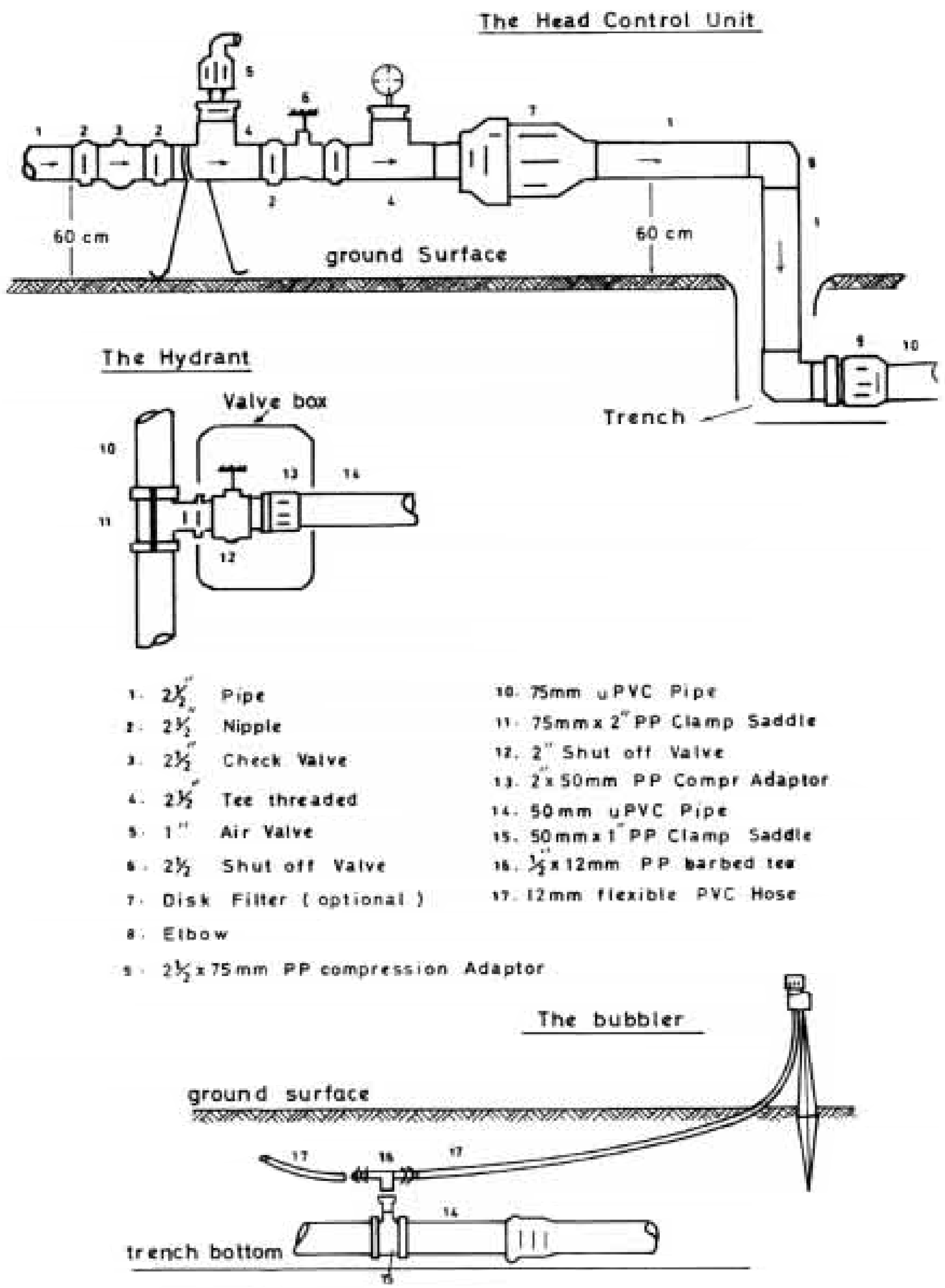
Bubbler in fruit trees (example design)



Equipment required for the system installation

Item	Description	Quantity	Unit price US$	Total price US$
	System distribution network			
1.	75-mm uPVC pipe, 6.0 bars, push-fit joint	120 m	1.90	228.00
2.	50-mm uPVC pipe, 6.0 bars, push-fit joint	850 m	1.20	1020.00
3.	75-mm x 2-in PP clamp saddle	10 pcs	2.25	22.50
4.	50-mm x 1-in PP clamp saddle	140 pcs	1.10	154.00
5.	75-mm x 2_-in PP adaptor	1 pcs	9.00	9.00
6.	50-mm x 2-in PP adaptors	10 pcs	4.00	40.00
7.	75-mm PP end plug	1 pc	9.00	9.00
8.	50-mm PP end plug	10 pcs	4.00	40.00
9.	2-in nipple	10 pcs	1.00	10.00
10.	2-in brass shut-off valve	10 pcs	12.00	120.00
11.	1-in PVC tee threaded	140 pcs	1.00	140.00
12.	1-in x _-in PVC bushing	280 pcs	0.60	168.00
13.	12-mm PP tee barbed	280 pcs	0.30	84.00
14.	12-mm x _-in PP adaptor barbed	280 pcs	0.25	70.00
15.	12-mm soft flexible PVC tube	1120 m	0.25	280.00
16.	Bubbler set, 225 litres/h at 2.0 bars (adjustable)	560 pcs	0.70	392.00
17.	Valve box, plastic 31 x 50 x 40 cm	10 pcs	20.00	200.00
18.	Trench excavation and backfilling	970 m	1.00	**970.00**
				3956.50
	Head control			
19.	2_-in brass check valve	1 pc	15.00	15.00
20.	2_-in brass shut-off valve	2 pcs	13.00	26.00
21.	2_-in tee (galvanized iron or PVC)	3 pcs	3.50	10.50
22.	2_-in nipple	4 pcs	1.00	4.00
23.	1-in single air valve	1 pc	12.00	**12.00**
				67.50
			Total cost	**4024.00**

Bubbler irrigation



CHAPTER 12: Drip irrigation

INTRODUCTION

In drip irrigation, water is applied to each plant separately in small, frequent, precise quantities through dripper emitters. It is the most advanced irrigation method with the highest application efficiency. The water is delivered continuously in drops at the same point and moves into the soil and wets the root zone vertically by gravity and laterally by capillary action. The planted area is only partially wetted.

In medium-heavy soils of good structure, the lateral movement of the water beneath the surface is greater than in sandy soils. Moreover, when the discharge rate of the dripper exceeds the soil intake rate and hydraulic conductivity, the water ponds on the surface. This results in the moisture being distributed more laterally rather than vertically. The following water lateral spread values are indicative:

Type of soil	Average radius of water spread
Light texture	0.30 m
Medium texture	0.65 m
Fine texture	1.20 m

SYSTEM LAYOUT AND COMPONENTS

A complete drip irrigation system consists of a head control unit, main and submain pipelines, hydrants, manifolds and lateral lines with dripper emitters.

Control station (head control unit): Its features and equipment depend on the system's requirements. Usually, it consists of the shut-off, air and check (non-return) valves, a filtering unit, a fertilizer injector and other smaller accessories.

Main and submain pipelines: The main and submain pipelines are usually buried, especially when made of rigid PVC.

Hydrants: Fitted on the mains or the submains and equipped with 2-3-in shut-off valves, they are capable of delivering all or part of the piped water flow to the manifold feeder lines. They are placed in valve boxes for protection.

Manifold (feeder) pipelines: These are usually 50, 63 or 75 mm. Where made of HDPE, they are attached to the hydrants through compression-type, quick release, PP connector fittings and remain on the surface.

Dripper laterals: These are always made of 12-20-mm soft black LDPE, PN 3.0-4.0 bars. They are fitted to the manifolds with small PP connector fittings at fixed positions and laid along the plant rows. They are equipped with closely spaced dripper emitters or emission outlets.

The mains, manifold and dripper laterals

In general, the distribution network (mains, submains and manifolds) consists of thermoplastic pipes and fittings (PVC, PE, PP, etc.), PN 6.0 and 10.0 bars. However, for the mains, submains and manifolds, other kind of pipes can also be used, such as quick coupling light steel pipes. In the past, permanently assembled buried rigid PVC pipes were used as mains and submains, with hydrants rising on the surface at desired points. More recently, surface-laid 50-75-mm HDPE pipes, PN 6.0 bars, have been used for the whole distribution network in smallholdings. Larger diameter PE pipes are also available but cost more than rigid PVC pipes of the same size.

The system's pressure ranges from 2.0 to 3.0 bars. Therefore, all drip irrigation systems can be classed as low pressure, localized, solid permanent or seasonal installation systems.

DRIP EMITTERS (DRIPPERS)

The drippers are small-sized emitters made of high quality plastics. They are mounted on small soft PE pipes (hoses) at frequent spaces. Water enters the dripper emitters at approximately 1.0 bar and is delivered at zero pressure in the form of continuous droplets at low rates of 1.0-24 litres/h. Drippers are divided into two main groups according to the way they dissipate energy (pressure):

- orifice type, with tiny flow areas of 0.2-0.35 mm^2;
- long-path type, with relatively larger flow areas of 1-4.5 mm^2.

Both types are manufactured with various mechanisms and principles of operation, such as a vortex diode, a diaphragm or a floating disc for the orifice drippers, and a labyrinthine path, of various shapes, for the long-path ones. All the drippers now available on the market are turbulent flow ones.

Drippers are also characterized by the type of connection to the lateral: on-line, i.e. inserted in the pipe wall by the aid of a punch; or in-line, where the pipe is cut to insert the dripper manually or with a machine.

On-line multi-exit drippers are also available with four to six ‘spaghetti’ type tube outlets.

Specifications that should be stated by the supplier are:

- dripper discharge (flow rate) at the recommended operating pressure, usually 1.0 bar;
- dripper discharge versus pressure variations and the optimum length of dripper line with different spacing and slopes;
- type of connection;
- filtration requirements;
- Coefficient of variation (cv) (the drippers’ manufacturing variability).

Dripper emitters which are available as separate items, not built into the pipe, can be referred to as separate source point drippers.

DRIP TAPES

These are thin-walled integral drip lines with emission points spaced 10, 20, 30, 45 cm or any other distance apart, delivering lower quantities of water than the usual drippers at very low pressures, i.e. 0.4-1.0 litres/h at 0.6-1.0 bar. They are integrated drip lines where the drippers are built in the pipe walls at the desired spacing during the manufacturing process.

They are ready-made dripper laterals with a very high uniformity of application. Drip tapes are made of LDPE or other soft PE materials in various diameters from 12 to 20 mm and in several wall thicknesses (0.10-1.25 mm). Thanks to a filtration system incorporated inside the tubing, they are less susceptible to mechanical and biological blockages than conventional drippers are.

POROUS-WALL PIPES

These pipes are small-sized (about 16 mm) thin-walled porous flexible hoses made from PE fibres, PVC, ABS or rubber. They permit water and nutrients under low pressure to pass from inside the tube, by transpiration, and irrigate the crops. The porous pipeline discharge is not accurate because the size of the pores varies and is not stable. They are used as lateral drip lines beneath the surface. Their application is limited although they do offer some advantages.

FILTRATION

The filtration of the irrigation water is of major importance for the normal application of this system. The solid content in the water must be removed through effective filtration in order to avoid blockage damage in the drippers. The kind of filtration depends on the impurities contained in the water and the degree of filtration required.

IRRIGATION SCHEDULING

In drip irrigation, the soil volume in the root zone is only partly wetted and the availability of moisture restricted. The soil moisture depletion should not exceed 40 percent of the soil available moisture in the late growing stages of vegetables and fruit trees, and 20-30 percent in the early stages for vegetables. However, in order to obtain higher yields, the common practice is to irrigate every day in the later stages. Proper irrigation scheduling can be arranged by using tensiometers to indicate the soil moisture tension in the root zone. This should range from 10 cbars for light soils to 25 cbars for heavy soils.

DESIGN CRITERIA AND CONSIDERATIONS

Drip irrigation is mainly applied in intensive cultivations planted in rows (vegetables, fruit trees, melons, bananas, papayas, flowers, grapes, etc.). It is not recommended for potatoes, salad leafy vegetables, groundnuts, alfalfa and other dense planted crops, although it can be applied successfully.

The drippers and/or the lateral spacing are directly related to the crop planting spacing. In most vegetable crops, the dripper spacing is identical to the crop planting spacing, i.e. one dripper per plant and one dripper lateral per row of cultivation. With drip tapes there are several emission points per plant in order to ensure a continuous wetted strip along the row. Here, the arrangement is one drip tape per row of crop.

Under drip irrigation, most of the vegetables develop the bulk of their roots in the first 30 cm depth of the soil profile below the emission point. Thus, if both the crop and the emission points along the rows are closely spaced, most of the soil volume can be sufficiently wetted with optimum results.

Where the crop is planted closely in beds, one dripper lateral per two rows might be applied with good results. Other crops planted in double rows (celery, capsicum and hot peppers) are also irrigated by one dripper lateral placed in between the rows.

In widely spaced tree orchards, the dripper spacing differs from that for vegetables. As the soil surface is partially wetted, only a part of the root system is being wetted too. The main consideration is to wet the largest possible volume of soil per tree (root system volume), not less than 35 percent, and at the same time to avoid deep percolation, beyond 50-60 cm, which is the average root depth of fruit trees under drip irrigation. The above percentage corresponds to an area of approximately 10-12 m^2 of soil surface with a tree spacing of 5 x 6 m or 6 x 6 m. Based on this consideration and the indicative lateral water spread figures, the dripper lateral design arrangements in tree orchards can be as follows:

- Single line per row of trees, with 4-8 drippers at approximately every 0.8-1.2 m along the line;
- Circular layout, or ‘loop around the tree’. In this arrangement there is a single line per row and for each tree there is either a smaller extension line with 5-8 drippers around the tree, or a multi-exit dripper with 4-6 small emission tubes extending radially around the tree. The circle diameter can be from 1.2 to 2.2 m. Newly planted trees can have two drippers only on both sides of the trunk, 35-40 cm away from the trunk.
- Double lines per row of plants. This design is applied in banana plantations, with two dripper lines per row, one on each side, set approximately 1.2-1.6 m apart. The drippers along the lines are spaced at 0.7-1.2 m accordingly.

Double lines with bananas

COST

The cost for a complete drip irrigation installation is US$4 000-5 000/ha. The cost of the pipes (all tubing, laterals included) is about US$2 000, i.e. 45 percent of the total cost. The head control unit accounts for 30 percent of the total cost.

ADVANTAGES

- Water savings. The planted area is partially wetted with precisely controlled water amounts. Thus, large quantities of irrigation water are saved and the irrigated area can be expanded with the same water supply, resulting in higher income per unit of water.
- Utilization of saline water resources. With drip irrigation, low soil moisture tensions in the root zone can be maintained continuously with frequent applications. The dissolved salts accumulate at the periphery of the wetted soil mass, and the plants can easily obtain the moisture needed. This enables the use of saline water containing more than 3 000 mg/litre TDS, which would be unsuitable for use with other methods.

- Use on marginal fields. Small irregular marginal plots, remote because of land fragmentation with varying topography and shallow soil full of rocks, can be productive under drip irrigation techniques that deliver the required amounts of water and nutrients directly to the plants.
- Low labour operating requirements, reduced cultivation and weed control, and uninterrupted operation are among the other advantages of this irrigation method.

DISADVANTAGES

- High initial purchase cost.
- Good irrigation management is essential for skilled system operation, application of fertigation and maintenance of the head control unit equipment (filters, injectors, etc.).
- Emitter blockages. The first limitation on the successful introduction of drip irrigation techniques in developing countries is mechanical clogging of the emitters because of insufficient filtration of impurities in the irrigation water.

EXAMPLE DESIGN

Drip irrigation in watermelons

Area and crop: The plot dimensions are 120 x 83 m (about 1 ha), planted in the open with watermelons in rows 2.20 m apart and spaced along the rows at 0.5 m. The plot is divided into two parts, each with 54 rows 40.5 m long. There are 81 plants per row. Thus, there are 4 374 plants in each part, i.e. 8 748 plants in the whole plot and 108 plant rows.

Soil, water and climate: Heavy texture soil with low permeability (approximately 6 mm/h) and a high water holding capacity. The source of water is a nearby open water reservoir; it is of good quality but with a high impurity content of organic origin (algae). The crop growing season is from early April to early July; the evaporation pan average maximum readings are 3.3 mm/d in April, 4.64 mm/d in May and 6.13 mm/d in June.

Crop water requirements and irrigation schedule: The maximum irrigation requirements of the watermelons are during the mid-season stage and the yield formation in late May-early June, when the kc value is 1.0. The average reading for the two months is 5.38 mm/d, which multiplied by a correction factor of 0.66 gives an ETo of 3.55 mm/d. As kc = 1.0, ETc = 3.55 mm/d. The system's application efficiency is 90 percent.

Therefore, the daily gross requirements at peak are:
3.55 x 0.90 ÷ 100 = 3.94 mm/d
3.94 x 10 x 1 ha = 39.4 m^3/d

The irrigation scheduling in late May is not arranged at a fixed depletion of the available soil moisture, but at a fixed interval of one day. Therefore, irrigation takes place every day and the dose is 39.5 m^3. At the early stages of the growing season, the irrigation interval ranges from 4 to 2 days.

System layout: The system consists of a head control equipped with a gravel filter and a strainer, a fertilizer injector and a regulating valve. The 63-mm HDPE main line is laid on surface along the middle of the field. On this main line (which also serves as a manifold), there are 54 _-in hydrants at a spacing of 2.20 m. The laterals, connected to the hydrants, are 16-mm LDPE pipes laid perpendicular to the main line on both sides, one per row of plants. Separate point source drippers are inserted in the laterals at a spacing of 0.5 m, one per plant.

DRIPPER CHARACTERISTICS:

- on-line: 4 litres/h at 1.0 bar;
- filtration requirements: 160 mesh.

LATERAL CHARACTERISTICS:

- pipe: 16-mm LDPE, 4.0 bars PN, length 41 m;
- number of drippers: 81;
- water discharge: 324 litres/h;
- total number of laterals: 108;
- total number of drippers 8 748.

System flow and operation

For the simultaneous operation of all the laterals, the required flow is 35 m^3/h. If one irrigation is to be completed in three shifts, the flow of the system is 12 m^3/h, a reasonable size of flow for an area of 1 ha. The duration of application per shift at peak demand for an irrigation dosage of 39.5 m^3 is 1 h 2 min. The time required to complete one irrigation is 3 h 4 min.

Operating pressure

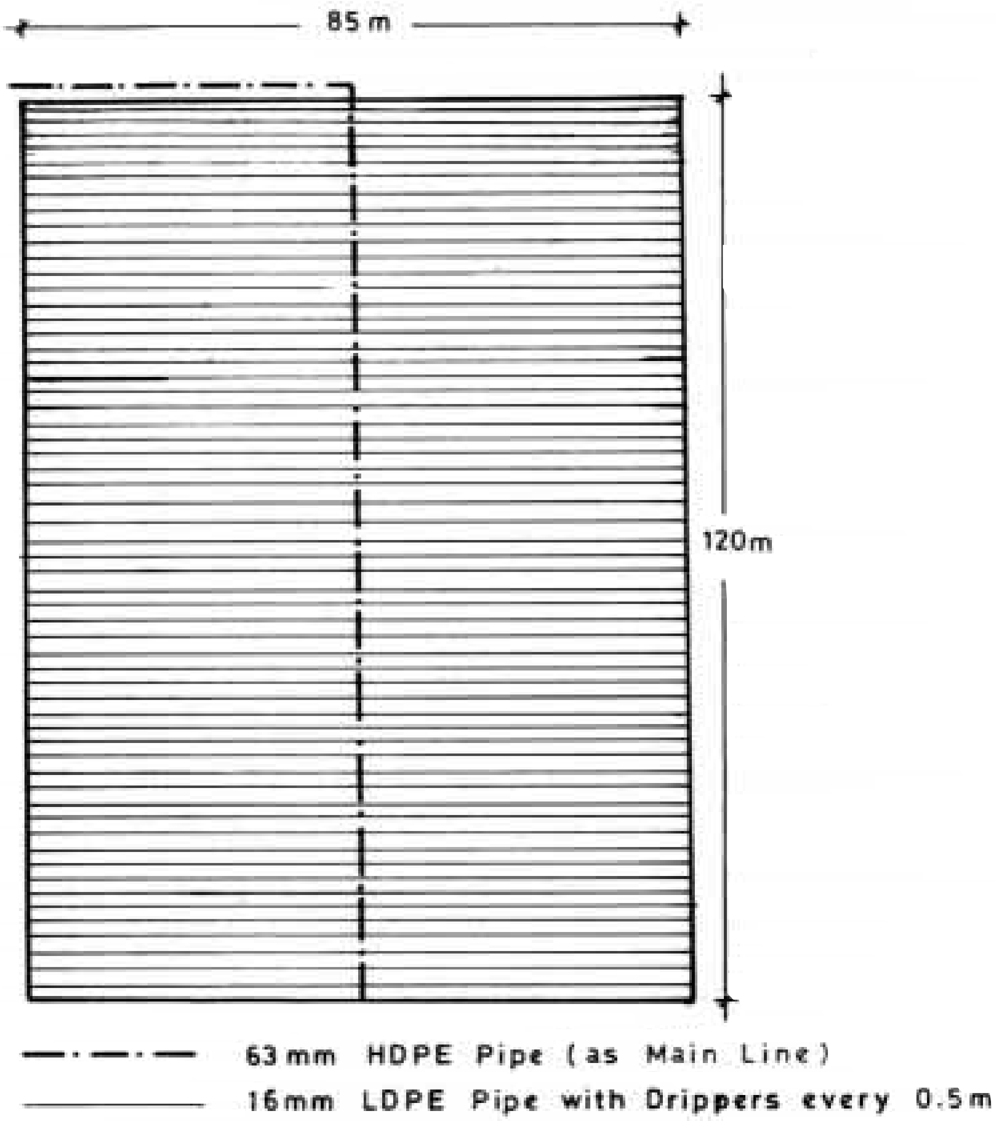
The required pressure for the normal operation of the system is:

Pressure for the drippers	**bars 1.00**
Friction losses in the dripper laterals	0.10
Friction losses in the main line	0.43
Friction losses in the head control	0.90
Minor local losses	0.22
Total dynamic head (pressure) of the system	2.65

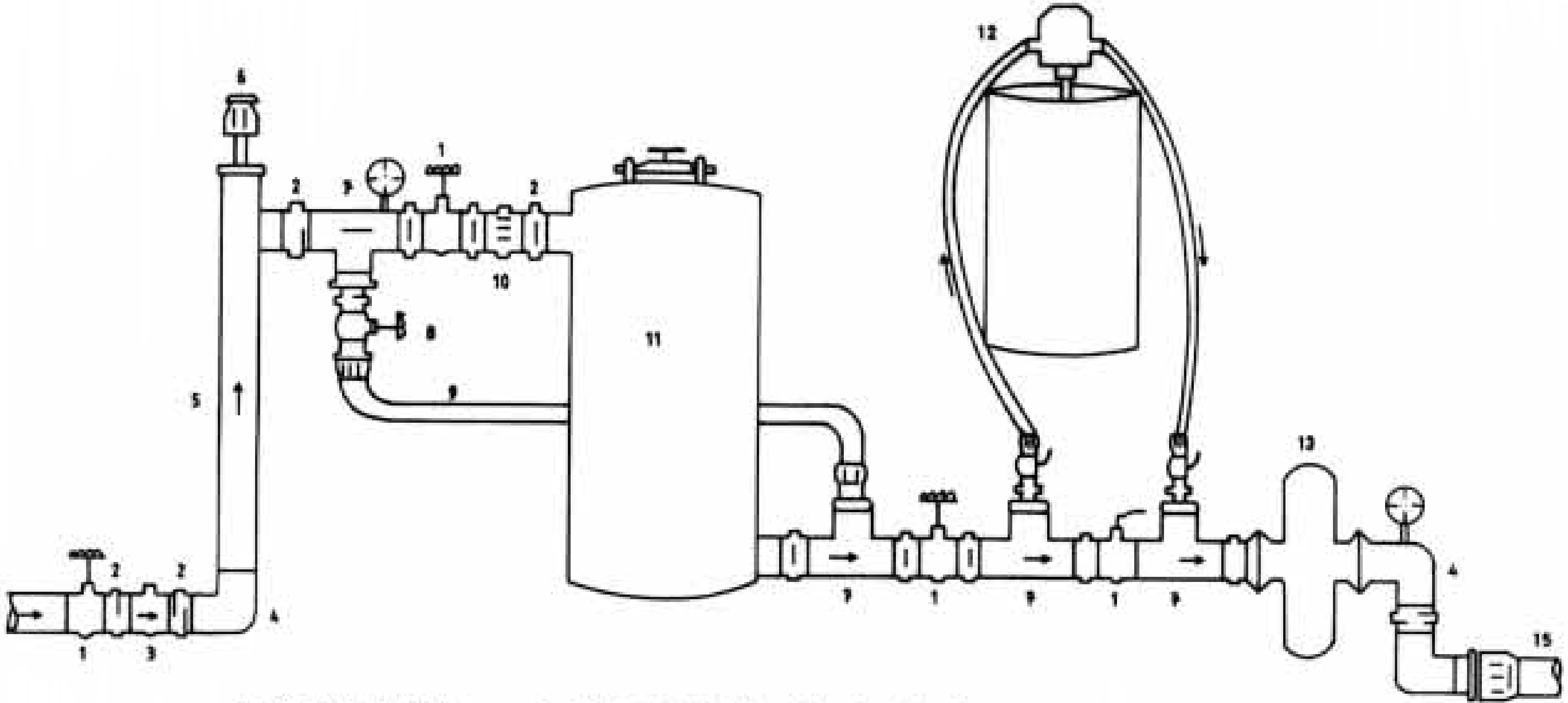
Equipment for system installation

Item	Description	Quantity	Unit price US$	Total price US$
	System distribution network			
1.	63-mm HDPE pipe, 6.0 bars	180 m	1.80	324.00
2.	16-mm LDPE pipe, 4.0 bars	4430 m	0.32	2302.60
3.	Drippers, 4 litres/h,1 bar	8750 pcs	0.06	525.00
4.	63-mm x 2-in PP adaptor	1 pc	6.00	6.00
5.	16-mm x _-in PP adaptor	108 pcs	0.80	86.40
6.	63-mm PP elbow	1 pc	8.00	8.00
7.	63-mm PP end plug	1 pc	6.00	6.00
8.	63-mm x _-in PP clamp saddle	54 pcs	1.30	70.20
9.	_-in nipple (galvanized iron or PVC)	54 pcs	0.25	13.50
10.	_-in tee (galvanized iron or PVC)	54 pcs	0.40	21.60
11.	_-in brass shut-off valves	108 pcs	2.30	**248.60**
				3609.70
	Head control			
12.	2-in brass check valve	1 pc	13.00	13.00
13.	2-in brass shut-off valve	2 pcs	12.00	24.00
14.	_-in brass shut-off valve	2 pcs	2.30	4.60
15.	2-in tee (galvanized iron or PVC)	3 pcs	2.00	6.00
16.	2-in nipple	4 pcs	1.00	4.00
17.	_-in nipple	4 pcs	0.25	1.00
18.	1-in air valve	1 pc	12.00	12.00
19.	2-in gravel filter complete	1 pc	600.00	600.00
20.	2-in disk filter, c/with gauges, etc.	1 pc	180.00	180.00
21.	Fertilizer injector complete, up to 150 litres/h	1 pc	500.00	**500.00**
				1344.00
			Total cost	**4953.70**

Drip irrigation in watermelons (Sample design)



The Head Control



1. 2" Shut off valve
2. 2" Nipple
3. 2" Check valve
4. 2" Bend threaded
5. 2" Threaded pipe
6. 1" Air valve
7. 2" Tee threaded
8. 1" Shut off valve
9. 32mm LDPE Hose (backwashing)
10. 2" Union threaded
11. 2" Filter Gravel media
12. Fertilizer injector
13. 2" Disk Filter
14. 2"x 63mm PP compr. Adaptor
15. 63mm HDPE Pipe Mainline

CHAPTER 13: Fertigation

INTRODUCTION

In micro-irrigation, fertilizers can be applied through the system with the irrigation water directly to the region where most of the plants roots develop. This process is called fertigation and it is done with the aid of special fertilizer apparatus (injectors) installed at the head control unit of the system, before the filter. The element most commonly applied is nitrogen. However, applications of phosphorous and potassium are common for vegetables. Fertigation is a necessity in drip irrigation, though not in the other micro-irrigation installations, although it is highly recommended and easily performed.

FERTILIZER INJECTORS

Several techniques have been developed for applying fertilizers through the irrigation systems and many types of injectors are available on the market. There are two main techniques: the ordinary closed tank; and the injector pump. Both systems are operated by the system's water pressure. The injector pumps are mainly either Venturi type or piston pumps. The closed tanks are always installed on a bypass line, while the piston pumps can be installed either in-line or on a bypass line.

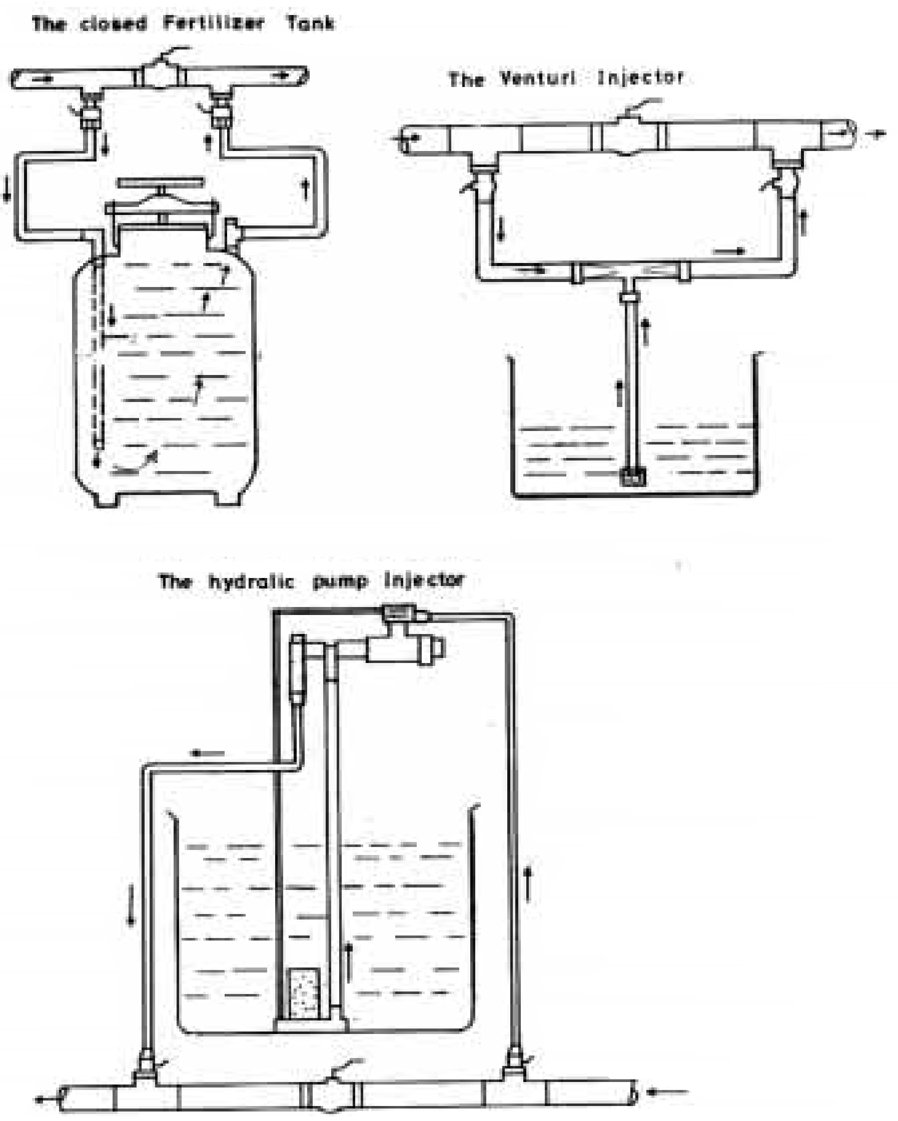
1. **Fertilizer (closed) tank.** This is a cylindrical, epoxy coated, pressurized metal tank, resistant to the system's pressure, and connected as a bypass to the supply pipe of the head control. It operates by differential pressure created by a partially closed valve, placed on the pipeline between the inlet and the outlet of the tank. Part of the flow is diverted to the tank entering at the bottom. It mixes with the fertilizer solution and the dilution is ejected into the system. The dilution ratio and the rate of injection are not constant. The concentration of fertilizer is high at the beginning and very low at the end of the operation. However, this apparatus is still in service on a very small scale in some countries because of its low cost and easy manufacture.

2. **Venturi type.** This is based on the principle of the Venturi tube. A pressure difference is needed between the inlet and the outlet of the injector. Therefore, it is installed on a bypass arrangement placed on an open container with the fertilizer solution. The rate of injection is very sensitive to pressure variations, and small pressure regulators are

sometimes needed for a constant ejection. Friction losses are approximately 1.0 bar. The injectors are made of plastic in sizes from _ to 2 in and with injection rates of 40-2 000 litres/h. They are relatively cheap compared to other injectors.

3 **Piston pump.** This type of injector is powered by the water pressure of the system and can be installed directly on the supply line and not on a bypass line. The system's flow activates the pistons and the injector is operated, ejecting the fertilizer solution from a container, while maintaining a constant rate of injection. The rate varies from 9 to 2 500 litres/h depending on the pressure of the system and it can be adjusted by small regulators. Made of durable plastic material, these injectors are available in various models and sizes. They are more expensive than the Venturi-type injectors.

The Fertiliser Injectors



FERTILIZER APPLICATION

The fertilizer solution in liquid form is fed into the system at low rates repeatedly, on a continuous basis, during irrigation. The flow rate of the injector should be such that the calculated amount of solution is supplied at a constant rate during the irrigation cycle, i.e. starting fertigation right after the system starts operation and finishing a few minutes before the operation ends. Regarding the choice of the fertilizers, apart from the amount and the kind, other parameters need to be considered, such as solubility, acidity, compatibility and cost.

Solubility. The fertilizer stock solution should always be dissolved in a separate container and then poured into the suction tank. The types of fertilizer should be highly soluble and when dissolved in water must not form scums or sediments which might cause emitter clogging problems. The solution should always be agitated, well stirred and any sludge deposited in the bottom of the tank should be periodically removed. The injector suction pipe should not rest on the bottom of the tank. Hot water helps dissolve dry fertilizers. Their degree of solubility varies according to the type and the country of origin. Potassium nitrate (13-0-46) seems to have a low solubility of approximately 1:8, i.e. 1 kg of dry fertilizer in 8 litres of water. The solubility of potassium chloride (0-0-62) is 1:3, while ammonium nitrate (34-0-0) and calcium nitrate (15.5-0-0) have a high solubility of approximately 1:1. Dry phosphorous fertilizers have a lower solubility than nitrates at about 1:2.5.

Acidity. The acidity produced by the several forms of nitrogen varies from type to type and is greatly affected by the kind of irrigation water and the type of soil. At least one check on the soil pH should be carried out at the beginning of the season and one at the end. Furthermore, a complete ionic analysis of the water is necessary.

Quantity. A simple method for calculating the amount of fertilizer required for fertigation is to divide the annual application by the number of irrigations. Various recipes nave been developed in different countries based on the conventional nutrition dosages. The total quantity of fertilizers applied is also related to the length of the growing season and the irrigation requirements.

Table 24 - presents some of the recipes applied in Cyprus for fertigation on a continuous basis, at a constant rate and feeding, during irrigation.

TABLE 24 - Net concentration of fertilizers in ppm (mg/litre, or net fertilizer g/m^3 irrigation water)

Crop	N	P	K
Citrus	50	12	15
Bananas	50	15	40
Tomatoes	180	50	250
Cucumbers	200	50	200
Bell peppers	170	60	200
Cabbage	100	60	200
Onions	100	50	150
Squashes	200	50	200
Potatoes	150	50	180
Groundnuts	120	50	200
Watermelons	150	50	150

Note: The above recipes vary in accordance with the fertilizer reserves in the soil.

Preparing the fertilizer solution

The above recipes are recommended for irrigation water with very low salinity. As a rule of thumb for average quality water, the maximum fertilizer concentration, which is added to the irrigation total salinity, should have an EC of about 0.5 dS/m. For higher concentrations, the salinity level in the soil root zone must be checked frequently and the application adjusted according to the soil test results.

EXAMPLE: FERTIGATION WITH VEGETABLES

Crop: Tomatoes;
Concentration of NPK fertilizers: 180-50-250;
Type of fertilizers available: Ammonium nitrate (33.5-0-0) NH_4NO_3
Diammonium phosphate DAP (16-48- 0) $(NH_4)2HPO_4$
Potassium chloride (0-0-60) K_2O;

System flow: 23 m^3/h;
Irrigation dosage: 18 m^3;
Duration of application: 1.5 hours.

Phosphate and potassium are given in oxides, therefore they are converted into P and K elements by multiplying by 0.4364 and 0.8302 respectively.

Calculation of the amounts of fertilizers needed in grams per cubic metre of water:

K = 250 x 100 ÷ (60 x 0.8302) = 0.502 kg K_2O.
P = 50 x 100 ÷ (48 x 0.4364) = 0.239 kg $(NH_4)2HPO_4$. This amount also provides 38 g of N.
N = (180-38) x 100 ÷ 33.5 = 0.424 kg NH_4NO_3.

Thus, for 18 m^3 of water, which is the irrigation dosage, the exact quantities are:

0.502 kg x 18 = 9.036 kg K_2O
0.239 kg x 18 = 4.30 kg $(NH_4)2HPO_4$
0.424 kg x 18 = 7.63 kg NH_4NO_3

The amount of water needed for the dilution of the above quantity of fertilizers is estimated by taking into account the solubility of the fertilizers:

9.036 kg K_2O x 3 litres	27.00 litres
4.30 kg Ca (H_2PO_4) x 2.5 litres	10.75 litres
7.63 kg NH_4NO_3 x 1 litre	7.63 litres
Minimum amount of water needed	45.00 litres

If the fertilizers are diluted in 60 litres of water and the duration of the irrigation is 1.5 h (1 h 30 min), then the injection rate should be about 40-45 litres/h in order to complete the fertigation in approximately 1 h 25 min.

CHAPTER 14: Low-cost hose irrigation

INTRODUCTION

In many countries the low-cost hose irrigation installations are popular among small and part-time farmers for the irrigation of many crops. This method of irrigation is an improvement on the traditional furrow-basin and furrow irrigation approaches. The water is applied to the basins and the furrows through _-1_-in plastic hoses which are portable, 'hand-move', and can be extended in various directions. When one furrow or basin has been filled up with water, the hose is moved manually to the next one and so on.

A considerable engineering development has turned this practice from an old open surface method into a highly efficient closed pipe modern irrigation method. It is a localized method using a low pressure system, and a semi-permanent hand-move installation. It has been applied on a large scale and used extensively in many southern Mediterranean countries of the semi-arid zone in family managed smallholdings of about 1 ha. Properly designed hose basin systems for trees have also been successfully installed and operated on farms up to 20 ha.

FIGURE 3.48 - Schematic diagram of hydram installation.

SYSTEM LAYOUT AND COMPONENTS

The layout of the system and the hydraulics of design and operation are almost the same as in the other closed pipe low pressure systems. On the main pipeline, there are hydrants with movable or permanently laid laterals running along the crop rows. Long hoses are connected on these lateral lines at a regular wide spacing to deliver water to each basin or furrow separately. Each hose covers many basins or furrows according to its length.

The system's piping network is also similar to the other low pressure irrigation systems. It can be either a complete installation with all component parts, as in the sprinkler and the micro-irrigation installations, or a simple one. A hose irrigation system usually consists only of a main pipeline of any kind, 50-90-mm (2-3 in) uPVC, HDPE or layflat, 4.0-6.0 bars, which also serves as a manifold, with hydrants to which the laterals are connected. The laterals can be of any kind of 50-63-mm pipe but are usually LDPE, 4.0 bars. Smaller diameter long plastic hoses are connected on the laterals. Sometimes, the hoses can be fed directly from the source of the water, which can be a small reservoir at a higher level, a low capacity pump, or a tap. There is no need for filters, injectors or other accessories for a head control.

HOSES

The hoses are the well-known and widely available garden hoses. They are elasticized soft small diameter (_-1_ in) flexible PVC tubes with plain ends. Soft black 20-32-mm PE hoses (LDPE, 2.5-4.0 bars), are also used. The length of the hoses varies from 18 to 36 m and the water flow is 1.5-8.0 m^3/h. Thus, each hose can irrigate an area of approximately 600-2 100 m^2 respectively, covered with a number of small basins or furrows according to the cultivation. These sizes and lengths have been found to be the most convenient for farmers. The average flow characteristics for 24-m hoses with flow velocities up to 2.0 m/s^2 are presented in Table 25.

TABLE 25 - Flow characteristics of 24-m hoses

Kind of hose	Nom. diameter	Average flow - m^3/h	Pressure losses - bars
Flexible PVC	_ in	2.0	0.40
	1 in	3.6	0.30
	1_ in	5.7	0.20
	1_ in	8.0	0.25
Soft polyethylene (LDPE)	20 mm	1.5	0.85
	25 mm	2.5	0.70
	32 mm	4.5	0.40

SYSTEM TYPES AND DESIGN CRITERIA

The types of hose irrigation systems refer to the characteristics of the water delivery hoses, their position in the field, the general operating procedure and the method of water distribution over the land (basin or furrow). In tree groves, each tree has a basin, whose shape and size is mainly determined by the age and the spacing of the trees. With close planting spacing, two to six trees can be in one larger rectangular basin along the row. With vegetables and other field crops, the land slope, type of soil, crop, water availability and farming practices determine the dimensions of the basins and furrows.

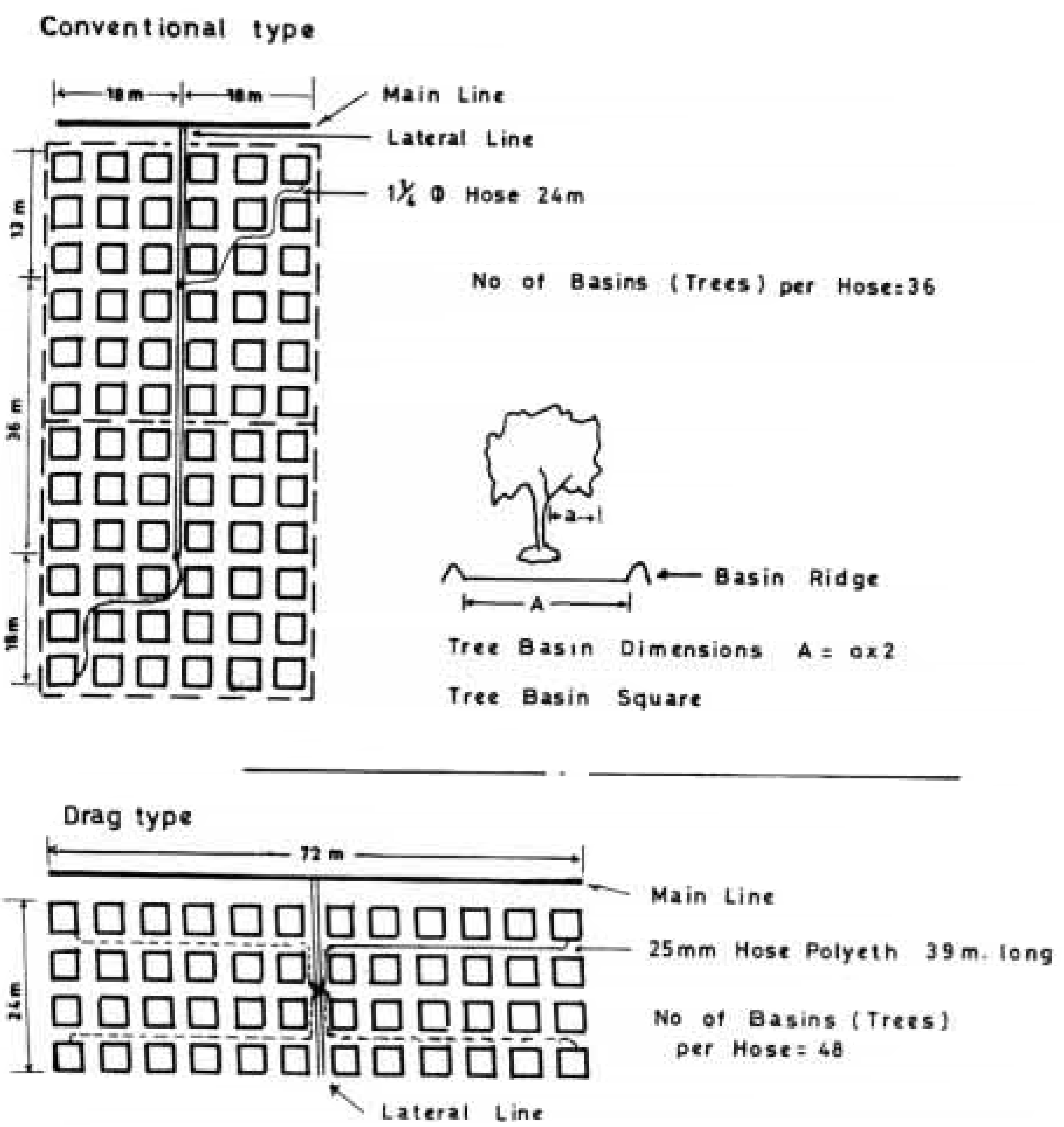
All types have movable water delivery hoses which are transferred or dragged from one spot to another. In this sense, there are four different types or variations of the system.

Conventional hose basin for trees. With a common tree spacing of 6 x 6 m, one 24-m-long hose can irrigate 36 tree basins in all directions in an area of about 1 300 m^2. The laterals are placed along the rows 36 m apart (every six rows) and the hoses are fitted on the laterals every six trees (36 m). Thus, the hose spacing is 36 x 36 m. With other planting spacings, the lateral and hose spacings differ, but not greatly, from the above. Flexible PVC garden hoses about 1_ in in diameter have proved to be the most suitable kind, as they can easily cross the field perpendicularly and diagonally without being damaged (cracked). The hoses are moved by hand from one basin to another.

FIGURE 3.48 - Schematic diagram of hydram installation.

Drag hose basin for trees. This type of system is an improvement on the conventional one as it is easier to design and operate. The water delivery hoses are 20-32-mm soft black LDPE pipes, 2.5 or 4.0 bars, connected to the laterals. Each hose can irrigate two or four rows of trees on both sides of the lateral line. The hose can be 20-40 m long, and the area covered from 900 to 1 800 m². It is called the drag hose system because at the beginning of each irrigation the hoses are extended to the distant end basins and then moved to the other basins by dragging them backwards.

Hose basin for trees

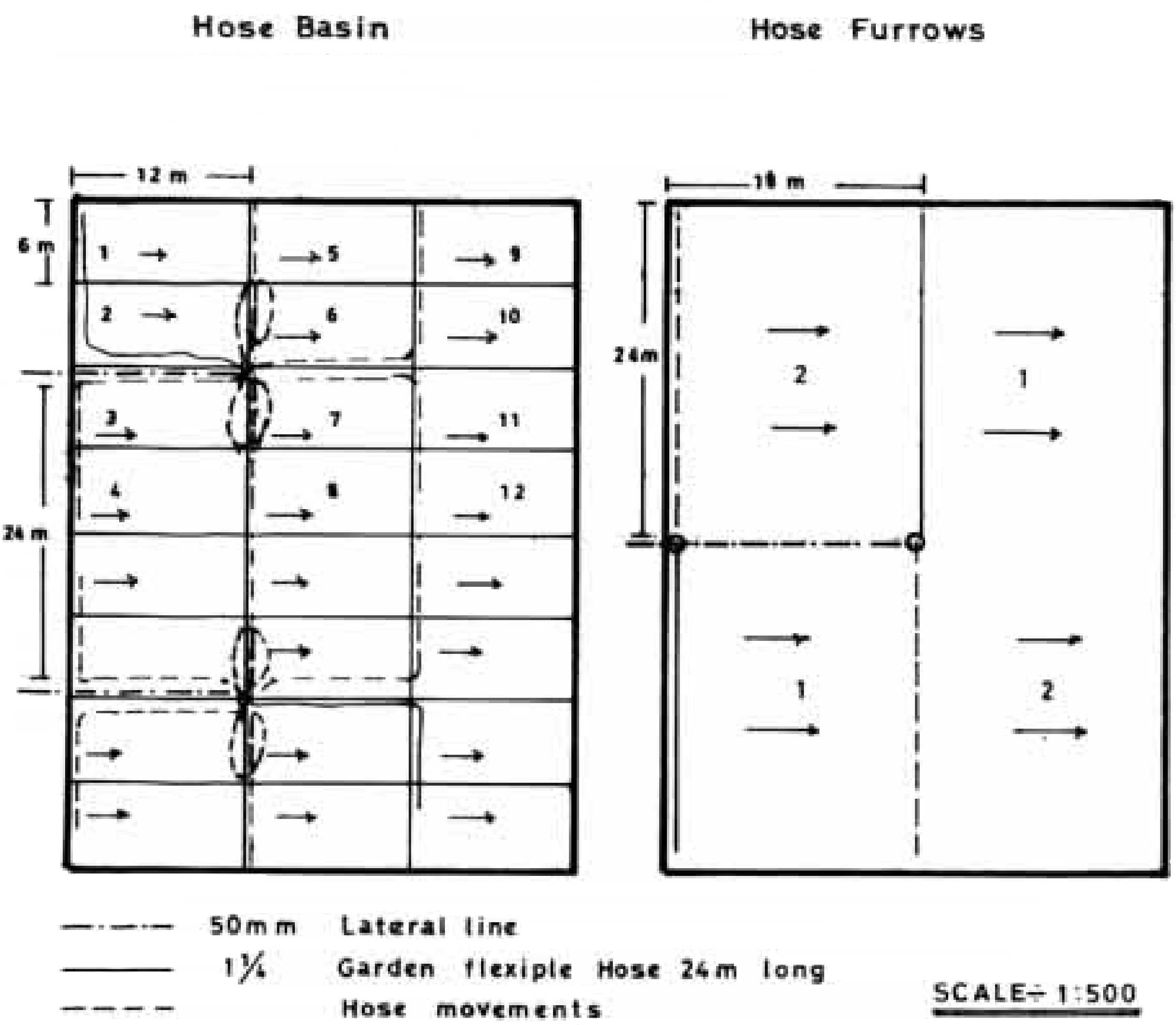


Hose basin for field crops. In this system, the hoses cannot cross the basins because they may damage the crop. The size of the small basins is usually 12 x 12 m, 6 x 12 m or 6 x 18 m. The laterals are placed at a closer spacing than for trees, in relation to the basins' dimensions and arrangement. The hoses can be of any kind, soft PVC or LDPE, in the appropriate lengths (18-24 m) and sizes (25 mm-1_ in). For example, with basins 6 m wide and 12 m long, the lateral lines are placed along the slope direction 24 m apart (every four basins). The 24-m hoses are connected to the laterals every three basin lengths (36 m), irrigating four basins upstream, two on each side, and eight basins downstream, four on either side, for a total of 12 basins, in an area of approximately 865 m^2. The hose spacing in this example is 24 x 36 m. However, it can vary as required. The hoses can be moved from one basin to another either by dragging them backwards or by carrying them.

Hose furrow for vegetables. Similar to the hose basin for vegetables, here the lateral lines are placed along the slope with the hoses connected at the head of the furrows. They are extended perpendicular to the lateral on either side delivering water to a number of furrows, as a drag system. The hoses are generally 25-32-mm soft black LDPE or 1_-in soft PVC garden hoses. The spacing of the hoses along the lateral is the same as the length of the furrows. The length of the furrows depends mainly on the type of soil, the slope, and the size of flow. With these systems, the furrows are usually short, 18-30 m long, 15 cm deep and about 1 m apart. The factors that influence the furrow layout are: farming practices; size and shape of the field; and irrigation application depth. The lower the depth of application and the size of the flow, the shorter the length; and the steeper the slope, the longer the furrow. In sandy soils, the furrow is shorter than in heavy clay soils. In medium texture soils, the following approximate relationship between slope and size of flow can be considered:

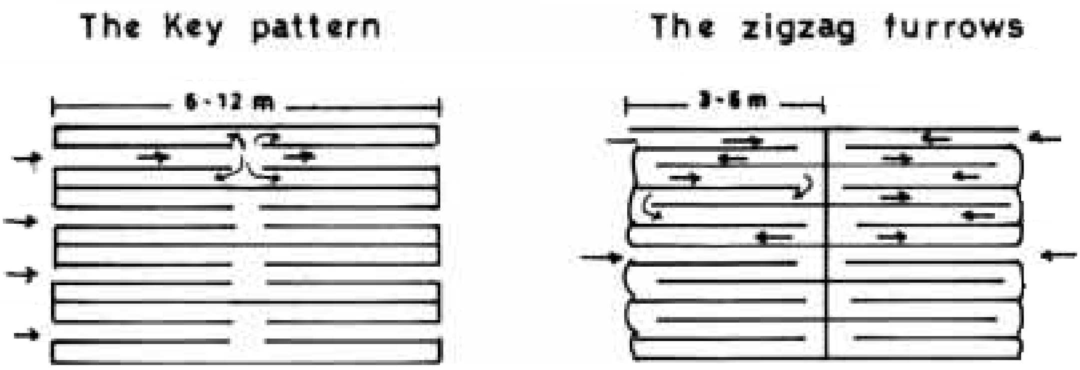
Slope %:	0.3	0.6	1.0	1.3	1.5
Size of flow m^3/h:	8.0	4.0	2.25	1.75	1.5

Hose irrigation for vegetables & field crops
Hose positions and movements



In small basins, the flow can be the minimum, while in large ones, the flow should be the maximum possible as the rate of application is proportional to the irrigation requirements. In sandy soils with high infiltration rates, the small discharge hoses can be moved from one place to another in the basin itself during the irrigation if necessary to ensure uniform distribution of water. It is common for farmers to subdivide the basins into smaller ones, or to construct short furrows within the basins in order to achieve ideal results. Several furrow layouts are applied (zigzag pattern, key pattern, etc.) in both types of systems. When the hose discharge is highly pressurized, some informal techniques are exercised on the spot by the farmer, such as the use of a tin vessel at the hose outlet, or a plastic bucket to avoid soil erosion and destruction of the ridges.

Short furrows



COST

Although hose irrigation systems are classed as semi-permanent installations, the water delivery hoses are the only movable component. However, the cost for a complete installation is very low compared with any other improved closed pipe technique. The average cost for all types of hose irrigation systems is about US$660/ha. Moreover, many years of study and observation have shown that the operating costs to the farmers, in terms of out-of-pocket money, are much lower than for any other system.

ADVANTAGES

- High application efficiencies of about 75 percent, resulting in considerable water savings.
- Low-cost improved irrigation installation.
- Simple technology easily managed by small children and old women.
- Gainful employment of available labour in small communities.
- Utilization of small water flows and quantities.
- Low energy (fuel) consumption.

DISADVANTAGES

- High labour requirements for system operation.

EXAMPLE DESIGNS

Hose basin with trees - conventional and drag types

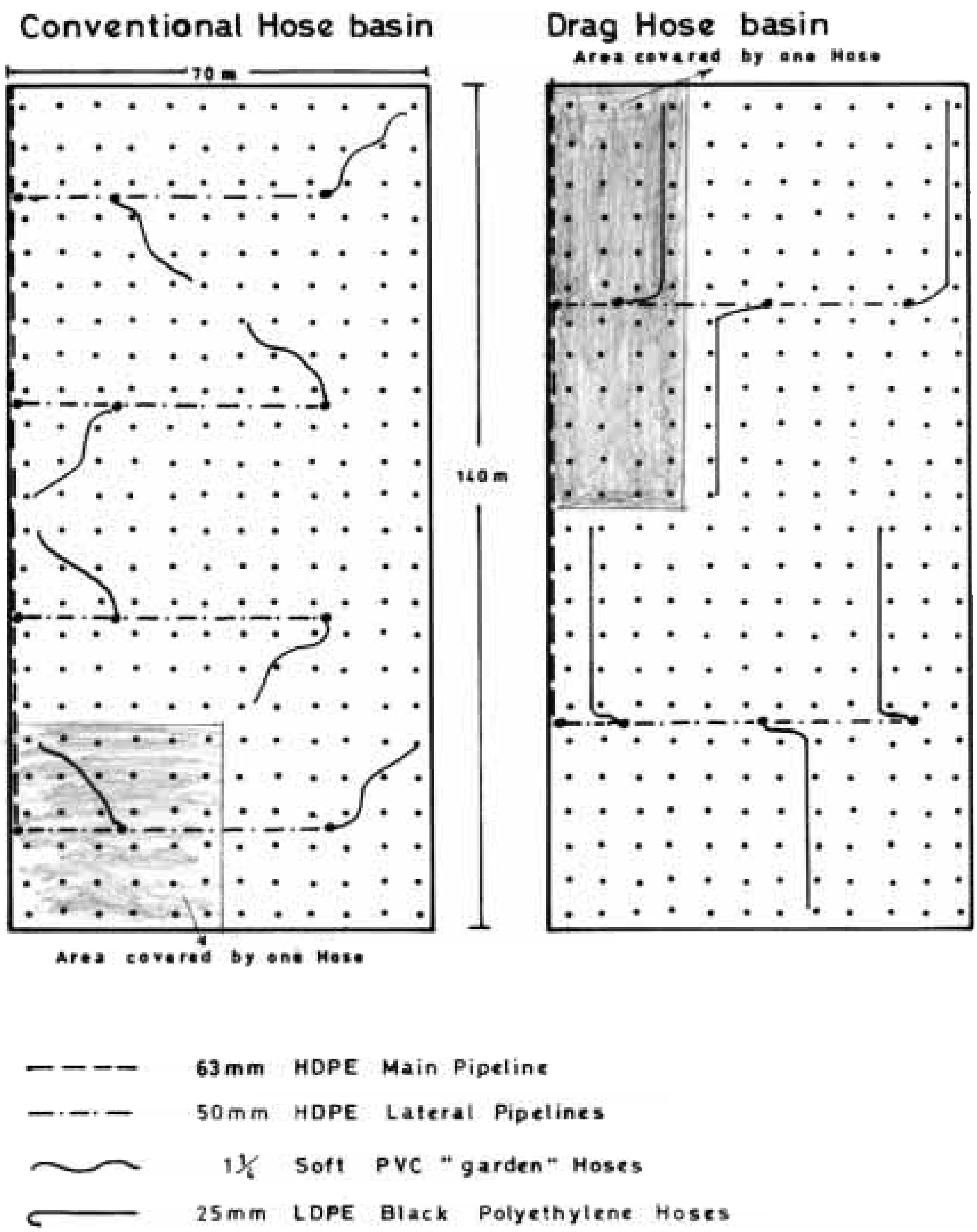
Area and crop: The field dimensions (for design purposes) are taken as 140 x 72 m (about 1.0 ha) with mature trees planted in a spacing of 6 x 6 m. There are 24 rows with 12 trees in each row for a total of 288 trees.

Soil, water and climate: Medium texture soil of good structure, with good infiltration and internal drainage. Soil available moisture: 150 mm/m depth. The water is of good quality with no salinity or toxicity hazards; the source is a high-level reservoir. The peak irrigation demand is in July; the evaporation pan average readings are 7 mm/d.

Crop water requirements and irrigation scheduling: The pan reading of 7.0 mm/d multiplied by 0.66 (pan correction factor) gives an ETo of 4.65 mm/d. The crop factor kc is 0.65. Thus, ETc = 4.65 x 0.65 = 3.0 mm/d. The area shaded by canopy is 70 percent and for calculation purposes this is taken as 82 percent. Therefore, the daily water requirements are: 3.0 x 0.82 = 2.48 mm/d net. With a system application efficiency of 75 percent, the gross daily irrigation requirements are: 2.48 x 100 ÷ 75 = 3.3 mm (33 m^3). If irrigation takes place every ten days, the gross irrigation dosage is: 10 x 33 = 330 m^3.

The maximum permissible irrigation interval in July on a 50 percent moisture depletion for a trees root depth of 0.6 m is: 150 x 0.6 x 0.5 ÷ 3.0 = 15 days. The irrigation frequency depends on many factors and in no case should exceed the maximum permissible irrigation interval.

Hose irrigation for trees (example designs) (area=1.0 ha)



Layout performance and hydraulics: In both the conventional and drag hose basin systems, a 63-mm HDPE or PVC main pipeline is placed along the border of the field with 2-in offtake hydrants, four for the conventional type and two for the drag type. Laterals of 50-mm LDPE are laid perpendicular to the mains, four and two respectively, connected to the hydrants. The hose arrangements of the two systems differ. In the conventional type, the hose spacing is 36 x 36 m with two 24-m-long 1_-in garden hoses per lateral. There are four laterals and eight hose positions. Thirty-six trees can be served from each hose position. In the drag system, the hose spacing is 24 x 48 m with three 36-m-long 25-mm LDPE hoses per lateral. There are only two laterals and six hose positions. Forty-eight trees can be irrigated from each hose position. The general characteristics of the systems are as follows:

	Conventional hose basin	**Drag hose basin**
System flow	16 m³/h	16 m³/h
Hoses	Soft PVC, 1_ in, 24 m	LDPE, 25 mm, 36 m
Hose discharge	4 m³/h	2.7 m³/h
Basins dimensions	5 x 5 m	5 x 5 m
No. of basins per hose	36	48
Irrigation frequency	10 days	10 days
Irrigation dosage	330 m³	330 m³
No. of hoses operating simultaneously	4 (double shift)	6
Time to fill a basin	17.4 min	26 min
Time to complete one irrigation	20.8 h	20.8 h
	bars	**bars**
Pressure losses in the hoses	0.2	0.7
Pressure losses in the laterals	0.3	0.4
Pressure losses in the main line	0.5	0.4
Minor local and other losses	0.5	0.5
Total dynamic head	1.5	2.0

EQUIPMENT FOR SYSTEM INSTALLATION

Conventional hose basin system (trees)

Item	Description	Quantity	Unit price US$	Total price US$
	System distribution network			
1.	63-mm HDPE pipe, 4.0 bars	125 m	1.80	225.00
2.	50-mm HDPE pipe, 4.0 bars	220 m	1.20	264.00
3.	63-mm PP compression end plug	1 pc	5.00	5.00
4.	50-mm PP compression end plug	4 pcs	3.00	12.00
5.	63-mm x 2_-in PP compression adaptor	1 pc	5.00	5.00
6.	50-mm x 2-in PP compression adaptor	4 pcs	3.00	12.00
7.	63-mm x 2-in PP clamp saddle	4 pcs	1.30	5.20
8.	50-mm x 1-in PP clamp saddle	8 pcs	1.10	8.80
9.	2-in brass gate valve	4 pcs	8.00	32.00
10.	1-in brass gate valve	8 pcs	3.00	24.00
11.	2-in nipple	4 pcs	0.80	3.20
12.	1-in nipple	16 pcs	0.40	6.40
13.	1_-in tap hose adaptor	4 pcs	0.70	28.00
14.	1_-in soft PVC garden hose, 24 m long	4 pcs	30.00	**120.00**
			Total cost	**750.60**

Item	Description	Quantity	Unit price US$	Total price US$
	Drag hose basin installation (trees)			
	System distribution network			
1.	63-mm HDPE pipe, 4.0 bars	105 m	1.40	147.00
2.	50-mm HDPE pipe, 4.0 bars	120 m	0.80	96.00
3.	63-mm PP compression end plug	1 pc	5.00	5.00
4.	50-mm PP compression end plug	1 pc	3.00	3.00
5.	63-mm x 2_-in PP compression adaptor	1 pc	5.00	5.00
6.	50-mm x 2-in PP compression adaptor	2 pcs	3.00	6.00
7.	63-mm x 2-in PP clamp saddle	2 pcs	1.30	2.60
8.	50-mm x 1-in PP clamp saddle	6 pcs	1.10	6.60
9.	2-in brass gate valve	2 pcs	8.00	16.00
10.	1-in brass gate valve	6 pcs	3.00	18.00
11.	2-in nipple	2 pcs	0.80	1.60
12.	1-in nipple	6 pcs	0.40	2.40
13.	1-in x 25-mm PP compression elbow	6 pcs	1.20	7.20
14.	25-mm soft LDPE hose, 4.0 bars, 36 m	6 pcs	14.40	**86.40**
			Total cost	**402.80**

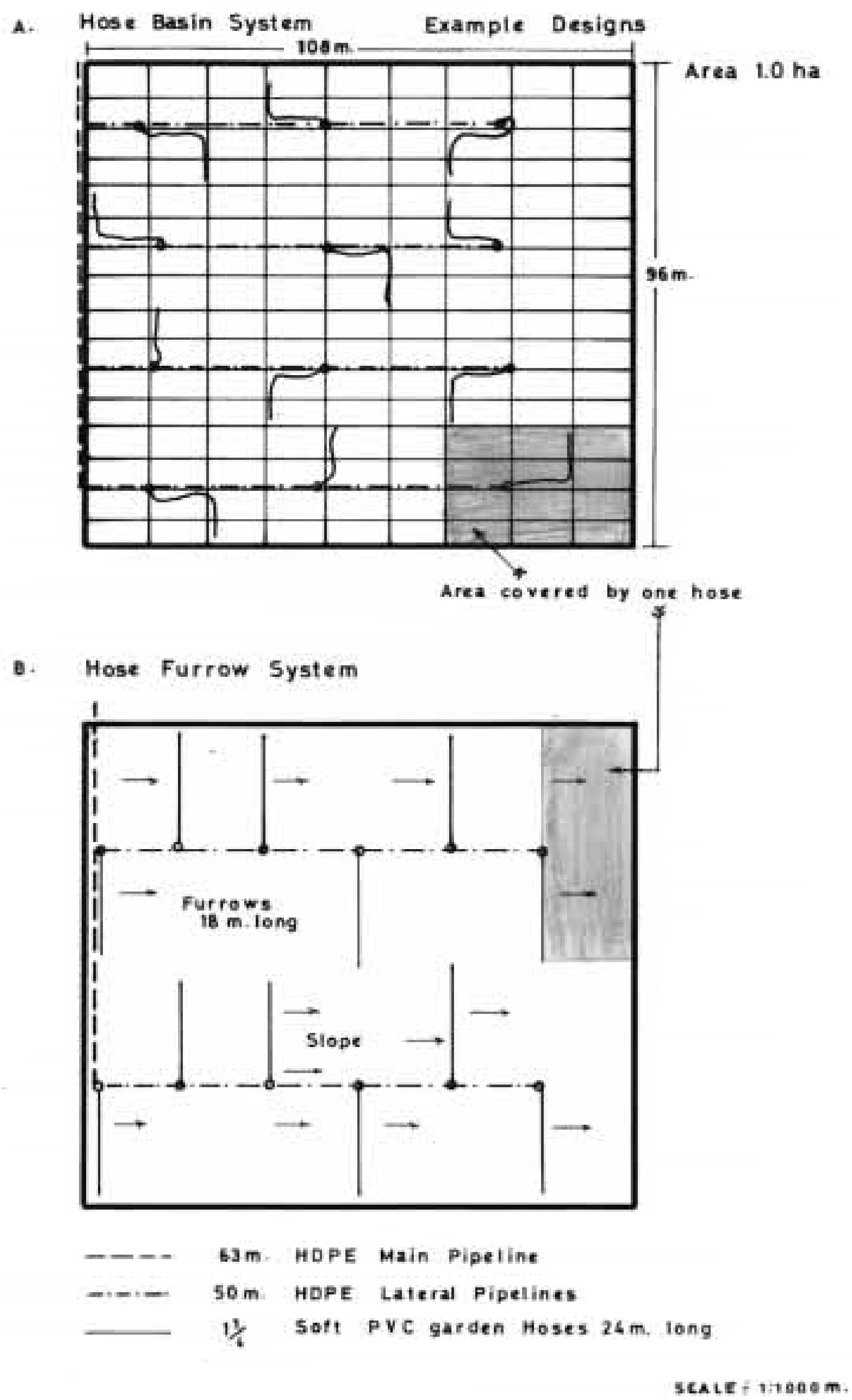
Hose basin irrigation for maize and hose furrow for tomatoes

Area and crops. Two plots of the same dimensions 108 x 96 m, 1.0 ha area each, are planted with maize and tomatoes respectively in mid-April. The maize plot is arranged in small basins, 6 x 12 m, for a total of 144 basins. The tomato plot is planted in short furrows 18 m long.

Soil, water and climate. Medium texture soil of good structure, with good infiltration and internal drainage. Soil available moisture: 150 mm/m depth. The water is of good quality with no salinity or toxicity hazards; the source is a high-level reservoir. The peak irrigation demand is in July; the evaporation pan average readings are 7 mm/d.

Crop water requirements and irrigation scheduling. The pan reading of 7 mm/d multiplied by 0.66 (pan correction factor) gives an ETo of 4.65 mm/d. The crop factor for maize at harvest time in July is taken as 1.0 and for late season tomatoes as 0.85. Thus, ETc maize: 4.65 x 1 = 4.65 mm/d, and ETc tomatoes: 4.65 x 0.85 = 3.95 mm/d. The system's application efficiency is 75 percent. Therefore, the gross daily irrigation requirements at peak are: 4.65 ÷ 0.75 = 6.2 mm (62 m^3) for maize; and 3.95 ÷ 0.75 = 5.26 mm (52.6 m^3) for tomatoes. At peak demand, the irrigation frequency for maize is every seven days, while for tomatoes it is every other day. Thus, the irrigation dosage would be: 7 x 62 = 434 m3 for maize; and 2 x 52.6 = 105 m^3 for tomatoes. The available system flow is 16 m^3/h.

Hose irrigation for vegetables and field crops



Layout, performance and hydraulics: In both systems, the pipe network is almost the same, i.e. 63-mm HDPE pipes for the main line, 50-mm HDPE pipes for the lateral lines, and 1_-in flexible PVC garden hoses. In the basin system, the hose spacing is 36 m along the laterals and 12 m between the laterals. There are four laterals with three hoses each for a total of 12 hose positions. Each hose position can serve 12 basins.

In the short furrow system, the hose spacing is 18 m along the lateral and 24 m between the laterals. There are only two laterals with six hoses each, for a total of 12 hose positions irrigating the furrows downstream on either lateral side. The general characteristics of the systems are:

	Hose basin	**Hose furrow**
Area	1.0 ha	1.0 ha
Crop	Maize	Tomatoes
System flow	16 m^3/h	16 m^3/h
Hose type	Soft PVC, 1_ in, 24 m	Soft PVC, 1_ in, 24 m
Hose discharge	5.3 m^3/h	5.3 m^3/h
No. of hoses operating simultaneously	3	3
No. of hose positions	12	12
No. of shifts per irrigation	4	4
Irrigation frequency at peak	7 d	2 d
Irrigation dosage (gross)	434 m^3	105 m^3
Time to complete irrigation	27 h	6.5 h
	bars	**bars**
Pressure losses in the hoses	0.20	0.20
Pressure losses in the laterals	0.40	0.40
Pressure losses in the main line	0.45	0.40
Minor local and other losses	0.55	0.50
Total dynamic head	1.60	1.50

EQUIPMENT FOR SYSTEM INSTALLATION

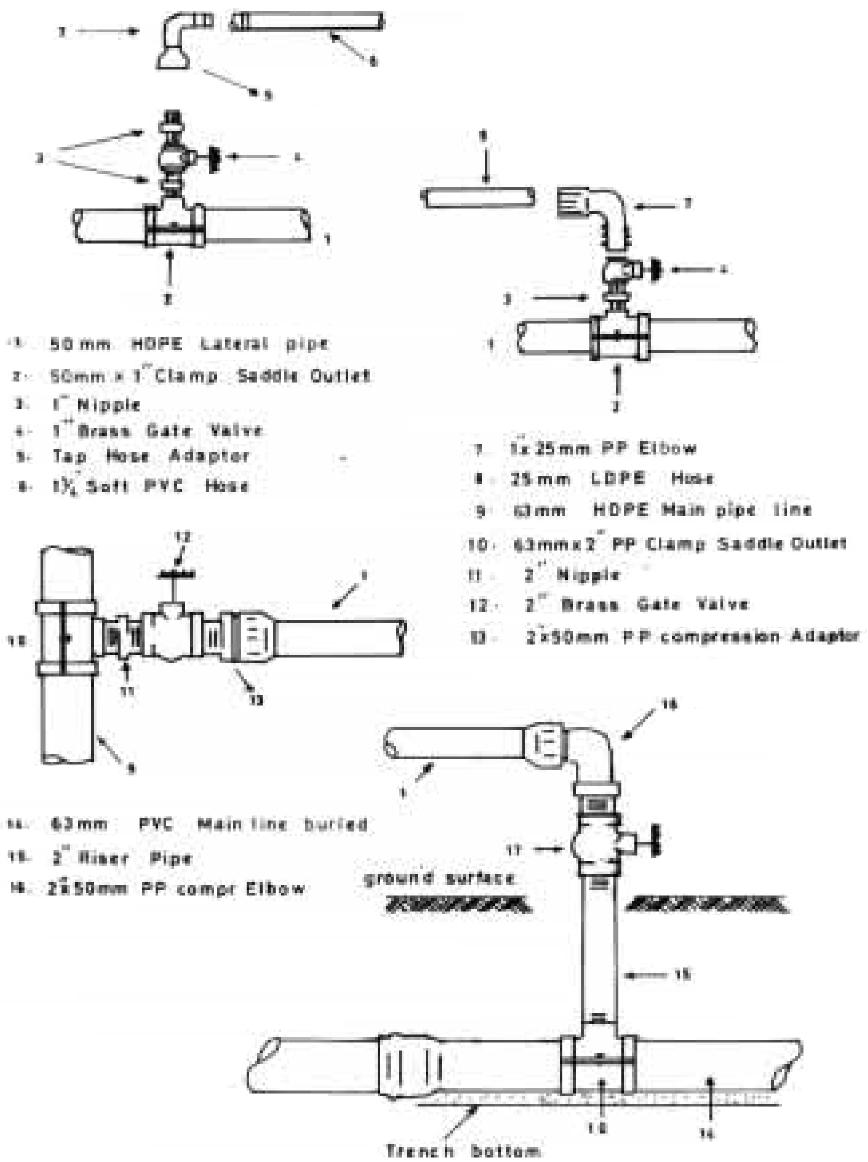
Hose basin installation (maize)

Item	Description	Quantity	Unit price US$	Total price US$
	System distribution network			
1.	63-mm HDPE pipe, 4.0 bars	84 m	1.80	151.20
2.	50-mm HDPE pipe, 4.0 bars	336 m	1.20	403.20
3.	63-mm PP compression end plug	1 pc	5.00	5.00
4.	50-mm PP compression end plug	4 pcs	3.00	12.00
5.	63-mm x 2_-in PP compression adaptor	1 pc	5.00	5.00
6.	50-mm x 2-in PP compression adaptor	4 pcs	3.00	12.00
7.	63-mm x 2-in PP clamp saddle	4 pcs	1.30	5.20
8.	50-mm x 1-in PP clamp saddle	12 pcs	1.10	13.20
9.	2-in brass gate valve	4 pcs	8.00	32.00
10.	1-in brass gate valve	12 pcs	3.00	36.00
11.	2-in nipple	4 pcs	0.80	3.20
12.	1-in nipple	12 pcs	0.40	4.80
13.	1_-in tap hose adaptor	6 pcs	0.70	4.20
14.	1_-in soft PVC garden hose, 24 m long	6 pcs	30.00	**180.00**
			Total cost	**867.00**

Hose furrow installation (tomatoes)

Item	Description	Quantity	Unit price US$	Total price US$
	System distribution network			
1.	63-mm HDPE pipe, 4.0 bars	72 m	1.80	129.60
2.	50-mm HDPE pipe, 4.0 bars	180 m	1.20	216.00
3.	63-mm PP compression end plug	1 pc	5.00	5.00
4.	50-mm PP compression end plug	2 pcs	3.00	6.00
5.	63-mm x 2_-in PP compression adaptor	1 pc	5.00	5.00
6.	50-mm x 2-in PP compression adaptor	2 pcs	3.00	6.00
7.	63-mm x 2-in PP clamp saddle	2 pcs	1.30	2.60
8.	50-mm x 1-in PP clamp saddle	12 pcs	1.10	13.20
9.	2-in brass gate valve	2 pcs	8.00	16.00
10.	1-in brass gate valve	12 pcs	3.00	36.00
11.	2-in nipple	2 pcs	0.80	1.60
12.	1-in nipple	12 pcs	0.40	4.80
13.	1_-in tap hose adaptor	6 pcs	0.70	4.20
14.	1_-in soft PVC garden hose, 24 m long	6 pcs	30.00	**180.00**
			Total cost	**626.00**

Hose irrigation jointing techniques



CHAPTER 15: Operation and maintenance

INTRODUCTION

The efficient operation of an irrigation system depends mainly on the ability of the farmer to make the best use of it. For every system, depending on the kind and the type of the installation and the way the water is delivered to the farm, there are several steps to be taken and factors to consider in order to ensure the efficient operation and performance of the installation. Sometimes, the irrigation installation fails to give full satisfaction because of poor design, faulty installation, or equipment that does not conform to specification. However, the way both the irrigation system as a whole and its component parts are operated and maintained will determine the success or failure of any properly designed and installed system.

The O&M of the irrigation system is also the key factor for good irrigation management. Farmers need a sound knowledge of the O&M procedures of their installation. This knowledge should be acquired from complete information, demonstration and written instructions from the designers and the suppliers.

OPERATION

When and how long to irrigate

The application of the exact amount of water required by the crops at the right time is the main achievement of the irrigation installation. Farmers normally understand matters concerning the main elements of irrigation programming, such as water discharge and rate, operating hours and irrigation frequency, and they can follow instructions. Properly installed, operated and maintained irrigation networks enable farmers to exercise absolute control over water use at farm level. Thus, it is easy for them to apply irrigation schedules based on crop, soil, weather, and water availability and quality factors.

Starting and stopping the system

Starting and shutting down the pressurized irrigation installation needs to be done very carefully in order to prevent surges and water hammer and to avoid air pockets in the pipelines.

The opening and closing of the valves at the head of the system, the main and submain pipelines, should always be done slowly.

Where there is a pump, engine or motor driven, the supplier's instructions should be followed. Priming the pump, filling the pipes, adjusting the speed and lubricating the pumping equipment are matters of major importance. Manufacturers provide detailed instructions in their literature for starting and operating each pumping unit.

System performance

Frequent observations and checks should be carried out during the irrigation season to ensure the proper functioning and good performance of the system. This involves a number of procedures for simple evaluations based on measurements taken under field conditions.

The equipment needed for this task is as follows:

- a map/sketch of the irrigated area showing the locations of all the system's component parts and the various plots;
- a portable pressures gauge (0-6.0 bars) with a special adaptor and pivot tube adjustment;
- a stopwatch (chronometer);
- a measuring tape, approximately 20 m;
- graduated vessels, capacity 1-5 litres;
- a soil auger, shove or probe;
- a notebook for recording data.

In most closed pipe pressure systems there are a number of factors that should be evaluated to determine the level of operation and that can be readjusted where not satisfactory.

Operating pressures: With the system in operation, pressure measurements are taken at various points on the piping network, preferably at the beginning and at the far end of the main and the submain pipelines. The operating pressures of the first and last emitters on a number of laterals are also measured. All pressures should be within the designed range. The difference in the emitter pressure should not differ from the recommended average pressure by more than 20 percent on level ground. Any change should be investigated immediately.

Flow rates and water discharge: The flow rates (discharge) of the same emitters whose operating pressures are measured are also determined. This is done by recording the time required to fill up a graduated vessel with water. The figures should be in accordance with the supplier's specifications and the difference between them should be less than 10 percent. The system's rate of discharge is the sum of the emitters' average flow rates.

Uniformity of application and depth of wetting: This may be checked by probing the soil at various locations using a probe, shovel or soil auger. The examination can be made 12-24 h after irrigation depending on the type of soil. Water should penetrate a few centimetres below the root depth. Areas taking less or more water can be easily identified for further investigation.

Visual observations for evaluation purposes of any type should be avoided as they might lead to misjudgements.

In addition to the above simple evaluations, the following checks, on-site modifications, re-arrangements and preventive maintenance are necessary:

- Check and repair any leakage in piping or through valves.
- Position the sprinklers vertically to the ground and check spacing.
- Replace or rehabilitate clogged emitters.
- Flush the system network at least three times during the irrigation season when water originates from underground. With reservoir water, flush once every fourth irrigation. An approximate flushing time of 2-3 min for each line will prevent sedimentation on the inner pipes walls.
- Clean the filters of the system thoroughly before every irrigation. During operation, check for the minimum difference in pressure between the inlet and the outlet of the main filter.
- Check the air and check valves periodically for proper functioning.
- Inspect plastic equipment, valves and devices for cracks and other physical damage.
- Flush fertilizer injectors (pump and tank) after each use. Inspect hoses and valves.
- Conduct systematic checks to spot malfunctioning equipment affected by physical deterioration and other possible damage by machinery, animals, etc.
- Make frequent visual checks of the system to ensure that it is in good condition and operating efficiently.

Pump plant

Preventive maintenance of the pumping system is essential during the irrigation season. Equipment manuals contain trouble-shooting chapters which are useful for solving common problems associated with the normal operation of the pumping unit. The following checks and inspections are recommended for most engine or electric motor driven pumps:

- noise;
- vibration;
- leakage;
- temperatures of bearings and windings;
- fuel/power consumption;
- capacity and output (water discharge and dynamic head);
- ventilation screens, clean where necessary;
- oil pressure;
- oil, lubrication, change where necessary.

MAINTENANCE

The long-term operation of the irrigation installation depends upon simple maintenance carried out by the farmer. The periodic servicing of pumping plants and the repair of special devices (filters, injector, etc.) is carried out by trained maintenance and repair personnel.

Maintenance is carried out during a period of non-use to prepare the system: a) for the off-season shut-down; and b) for use before the next season. All equipment requires a certain amount of care in handling for storage and maintenance. For every installation there is a procedure which concerns various aspects of the distribution network and the pumping unit.

System network

The procedure for the network is as follows:

- Flush mains, submains, manifolds and laterals.
- Inspect for possible damage to the network and repair it.
- Open fully and drain completely all valves.
- Remove dirt, corrosion and other foreign material from the component parts.
- Check emitters for possible clogging, damage, wear and signs of deterioration, and replace where necessary.
- Store all emitters in a dry clean place on shelves away from fertilizers, chemicals, oil, grease and lubricants.
- Examine the condition of air and check valves.

- Flush and drain filtration and fertilizer injection equipment.
- Clean all filter elements.
- Check condition of gaskets and seals; remove, clean and store in a dry place.
- Retrieve all portable plastic tubes by rolling them up in coils; store properly.
- Inspect all portable metal pipes for any kind of damage and consult suppliers for repair; store properly away from power lines and wiring.
- Drain completely all pipes left in the open.

Pump plant

Pump plants usually consist of a centrifugal pump of some type and the power unit (electric motor or internal combustion engine). Maintenance instructions are available from manufacturers, pump users associations and other technical organizations. Special care should be taken to protect engines from moisture that can accumulate inside the machines and cause serious damage.

Below is a list of checks, inspections and steps to be taken for the preparation of the pumping plant a) for the off-season period and b) for use before the next season:

Maintenance for the off-season period

Centrifugal pumps

- Drain all the water from pump and connecting pipelines.
- Where possible, remove suction lines and store them.
- Cover shaft and any exposed metal and all oil or grease lubricated bearings with protective lubricant.
- Loosen ‘v’ belt or flat belt drive and insert piece of greaseproof paper between belts and pulley.
- Loosen packing gland.
- Clean debris and any other material from impeller and volute.

Internal combustion engines

- Run engine to thoroughly warm up oil in the crankcase; stop engine and drain crankcase oil; replace drain plug and refill crankcase with high-grade engine oil; start engine and run slowly for two minutes to complete oil distribution on all surfaces.
- Stop engine; remove all spark plugs; pour 60 ml of engine oil into each spark plug hole; with ignition switch off, crank engine for several revolutions to distribute oil over the cylinder walls and valve mechanism; replace spark plugs.

- Drain oil from crankcase; drain cooling system and close drain cocks; drain all fuel from tank, lines and carburettor bowl; replace all plugs and close drain cock.
- Lubricate all accessories and seal all openings airtight, including air cleaner inlet, exhaust outlet, and crankcase breather tube, with weatherproof masking tape.
- Check oil filler cap, gas tank and radiator cap.
- Spray all accessories and electrical equipment with suitable insulating compound.
- Insert a strip of greaseproof paper under the ‘v’ belt pulley.
- Remove battery and store fully charged.
- Where the engine is in the open, cover with waterproof material.

Electric motors

- Ensure that all bearings are well lubricated.
- Cover motor to protect against rodents, insects and dust, but provide ventilation.
- Lock control box in ‘off’ position and cover with a canvas where exposed in the open to protect against moisture and dust.

Preparation for use before the next period

Centrifugal pumps

- Where there is a trash screen, clean and install it properly.
- Ensure foot valve on suction line of horizontal centrifugal pumps operates properly.
- Install suction line of horizontal pumps and/or vertical turbine pumps and/or check they are adequately submerged; check impeller adjustment of deep-well vertical turbine pumps.
- Clean all passages for liquid.
- Tighten packing gland to proper setting.
- Replace bearing oil, or lubricate bearings with grease.
- Ensure pump shaft turns freely without noticeable dragging.
- Start pump and check for normal operation.

Internal combustion engines

- Remove all tape from sealed openings.
- Open fuel tank valve; shut water drain cocks and add coolant.
- Check oil drain plug; replace oil filter and add correct amount of oil to engine.
- Remove spark plugs and spray cylinder walls with a light engine oil.
- Replace spark plugs and crank engine several revolutions by hand to spread oil on cylinder walls.
- Lubricate all engine accessories.

- Where a distributor is used, clean inside and outside of cap; inspect cap and rotor for cracks; lubricate distributor sparingly with suitable lubricant; where a magneto is used, inspect breaker points for wear and gap; lubricate rotor.
- Where oil bath air cleaner is used, clean and fill with correct grade oil.
- Check all terminals and electrical connections.
- Start engine; run slowly for a few minutes; monitor oil pressure; if it fails to come up to correct reading, stop engine and investigate cause.
- Check oil level in crankcase and bring level up to proper mark on dipstick.

Electric motor

- Clean all debris accumulated during the storage period.
- Change motor bearing oil with special type of lubricant, do not overfill, use grease gun to lubricate bearings.
- Change oil in reduced voltage starters.
- Check that motor ventilation vents are open; clean dust and dirt from all moving parts of motor and panel.
- Check and tighten all electrical connections, replace overheated connections with new material; test all coils and heaters for continuity and shorts; clean all magnet surfaces; check for spare fuses of proper size; ensure all conduits or shielded cables are in good condition; check that all conduct points are corrosion free.
- Ensure service cabinet interior is moisture free.
- Operate all moving parts by hand before applying power.

CONCLUSION

Through investment in equipment for improved irrigation techniques, farmers expect to save considerable amounts of water, to increase yields and to improve crop quality.

Professionals and irrigation extensionists in association with manufacturers and farmers have been working for years on the proper O&M of irrigation system installations. Water conservation is and will continue to be a major goal for farmers, industry and governments. All parties concerned should cooperate to achieve this goal.

CHAPTER 16: Irrigation terminology

A.	
Actual evapotranspiration	Represents the actual rate of water uptake by the plant which is determined by the level of available water in the soil.
Alternative technology	Technology that aims to use resources sparingly and to do the minimum damage to the environment or to species inhabiting it while permitting the greatest possible degree of control over the technology.
Aquifer properties	The properties of an aquifer that determine its hydraulic behaviour and its response to abstraction.
Available soil water storage	Amount of water storable in the root zone at the time of irrigation.
B.	
Balance of water resources and needs	The usable water resource of a certain water management unit in a given period of investigation, and the assessment and comparison of quantitative and qualitative characteris-tics of the water requirements to be supplied by this resource.
Base flow	The sustained or dry weather flow of streams resulting from the outflow of permanent or perched groundwater, and from the drainage of lakes and swamps. Also included are water from glaciers, snow and other possible sources not resulting from direct runoff.
Baseline study	Study of the environmental conditions and organisms exist-ing in a region prior to unnatural disturbances.
Basin irrigation	An irrigation method in which crops are surrounded by a border to form a submersion check called basin of round, square or any other form. Irrigation water generally comes directly from the supply ditch/canal or from other basins.
Border irrigation	A sub-system of controlled flood irrigation in which the land is divided into parallel border strips demarcated from one another by earth ridges. Water is successively delivered into each strip from a head or field ditch at its upper end. On the upstream part of each strip is a flat zone, the level portion from which the stream of water spreads evenly across the entire downstream portion.
C.	
Cadastral surveys	Surveys relating to the establishment of land boundaries and subdivisions made to create or define limitations of titles. They also include surveys to retrace or restore proper-ty lines and corners.
Calibrated orifices	A water control structure whose orifice, perforated with great accuracy in a thin wall, allows the passage of relatively large discharges of 50-150 litres/s, meant to be temporarily stored in a basin or furrow.
Canal evaporation losses	Losses due to evaporation from the water surfaces of canals. They are generally accounted for as part of the total losses occurring in an irrigation system.

Capacity of a well	The rate at which a well will yield water, in litres per second or cubic metres per second.
Capital cost	The total expenditure incurred on a work since the beginning of its construction, excluding cost of operation, maintenance and repairs, but including cost of investigations and of all extensions and improvements.
Case study	**General:** Record of the history of a specific study or project performed.
Catchment area	**Specific:** A written account of an event or situation to which participants are to react. Emphasis is on decision making. A case study can be used to start a general session, or as part of a small group session.
Centre pivot sprinkler	The area from which a lake, a reservoir or a chosen cross-section of a stream or waterway receives water (= watershed or drainage basin, but usually smaller).
Check and drop structure	A sprinkler system in which the water source is in the centre, and a system of pipes and sprinkler heads rotates or pivots about the central point to water a given circular area.
Classification of drippers	A fall or drop designed to serve, or serving also, as a flow regulating structure. It is based on several criteria: • the number of outlets per dripper (generally one, from six to ten in certain cases of fruit or garden crops); • the type of hydraulic functioning (short or long-flow path drippers); • the method of mounting on the nozzle-line (on-line, in-line and built-in drippers); • the method of regulating the discharge according to the pressure in the nozzle-line (self-regulating and non-self-regulating drippers).
Climatic cycle	Actual or supposed cyclic recurrences of such weather phenomena as wet and dry years, hot and cold years, at more or less regular intervals in response to long-range terrestrial and solar influences, such as volcanic dust and sunspots.
Cluster sampling	Where clusters of observation are formed on a basis that reduces cost (e.g. within a limited area). Care is taken to ensure heterogeneity and to avoid redundancy of information.
Conjunctive irrigation planning	Planning an irrigation project in a given area having groundwater resources and surface water, so that both the surface and groundwater resources yield the most economical and suitable combination of the use of water from the two sources.
Constant-head orifice offtake regulator	An offtake structure containing a calibrated gate (or orifice) upstream and an adjustable gate downstream to control a constant head difference between the two gates and to divert (and measure) a constant water volume from a main irrigation canal to a distributing canal (= constant-head orifice turnout)
Consumptive water use	The quantity of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from the soil or from intercepted precipitation on the area in any specific time. It is expressed in water depth per unit of time (= consumptive use or evapotranspiration).
Continuous supply	Continuous and constant discharge to inlets of the individual farms or fields.
Continuous flow irrigation system	A system where the individual irrigators receive the quantity of water to which they are entitled in the form of a continuous flow.
Contour ditch irrigation	A sub-system of controlled irrigation in which water flows through openings in ditches (which more or less follow the contours) or over the ditch banks as sheet flow across the fields. The delivery is controlled by the spacing between ditches and by the size and site of the openings of each ditch.
Control structure	A stage-discharge regulating device of a spillway. It may be of any form, viz. weir, side channel, glory spillway, orifice, tube, pipe or a channel.

Controlled flooding	Water is diverted to levelled lands and in a sequential manner in such a way as to deliver the desired dose to all points; it includes flooding from ditches, border irrigation and corrugation irrigation.
Conventional technology	Technology based on a long history of experience without making use of later developments (compare with alternative technology).
Conveyance losses	Losses of water in transit from the source of supply to the point of service whether in natural channels or in artificial ones, such as canals, distributaries, ditches or watercourses. They comprise evaporation from the water surface, seepage, and incidental transpiration by vegetation growing in the water or along the banks of natural channels, canals or watercourses (= transmission losses).
Conveyance structures	Structures built to help provide general control and conveyance of the flow from the intake structures to the area to be irrigated.
Cooperative	Democratic organization for service provision controlled by its members, who contribute equitably to the capital of the cooperative.
Corrugation irrigation	A sub-system of controlled flood irrigation. Corrugations between crop rows are fed at the head by flows from a furrow long enough to wet laterally the ridges situated between the corrugations. In soils with a large natural slope, corrugations with a small longitudinal slope appear to be parallel to the contours.
Cost-benefit analysis	Quantitative and qualitative evaluation of the positive and negative impacts of a project.
Crop irrigation requirement	Consumptive use minus effective precipitation.
Crop water requirement	The total water needed for evapotranspiration from planting to harvest for a given crop in a specific climatic regime when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield.
Cross-irrigable area	The total area within the extreme limits set for irrigation by a project, supply system or canal less areas excluded because of their un-suitability for irrigation (nature of the soil, ground too high to be irrigated by gravity flow or economically by pumps or other water lifting devices).
Cut-off drainage system	A drainage system for draining seepy hillsides. Tiles are placed along the hillside to intercept the seep water and prevent it from reaching the bottom land, or an open channel is dug along the hillside to achieve the same effect.
D.	
Data transmission	The sending of data from one place to another, or from one part of the system to another, utilizing different transmission facilities, such as telephone or telegraph lines, direct radio links, or satellite transmission systems.
Decision support system	Systems for helping planners make decisions using models to select the most favourable solution from among alternatives that are available according to established criteria.
Delivery structures	All the structures (canals or pipes and their appurtenant works, such as intakes, distributors, drops and discharge structures) which ensure delivery of water to the irrigators of an irrigation area from the main canal.
Demand management	The programme adopted to achieve effective management of the use of water resources in order to meet the general objectives of: economic efficiency, environmental conservation, and community and consumer satisfaction.

Depreciation and renewal funds	The provision for interventions necessitated by the changing of spare parts is covered by a renewal fund which capitalizes the depreciation stocks normally constituted for this purpose. However, it is possible to practise a less expensive policy by capitalizing only lesser amounts based on the technical depreciation periods of equipment, which always exceed those for legal or fiscal depreciation.
Depth integrating sediment sampler	A device to take a sample of suspended sediment in a stream. It is lowered from the stream surface to the bed and raised to the surface again at a constant rate. The sample of sediment laden water is drawn in continuously, thus obtaining a composite sample which is integrated over the depth of the stream.
Derived data	Records of observations and measurements of physical facts, occurrences and conditions which have been developed from **basic data** by means of standard methods of computation and estimation.
Design flood	1. The maximum flood that any structure can pass safely. 2. The flood adopted to control the design of a structure. 3. The flood against which a given area is to be protected.
Detailed investigation	The investigation following reconnaissance. Such an investigation comprises: (i) collection of necessary physical, hydrologic, geologic, topographical and structural data to give engineers the basis for planning and estimation; (ii) collection of data on flood damage, land use, population, water consumption patterns, volume of water, and the expected social, environmental and economic impact of the project; (iii) financial and economic studies; (iv) manpower, equipment and machinery requirements; (v) overall cost in domestic and foreign currencies, and preparations of cost estimates.
Discharge rating curve	A curve which expresses graphically the relation between the discharge and its corresponding stage (or elevation of water surface) in a stream or conduit at a given point.
Discounted cash flow	A method of evaluating cash flows in which future income and expenditure are reduced to present values by applying a discount rate.
Distribution works and related collective structures	A series of structures and equipment starting from the **headworks** for the purpose of supplying water to the head of the plots belonging to a group of farmers whose properties are part of the same irrigated area. It includes: the system of drains to remove excess water up to the main drain; all the units and necessary constructions for the O&M of the irrigated area; various systems of protection of the latter (e.g. against floods); and the O&M roads.
Diversion structure	A collective term for all works (weirs or diversion dams, head regulators, upstream and downstream river training works and their appurtenant structures) required at intakes or main or principal canals to divert and control stream/ river flows and to regulate water supplies into the main canal or canals (= headworks or diversion work).
Downstream regulation	A method of operation in which the head and cross-regulators are controlled in such a way that each controlled section of the canal or pipeline system or sub-system is continuously in a position to respond immediately and fully to any change in downstream and lateral demand. In practice, downstream control of a system can only be achieved through automatic control, e.g. with head and cross-regulators under distributed automatic downstream control which react to changes in water demand sequentially from down-stream to upstream.
Drip irrigation	In its simplest form, it is an irrigation method using a system of perforated plastic pipes laid along the ground at the base of a row of plants (= trickle irrigation). In its more advanced form, it is a micro-irrigation system in which water flow is very low, generally less than 8 litres/h and without pressure, i.e. drop by drop. The water emerging infiltrates directly into the soil where it wets a volume of soil called bulb.

Drop structure	A structure designed to secure the lowering of the water surface in a channel in a short distance, and the safe destruction of the liberated surplus energy.
Dry spell	A sustained period of time with insufficient precipitation.
Duty of water	The relation between the area irrigated, or to be irrigated, and the quantity of water used, or required, to irrigate it for the purpose of maturing its crop. Duty is stated with reference to a base period and the place of its reckoning or measurement. It is usually expressed in volume of water or rate of flow per unit area (litres per hectare).
E.	
Ecological impact	The total impact of an environmental change, either natural or man-made, on the ecology of the area.
Economic value of unit of irrigation water	The value of a crop raised by a unit of irrigation water if run continuously throughout the life of the crop.
Effective rainfall	1. In general, rain that produces runoff. 2. In irrigation practice, that portion of the total precipitation which is retained by the soil so that it is available for use for crop production. 3. In geohydrology, that part of the total precipitation that reaches the groundwater.
Effective rooting depth	Soil depth from which the crop extracts most of the water needed for evapotranspiration (also called design rooting depth).
Effective water holding capacity	The amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased, preferably given as a percentage by volume and not by weight (= field capacity, moisture capacity).
Environmental assessment	A formal process to predict the environmental consequences of human development activities and to plan appropriate measures to eliminate or reduce adverse effects and augment positive effects (= environmental impact assessment (EIA)).
Environmental impact	A change in effect on an environmental resource or value resulting from human activities including project development, often called an effect.
Environmental monitoring	Observation of effects of development projects on environmental resources and values.
Erosion control	The application of necessary measures to control accelerated erosion of land surfaces by vegetation or artificial structures, such as terraces, dams or bunds.
Eutrophication	The process of a water body becoming anaerobic, i.e. without oxygen. Human activities that add nutrients to a water body can accelerate this process.
Evaluation of alternatives	The searching out of comparative advantages and disadvantages of alternatives in an attempt to find the one that 'fits' best. The criterion of fit is sometimes called measure of effectiveness. During the planning process, the original goals and objectives are frequently modified and refined. Thus, the measure of effectiveness also needs to be altered. As the planner approaches the design stage, evaluation becomes more precise.
Exchangeable sodium percentage (ESP)	The degree of saturation of the soil exchange complex with sodium. It may be calculated by the formula: ESP = exchangeable sodium (meq/100 g soil)/cation exchange capacity (mec/100 g soil) x 100.
Expert system	Software that applies the knowledge, advice and rules defined by experts in a particular field to a user's data to help solve a problem.

F.	
Farm budget analysis	Analysis of the farm's income (including that from off-farm employment opportunities) and expenditure.
Farm irrigation efficiency	The ratio or percentage of the irrigation water consumed by crops of an irrigated farm to the water diverted from the source of supply, measured at the farm head-gate (= farm delivery efficiency).
Farmer's labour return	Gross farm income less interest on average farm capital.
Financial rate of return	The ratio of the net revenue and the sum-at-charge, expressed as a percentage, attained or estimated to be attained after the development period of a project.
Flood control	The use of techniques to change the physical characteristics of floods. These techniques include purpose built-in river control structures. Management of inflow of floodwater into a region as well as its outflow in such a manner that any flooding is either kept to a minimum (return period, extent) or occurs at a planned moment and during a planned period.
Flood control works	Engineering structures: built to protect land and property from damage by flood, e.g. levees, banks or other works along a stream; designed to confine floodwater to a particular channel or direct it along planned pathways; or a flood control reservoir.
Flood frequency analysis	The estimation of the frequency of occurrence of floods at a site. Flood frequency analysis attempts to fit a probability distribution to flood discharge data and generalize the results for use at sites with no flood data. Many techniques are in use.
Flood frequency method	A method to determine only a peak discharge rate of known frequency which deals with the runoff directly.
Flood irrigation	All types of irrigation which make use of rising water from flood for inundating areas without major structural works, e.g. flood recession, spate irrigation and wild flooding.
Flood spreading	The flooding of gravelly or otherwise relatively pervious lands in order to recharge a groundwater basin.
Flow-duration curve	A duration curve of stream flow, used for example to define minimum discharge and identify low-flow periods for the appraisal of irrigation water with-drawal.
Full supply level	Water level in a canal running with full supply discharge.
Fully automatic irrigation system	An irrigation system or network on a farm, whereby the water requirements of the plants are met automatically. It makes use of devices which measure soil moisture (e.g. tensiometer), or other indicators of irrigation need (e.g. time elapsed since rainfall), and trigger a series of operations to convey the necessary water through the network at the proper time.
Furrow irrigation	A method similar to corrugation irrigation used in permeable soils. It consists in feeding narrow furrows very close to one another with small discharges so as to wet more easily all the soil situated between two rows of crops (often orchards). Furrows parallel to the rows may be laid mechanically with a drill plough.
G.	
Geographic information system (GIS)	All information concerning a point or a group of points georeferenced on the Earth's surface, such as maps or satellite images, digitally stored, processed and manipulated by a computer program (e.g. IDRIS, MAPINFO, ARCINFO).

Geologic survey	A survey or investigation of the character and structure of the Earth, of the physical changes which the Earth's crust has undergone or is undergoing, and of the causes of those changes. The term geological survey is used to designate an organization conducting geologic surveys and investigations.
Gravity irrigation	Method of operating a system or part of a system using gravity alone, water being available at a sufficient level (or pressure) to ensure its conveyance or delivery to the fields or its distribution in the fields.
Greenhouse effect	The warming of the Earth's atmosphere caused by the build-up of carbon dioxide, which allows light from the sun's rays to heat the earth but prevents the loss of heat.
Groundwater balance	A systematic review of inflow, outflow and storage as applied to the computation of groundwater changes. It is based on the concept that all inputs of water in a defined space and time are equal to the sum of all outputs of water, and the changes of water storage, in the same space and time.
Groundwater inventory	A detailed estimate of the amount of water added to the groundwater reservoir of a given area (recharge) balanced against estimates of amounts of withdrawals from the groundwater reservoir of the area during a specific period.
Groundwater recharge	Replenishment of groundwater supply in the zone of saturation, or addition of water to the groundwater storage by natural processes or artificial methods for sub-sequent withdrawal for beneficial use or to check saltwater intrusion in coastal areas.
H.	
Headworks	A collective term for all works (weirs or diversion dams, head regulators, upstream and downstream river training works and their appurtenant structures) required at intakes of main or principal canals to divert and control river flows and to regulate water supplies into the main canal or canals.
Hydraulic conductivity	1. The rate of flow of a fluid through a unit cross-section of a porous mass under a unit hydraulic gradient, at a specified temperature (sometimes called unit of permeability, transmission constant or coefficient of transmission). 2. The flux of water per unit gradient of hydraulic potential.
Hydrologic cycle	The circulation of water from the sea through the atmosphere to the land and then, often with many delays, back to the sea or ocean. The water passes through various stages and processes, such as precipitation, interception, runoff, infiltration, percolation, groundwater storage, evaporation and transpiration; also the many shortcuts of the water that is returned to the atmosphere without reaching the sea.
Hydrologic studies	Collection of hydrological data and appraisal of available water supply for various phases of water resources development, and appurtenant works and operations related thereto, including the determination of the extremes, such as floods and droughts. It includes methods and techniques for installing and using hydro-meteorological observation stations.
I.	
Indicator	An operationally measurable term used in logical framework analyses, such as objectively verifiable indicator (OVI) for the verification of project objectives and results with regard to quantity, quality, time, place and beneficiaries.
Individual irrigation system	Systems located downstream of the outlets served by the collective irrigation system and meant to deliver water to the farms or fields of an individual area.

Infiltration rate	The rate at which water penetrates the surface of a soil. The term usually refers to water occurring as precipitation, but it is also applied to water flowing or standing upon soil.
Inlet structure	A structure built at the upstream end of the outlet conduit of the outlet works and housing the regulating or emergency gates; usually combined with the trash rack structure.
Institutional arrangements	An interrelated set of entities and rules that serves to organize societies' activities for achieving social goals. The institutional arrangements should ensure that the integrated approach is included in decisions and policies regarding river basin management and irrigation development.
Intake	A structure placed in a surface water source to permit water withdrawal.
Integrated river basin management	The process of formulating and implementing a course of action to achieve specific objectives involving the natural, agricultural and human resources of a river basin, and taking into account the social, economic and institutional factors operating in a river basin and their impact on the environment. It signifies the interactions of components and the dominance of components in the particular area.
Inventory of resources	That part of the development resources vector needed for the implementation of a specific project. It comprises the collection, generation and processing of information on resources and their interaction.
Irrigation cycle	Successive deliveries of water on all the units of a network in such a way as to achieve a given irrigation on the entire field concerned.
Irrigation efficiency	The ratio or percentage of the irrigation water consumed by crops of an irrigated farm, field or project to the water diverted from the source of supply. It is called farm irrigation efficiency or farm delivery efficiency when measured at the farm head-gate; field irrigation efficiency when measured at the field or plot; and water conveyance and delivery efficiency, or overall efficiency when measured at the source of supply.
Irrigation potential	Total possible area brought under irrigation, plus that which can be planned for irrigation in a river basin, region or country, from available water resources, with designs based on good technical practice at the time of assessing the potential.
Irrigation requirements	The quantity of water exclusive of precipitation, i.e. quantity of irrigation water, required for normal crop production. It includes soil evaporation and some unavoidable losses under the given conditions. It is usually expressed in water-depth units (millimetres) and may be stated in monthly, seasonal or annual terms, or for a crop period.
Irrigation units and sub-units	Generally, the flow subscribed does not irrigate the field served in one application, but only a fraction thereof, called irrigation unit. Each unit may be a single block but may also comprise several separate parts called sub-units; this in order to reduce the diameter of pipelines and consequently the investments.
Irrigation water quality table	This indicates guidelines for the interpretation of water quality for crop production. The table was adapted from the University of California Committee of Consultants, the United States, in 1974 and revised in 1979. It emphasizes the long-term influence of water quality on crop production and farm management.
Isohyetal map	A map showing lines connecting points of equal rainfall depth.

L.	
Land reclamation	Making land capable of more intensive use by changing its general character, as by drainage of excessively wet land, irrigation of arid or semi-arid land, or recovery of submerged land from seas, lakes and rivers.
Land survey	Surveys relating to the establishment of land boundaries and subdivisions made to create or define limitations of titles. They also include surveys to retrace or restore property lines and corners. The term land survey is synonymous with property survey and cadastral survey.
Land use planning	The development of plans for the uses of land that will, over a long period, best serve the general welfare, together with the formulation of ways and means of achieving such uses.
Land use capability classes	Division of agricultural land into classes of similar production potential with a view to making the best use of each piece of land without causing excessive erosion, or loss of productivity.
Lateral-move irrigation machine sprinkler method	A sprinkler method using an automatic irrigation machine, consisting of a nozzle-line fitted with rotating sprinklers or fixed diffusers, and divided into sections by self-propelled towers with an electric motor. The nozzle-line, straight or slightly curved in shape, moves by translation in a direction perpendicular to its axis. It therefore irrigates a rectangular field. It is supplied with water at some point either by directly pumping from a ditch parallel to its movement or by successively connecting a flexible pipe to outlets fed by a pipeline under pressure.
Leaching requirement	The fraction of water entering the soil that must pass through the root zone in order to prevent soil salinity from exceeding a specified value. Leaching requirement is used primarily under steady-state or long-term average conditions.
M.	
Main drainage system	System which conveys drainage water from the field drainage system to an outlet.
Management of an irrigation development project	Series of actions to design, implement, perpetuate and improve an irrigation development project for the achieving of set objectives.
Mathematical modelling	A specialized application of methods and concepts of mathematics, logic, engineering and other social, economic, environmental and physical sciences to determine what needs to be done and the best method of accomplishing it. Sometimes referred to as operational analysis, systems engineering or management science.
Maximum probable flood	Flood which would be produced by the maximum probable precipitation and which is computed using a rainfall-runoff relationship.
Method of water delivery	Way of making an irrigation system function to convey water from the source of supply to each field served by the system.
Micro-basin irrigation	A water harvesting method used in small fields on gentle slopes. A moulding of the land surface enables the creation on very small slopes of an artificial micro-relief in each small field. Here the runoff water from the upper portion (run-off area) becomes concentrated in the lower portion (crop area) where the crops are raised, and which are sometimes reduced to a single tree (Negarin method).

Micro-irrigation with mini-diffusers	A micro-irrigation system in which water is emitted in small sprinklings through fixed small diffusers in the form of fine droplets distributed over a certain area, or by individual low pressure jets localizing the water on the soil in separate spots. Their discharge is generally limited (20-60 litres/h at 1 bar) and often emitted in the form of circular sectors either to avoid wetting the neck of the trees or to limit the range on the sides of the space between rows, which should remain dry. Their use is limited to orchards.
Mitigation	To render or become mild or milder; to modify; to reduce negative impacts of projects, structures or any action on the socio-economy and environment.
Mobile micro-irrigation	An irrigation machine (generally frontal nozzle-line) in which the mobile nozzle-line functioning at low pressure applies water directly to the space between rows of annual crops. Suspended flexible pipes fitted with mouthpieces at their end feed continuously into small basins dug beforehand or simple partitioned corrugations.
Mode of control	The characteristic manner in which an automatic controller reacts to deviations of the controlled variable(s), or in which an automatic control system performs control functions.
Modernization of a system	This operation consists in replacing certain structures by using a new or improved technology, e.g. replacing channels and ditches by underground pipes.
Modular range	The range of conditions between modular limits within which a module or semi-module works as designed.
Moisture-holding capacity	The amount of water required to fill all the pore spaces between the soil particles, i.e. the upper limit of the possible moisture content. It is usually expressed as the percentage of the soil volume (1 percent equals 1 mm/dm of soil depth), or sometimes as the percentage of the dry weight of the soil.
Monitoring well (or observation well)	A non-pumping well used for observing the elevation of the water table; or a well used for some anticipated, generally undesirable, conditions, such as encroachment of a saltwater front or a pollutant introduced to groundwater.
Monitoring programme	A programme designed to measure quantitatively or qualitatively the level of a substance over a period of time.
Multi-objective planning	Planning requiring the satisfaction of a number of mutually competitive goals.
Multi-criterion decision making	A multi-criterion decision-making problem means a multi-attribute or a multi-objective decision problem or both. Multi-criterion decision making is used to indicate the general field of study which includes decision making in the presence of two or more conflicting objectives and/or decision analysis processes involving two or more attributes.
N	
Net farm income	Farm revenue minus direct costs.
Net irrigation requirement	This is the crop's irrigation need (without including losses of any kind) expressed as a layer of water in millimetres per day, month or other period of time.
Net present value	Value of benefits minus the value of costs, capital and maintenance.
Net revenue	Gross revenue less direct and indirect expenditures including interest for the year taking into consideration the sum-at-charge.

Nominal discharge of a dripper	Discharge in litres per hour at the nominal pressure indicated by the manufacturer. This discharge is determined by a test carried out as per the ISO standard on 25 samples taken at random. In the case of a self-regulating dripper, the test pressure is the arithmetic mean of the minimum and maximum pressures in the regulation range indicated by the manufacturer.
Non-beneficial consumptive use	The water consumed by native vegetation, evaporated from bare and idle land surfaces and from water surfaces.
Non-renewable resource	Those resources which do not regenerate themselves or maintain a sustained yield after being utilized or destroyed.
O.	
Open channel drainage	Drainage accomplished by open channels or ditches.
Operation and maintenance (O&M)	Operation is the organized procedure for causing a piece of equipment, a treatment plant, or other facility or system to perform its intended function, but not including the initial building or installation of the unit. Maintenance is the organized procedure for keeping the equipment, plant, facility or system in such condition that it is able to perform its intended function continually and reliably.
Operation of a canal with constant volume	Method of operation aimed at maintaining constant, under all conditions of steady flow, the volume of a canal reach situated between two gates.
Operation of a canal with volume control	Method of operation where the volume of a canal reach situated between two gates is controlled so as to take into account inflows and withdrawals (by drawing out or pumping) which are variable over time.
Operation of a collective irrigation system	Method or way of controlling or operating a collective irrigation system with the main objective of distributing to all farms or fields in the area the water which they should receive in a safe and economical manner.
Operation of irrigation projects	1. Functioning of irrigation works and equipment to the advantage of users for optimum achievement of the objectives of the project. This function is responsible for optimal management of water resources. 2. Technical support and management advice to users. 3. Suggestions for water policy and collection of dues linked to water services (this function is responsible for the economical sustainability of the project)
Operation of hydraulic engineering works	The operation of structures such as weirs and dams; for example to alleviate downstream flood conditions.
Operation policy	Principles concerning operation of components of an irrigation development project according to the management policy adopted for a given time within the system. It can be one for the whole project or be differentiated within the system per type of component or geographical zone, each one of which operates according to particular modes of management. The choice of an operation policy is influenced considerably by the physical, human, socio-economic and historical environment in which the development project is conceived and then developed.
Orographic precipitation	Precipitation resulting from the lifting of moist air over an orographic barrier, e.g. a mountain range.
Overall efficiency	The ratio or percentage of the irrigation water consumed by crops to the water diverted from the source of supply (measured at the source of supply).
Overhead irrigation	Irrigation by which water is ejected into the air to fall on the soil surface as spray.

Over-irrigation	Excessive irrigation with regard to the actual requirements, due to excessive doses of watering, an insufficient irrigation interval or an overestimation of the requirements (lesser evapotranspiration or excess of rains with respect to the normal). It causes either a leaching of the soil if it is sufficiently drained, or a water-logging of the soil which harms crop growth.
P.	
pF of soil water	The common logarithm of the water pressure expressed in centimetres of water necessary to produce the suction corresponding to the capillary potential. Term introduced by Schofield to express the energy with which water is held by soils.
Pan evaporation	Rate of water loss by evaporation from an open water surface of pan (usually, Class A pan or Colorado sunken pan).
Parshall flume (Parshall measuring flume)	An improved Venturi flume developed by the US Department of Agriculture and the Colorado Experiment Station at Fort Collins, Colorado, the United States, under the direction of R.L. Parshall, to measure the flow of water in open conduits. It consists essentially of a contracting length, a throat and an expanding length. At the throat is a sill over which the water is intended to flow at Belanger's critical depth. The upper head is measured at a definite distance downstream from the sill. The lower head need not be observed except where the sill is submerged more than approximately 67 percent.
Partial duration series	A list of events, such as floods, occurring above a selected base, without regard to the number within a given period. In the case of floods, the selected base is usually equal to the lowest annual flood, this in order to include at least one flood each year.
Participation in the designing	The operators should be consulted, either directly if it is a project which they are following up, or through their officers in their hierarchy where the units of the development corporation are responsible for the engineering of new works, rehabilitation works or modernization works.
Participation of users in rehabilitation	The planning of rehabilitation requires that any operation of a physical or organizational character be preceded by a phase of active training, which could be based on some carefully prepared pilot models. This way of proceeding is accompanied by a campaign of consultation with users. The latter could themselves take charge, at a low cost, of a large portion of the final project's terminals. This creates the dynamism necessary for the success of the operation.
Peak period crop water requirements	For a given crop, the peak crop water requirements during the month of highest water requirements.
Percolation rate	The maximum rate at which water will flow into the subsoil from the topsoil under specific conditions, expressed in millimetres per hour or day.
Perennial irrigation	An irrigation is termed perennial when the lands of the area can be irrigated throughout the year and have the volume of water actually required.
Perfect module (rigid module)	A device for ensuring a constant discharge of water passing from one channel into another, irrespective of the water level in each, within certain specific limits.
Perforated pipe sprinkler irrigation	A sprinkler method in which the nozzle-lines consist of portable and lightweight pipes, the wall of which is perforated with several rows of small holes in such a way as to cause the water to be applied on both sides of the nozzle-line.
Permanent wilting point	The moisture content of the soil, expressed as a percentage of the soil volume or as a percentage of dry weight, at the time when the leaves of a plant growing in the soil first undergo a permanent reduction in their moisture content as the result of the deficiency in the soil moisture supply.

Permeability	The property of a material which permits appreciable movement of water through it when saturated and actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.
Permissible velocity	The highest velocity at which water may be carried safely in a canal or other conduit. The highest velocity throughout a substantial length of a canal or other conduit that will not scour.
Phreatic divide	An underground divide that fixes the boundary of the area that contributes groundwater to each stream or river system (catchment area).
Pictogram	A variant of the bar chart where the bars are replaced by small schematic pictures depicting the characteristic represented by the bar, each picture denoting the magnitude of the characteristic.
Pilot project	An early, usually small, project set up to gain experience for operating the actual project.
Planning for a total rehabilitation	If the project to be rehabilitated is large, financial and practical reasons may make it impossible to carry out a general operation on the entire system. It is advisable to proceed by stages, on the geographical and structural reorganization levels.
Policy analysis	This involves processes for making a set of decisions.
Ponding method (Tapoon)	A method for measuring seepage losses from canals in which a selected canal section is segregated by dikes at each end. Seepage losses are most accurately determined by measuring the inflow required to maintain the water level in the ponded section at a given level, due allowance being made for evaporation.
Poor drainage	Occurs in soils which lose gravitational water slowly, or which are situated where the groundwater table remains high in the profile. In most years, the soil root zone loses excess soil water only during the summer months. In an unimproved condition, successful cropping is unlikely (e.g. standing water, water margin, wetland and peatland environments).
Portable flume (portable weir)	A portable flume for measuring small discharges, such as in farm laterals or watercourses, and consisting of a miniature broad-crested weir made of wooden or iron sheets.
Potential evapotranspiration	1. The amount of water that could pass into the atmosphere by evapotranspiration if the amount of soil water were not a limiting factor. 2. The amount of water utilized by a crop for its growth plus evaporation from the soil if the soil contains sufficient moisture for crop growth at all times.
Potential yield (of a well)	The greatest rate of artificial withdrawal from an aquifer which can be maintained throughout the foreseeable future without regard to cost of recovery. The potential yield (or physical yield limit) is, therefore, equal to the present recharge, or that anticipated in the foreseeable future, less the unrecoverable natural recharge.
Preliminary surveys	The collection of survey data in the early stages of project planning. They are further classed as reconnaissance surveys and preliminary location surveys.
Pricing - users' fees	The user, water and support service consumers owe to the providing agencies or their WUA appropriate dues defined in bilateral contracts. Such contracts engage reciprocally the agency (WUA) to supply the service or expected water delivery and the user to pay for them. Such contracts can work only if the mutual commitments are honoured without either party defaulting.

Private farming management	Management activities of the basic farm unit carried out by the farmers themselves and under their responsibility. These actions cover all the functions of management except those beyond their competence. This does not exclude their participation in all the functions as they can be consulted before any decision. This mode of management also concerns a small group of farmers who jointly exercise these responsibilities within a small irrigated area.
Probable maximum flood	1. The largest momentary discharge believed to be possible from a consideration of meteorological conditions and snow cover on the watershed. It presupposes simultaneous occurrence of all possible natural contingencies favourable to high floods. 2. The maximum flood that can reasonably be expected to occur on a given stream at a selected point with a known frequency during a designated period or during an infinite period, assuming complete coincidence of all factors that would produce the heaviest rainfall and maximum runoff. 3. The most severe flood that is considered reasonably possible at a location as a result of meteorological and hydraulic conditions.
Proportional moduling	The fitting of proportional modules on a supply channel.
Pumping irrigation	Method of operating a system or part of a system using, fully or partly, an artificial pressure for ensuring the conveyance of water, its delivery or distribution in the fields.
R.	
Rainfall intensity	The rate at which rainfall occurs expressed in depth units per unit of time. It is the ratio of the total amount of rain to the length of the period in which the rain falls.
Rainfall-runoff models	Any type of model simulating runoff processes as a function of rainfall and evaporation.
Raingun sprinkler method	A sprinkler method using heavy discharge and long-range rotating sprinklers, requiring pressures higher than 5-7 bars and functioning in a fixed position. Widely used in an individual form on mountain prairies, rainguns can constitute high pressure sprinkler covers in the plains at intervals of 90-100 m. These systems are highly automated. A central programmer enables individual control of the rainguns, so allowing the units to be split easily into sub-units.
Recession hydrograph	The falling limb of a hydrograph after a flood event representing the withdrawal of water from storage in the valley, stream channel and the subsurface runoff. A recession curve may sometimes be referred to as a recession hydrograph.
Reclamation	Act or process of reclaiming swampy, marshy, deteriorated, desert and virgin lands and making them suitable for cultivation or habitation; also conversion of foreshores into properly drained land for any purpose, either by enclosure and drainage, or by deposition of material thereon.
Reconnaissance investigations	Bringing together all readily available socio-economic and physical information, data and facts of a particular area; assimilating data from previous reports and maps; carrying out minimum possible field surveys, if required, consistent with reasonable accuracy; and examining within the shortest possible time all the above information and data with a view to: (i) evaluating human or socio-economic factors in the area, their present state, their trends, and the corresponding needs and requirements; (ii) making a detailed study of development potentials offered by water and other natural resources; and (iii) preparing a preliminary general programme of development which should outline the possible alternative projects, and ensure that whatever priority and timing is chosen for each individually, proper coordination or integration of water development schemes and of water uses will be maintained.

Recurrence interval	The average time interval between actual occurrences of a hydrological event of a given or greater magnitude, e.g. in an annual flood series, the average interval in which a flood of a given size recurs as an annual maximum.
Reference crop evapotranspiration (Eto)	The evapotranspiration rate from a reference surface (grass with specific characteristics) which is not short of water. ETo is a climatic parameter expressing the evaporation potential of the atmosphere at a specific location and time of the year. Hence, it does not consider crop characteristics and soil factors. The FAO Penman-Mon-teith method is recommended as the best method for determining ETo.
Regulation structure	A stage-discharge regulating device of a spillway. It may be of any form, viz. weir, side channel, glory spillway, orifice, tube, pipe or a channel. (= control structure)
Regulation with downstream control	Method of regulation in which the flow in a canal (or in a pipeline) is controlled at a gate by the level of the water (or pressure) measured by a sensor or by a float connected to the gate placed in the immediate **downstream** of the gate. It is a **supply**-oriented control method.
Regulation with upstream control	Method of regulation in which the flow in a canal (or in a pipeline) is controlled at a gate by the level of the water (or pressure) measured by a sensor or by a float connected to the gate placed in the immediate **upstream** of the gate. It is a **delivery**-oriented control method.
Regulation with volume control	Method of regulation in which the volume of water in a reach may vary for technical reasons but remains under the control of the operator.
Renewable resource	A resource capable of being continuously renewed or replaced through such processes as organic reproduction (biomass), groundwater recharge (water) or weathering of parent material (soil).
Resource management	The introduction and enforcement of restraints, including specific technical practices, to safeguard the future of renewable resources and uphold the principle of sustained yield.
Revenue value of unit of irrigation water	The net revenue earned by a unit of water if run throughout the life period of the crop.
Risk analysis	Qualification of the various sources of uncertainty in risk prediction and comparison of relative risk.
Roll-move sprinkler lateral system	A sprinkler method in which the nozzle-line, which carries medium pressure sprinklers, is used as an axle to the wheels which support it at regular intervals. Watering is done in a permanent shift and the nozzle-line is moved manually between waterings to its new position by rolling it fully.
Runoff coefficient	1. (precisely): The ratio of the maximum rate of runoff to the uniform rate of rainfall with a duration equalling or exceeding the time of concentration which produced this rate of runoff. 2. (commonly): The amount of runoff expressed as a percentage of the total rainfall in a given area.
S.	
Salinity control	Abatement or prevention of saltwater contamination of agricultural, industrial and municipal water supplies, or reducing alkaline salts and preventing deterioration of cultivable lands.
Seasonal irrigation	An irrigation is termed seasonal when the lands of the area are irrigated only during a part of the year, called watering season.

Sediment yield	The total sediment outflow from a watershed or past a given location in a specified period of time. It includes bedload as well as suspended load including dissolved solids. Usually expressed as load per unit of time (e.g. tonnes per year or kilograms per second).
Self-managed collective distribution networks	Where the network is the property of the users, routine maintenance is done by members of the network, possibly supported by a small number of paid personnel, for preventive maintenance as well as for corrective maintenance. Specialized maintenance is carried out by sub-contracting agencies under maintenance contracts.
Self-management of a collective project by its own users	In this mode of management, the responsibility of the O&M of the collective project belongs to the users of the project. They are organized as an association, farming society, cooperative or independent group. These organizations are structured so as to be officially represented and to control the specific activities which they entrust to a particular user among themselves or to a third party. They participate in the discussions at the design level, and in the subsequent ones and assess the results obtained. The specialized tasks of maintenance are dealt with under maintenance contracts with one or more competent bodies (company, fitter, artisan and development corporation).
Semi-automatic field water distribution system (partially automatic system)	Irrigation system in which the water distribution and field application are partly automatic and partly manual. A semi-automatic system may carry out a sequence of operations automatically for a single irrigation, but need to be manually started or manually reset prior to the subsequent irrigation. It may involve use of volumetric or timer controlled valves that are started manually but which close automatically.
Semi-module (flexible module)	A device that automatically delivers a discharge which is independent of fluctuations of water level or pressure on the delivery side, and only varies with water level or pressure on the supply side (used for regulation with down-stream control).
Sensitivity analysis	The study of the influence of discrete parameter changes on optimized results. Those parameters whose changes in value have more significant influence on the results need treating with great care, while other parameters can be recognized as relatively insignificant.
Social benefits	Benefits as a result of the project, during and after construction, consisting mainly of opportunities for: (i) employment of labour; and (ii) employment of capital.
Sodium adsorption rate (SAR)	A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil: $SAR = Na^{+} \times [(Ca^{++} + Mg^{++})/2]^{-0.5}$ where the ionic concentrations are expressed in meq/litre.
Soil classification systems	System of classification of soils based on recognition of the **type** and **predominance of the constituents** of soil considering grain size, gradation, plasticity and compressibility. Among the widely used soil classification systems are the US Soil Taxonomy and the FAO Soil Classification System.
Soil moisture deficit	The amount of water that must be applied to the soil to cause thorough drainage.
Soil moisture tension	The equivalent negative pressure or suction in the soil moisture; expressed in pressure units (bar or pascal).
Soil taxonomy	Basic systems of soil classification for making and interpreting soil surveys by the Soil Services Staff of the Soil Conservation Services of the US Department of Agriculture (→ soil classification systems).

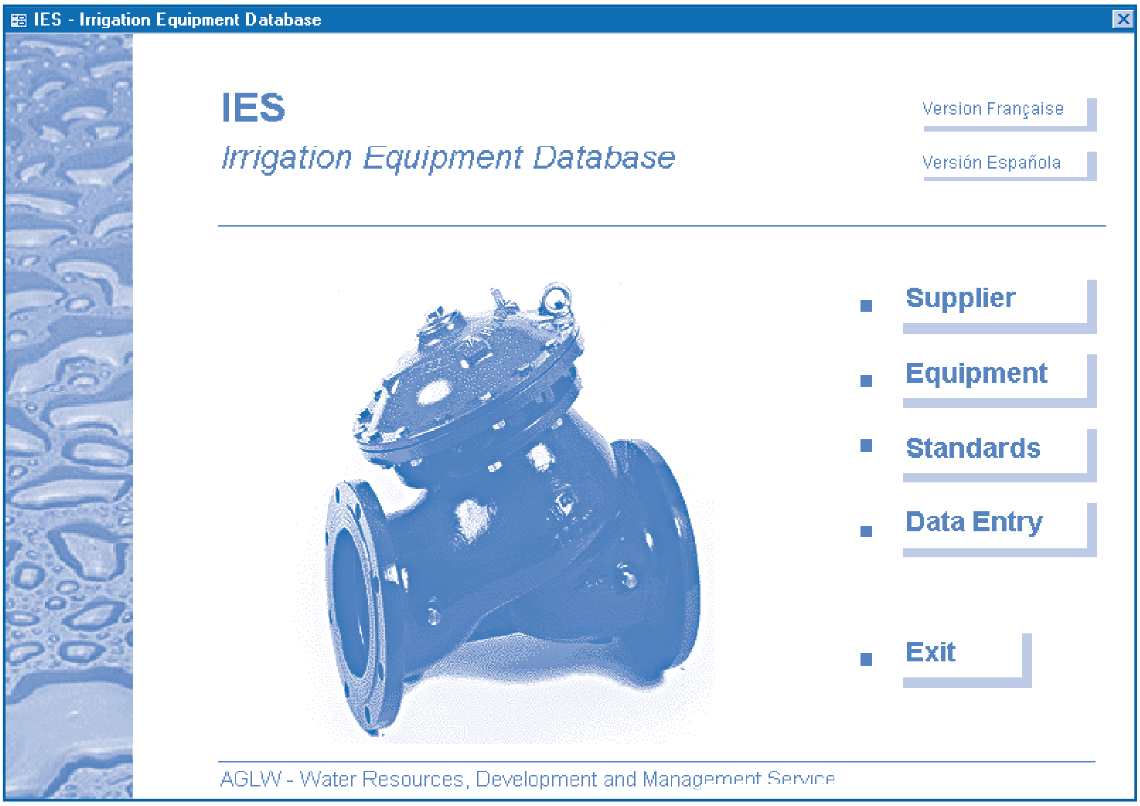
Soil water stress	Sum of soil water tension and osmotic pressure to which water must be subjected to be in equilibrium with soil water.
Solidization	The changing of a soil to a more highly leached and a more highly weathered condition, usually accompanied by morphological changes such as the development of an eluvial horizon.
Spate irrigation	A method of random irrigation using the floodwaters of a normally dry (stream, river) system. It includes the construction of earthen diversion banks across the bed and then canals leading to embanked fields where the water is ponded until total infiltration.
Sprinkler irrigation	A method of irrigation under pressure in which water is sprinkled in the form of artificial rain through lines carrying distribution components: rotary sprinklers, diffusers with permanent water streams, perforated pipes. In comparison with surface and drip irrigation, the length of the path of travel by the water drops through the air causes: 1. great sensitivity to wind, which reduces the uniformity of distribution; 2. 'air conditioning' effects on the crops if used in antifrost sprinkling or spraying.
State-of-the-art	Pertaining to the current stage of development or knowledge of a subject.
Stochastic hydrology	The study and application of random processes involved in hydrology.
Storm distribution pattern	The manner in which depth of rainfall varies from station to station throughout the area for a given storm.
Stratified sampling	In this type of sampling, the population is divided into groups according to some relevant characteristic and a simple random sample is taken from each group.
Stream gauging	The operation of measuring the velocity of the flow of water in a channel or conduit, and the area of cross-section of the flow for the purpose of determining discharge.
Strip chart water level recorder	A water-stage recorder in which the water stages are continuously recorded on a strip of lined paper with the help of a clock mechanism that propels the chart.
Subsurface drainage system	Any drainage system (drainage wells, open ditches or drain pipes) that is designed to control the groundwater table.
Supplemental irrigation	An irrigation carried out only occasionally to make good for short and irregular drought periods.
Supporting soil conservation practices	Special soil conservation techniques (that have gained general support) used to control soil erosion.
Surface drainage system	Shallow ditches or open drains that serve to receive surface flow or drainage water.
Surface irrigation	A method of irrigation in which water is applied to the land by allowing it to flow by simple gravity, before infiltrating. It includes various systems depending upon the relative magnitude of the surface flooding phase and infitration phase after accumulation (submersion).
Surge flow	Intermittent application of irrigation water to furrows or borders in a series of on-off watering periods.
Surveying and mapping	The measuring of ground surface, layout and structures, and the preparation of maps, profiles, cross-sections and alignments.
Synthetic unit hydrograph	A unit hydrograph developed on the basis of an estimation of coefficients expressing various physical features of a catchment.

T.	
Technology transfer (transfer of know-how)	Technology transfer consists in supplying project users or training personnel with technical knowledge and training essential for proper command of O&M functions. This transfer may remain too theoretical or abstract if not accompanied by: a transfer of know-how from the development corporation officials to the users; a set of demonstrations; and a suitable follow-up of the concrete operations (technical and management).
Temporary structures	Constructions of any kind built by the contractor for the purpose of executing permanent works, and which are dismantled afterwards.
Tensiometer	An instrument for measuring the suction that plant roots have to exert in order to extract moisture from the soil.
Time series	A set of ordered observations on a quantitative characteristic of an individual or collective phenomena taken at different points in time (e.g. sequences of hydrological events of specified magnitude, such as water level, discharge).
Topographic divide	A divide that demarcates the boundary of the area from which surface runoff is derived (→ watershed boundary).
Total available soil water storage (total available moisture (TAM))	Amount of soil water available in the root zone to the crop = difference between water content at field capacity and at wilting point.
Transfer of competence	When the authorities decide to restrict the role of the development corporation (or of the state as owner), the latter has to give a concrete shape to the new policy of users' direct accountability. A succession of initiatives follow with the aim of transferring all or a portion of the responsibility of the development corporation (or the state) in the interest of the users, either at once or by successive withdrawals.
Transmissivity (coefficient of transmissivity)	Transmissivity (of an aquifer) is the product of the field coefficient of permeability multiplied by the thickness of the saturated portion of the aquifer
Trap efficiency	The ability of a reservoir or lake to trap and retain sediment, expressed as a percent of the incoming sediment that is deposited in the reservoir or lake.
Turnkey contract	A contract in which the government or organization undertaking a construction project makes only one party responsible for all services connected with the work, including planning, design, drawing up of specifications and construction. This type of contract may be made on a firm-price or cost-plus basis. It is based on function specifications describing the general features and requirements of the finished works (e.g. an irrigation system). The contractor draws up all the detailed engineering designs and specifications, and performs the construction and testing. The work is considered complete when the contractor turns over the works in satisfactory operation to the owner.
U.	
Unconfined aquifers	An aquifer in which the groundwater table is free to rise and fall according to hydraulic gradients.
Underground drainage	Drainage, either natural or artificial, beneath the surface of the earth.
Undertree sprinkler method	Sprinkler method used in orchards with small sprayers with an outstretched jet in order not to wet the leaves and avoid the wind effect on the distribution of water. Such sprayers can be permanent, semi-permanent or portable.
Unit hydrograph	Hydrograph of storm runoff at a given point on a given stream which will result from an isolated rainfall excess of unit duration occurring over the contributing catchment area and resulting in a unit of runoff.

Upstream control (upstream regulation)	1. Of a controlling element, a controlled variable or a pool: a control logic, mainly applied to canals, in which the controlled variable is located upstream from the controlling element. 2. Of a delivery system, or part of it: a method of operation in which the flow allowed to the head of the system or sub-system varies freely according to water availability or is controlled according to a predefined schedule. The head structure or regulator is generally followed by a series of cross-regulators, whose duty may be: to divide the incoming flow into predetermined proportions; to maintain the water level above them within specific limits; or to pass predetermined flows to the downstream canal sections. Upstream control of a system can be achieved manually or automatically. For example, automatic upstream control of a canal can be achieved with cross-regulators under distributed automatic upstream control which will react to the changes in the incoming flow sequentially from upstream to downstream.
Use of stress meter for scheduling in micro-irrigation	This consists in measuring daily and at the same time the soil moisture stress at a given point of the bulb which is formed under an emitter representative of the system and recording its evolution over time. If the stress increases regularly, there is under-irrigation and the irrigator should increase the dose. If the stress decreases regularly, there is over-irrigation and the irrigator should decrease the dose. If the stress is stable, the irrigation level may be considered satisfactory.
User fees	All financial contributions to be borne by the users (or possibly their farmer in the case of renting). The fees pay for the supply of water and accompanying services.
V.	
Vector control	Process of controlling a (water-borne) disease, parasite or infection by control of the carrier.
Volumetric water rate	The charge levied according to the quantity of water actually delivered to the outlet or turnout.
W.	
Wash load	Suspended material of very small size (generally clay and colloids) originating primarily from erosion on the land slopes of the catchment area and present to a negligible degree in the river bed itself.
Water balance	Mathematical calculations for in- and outflow of water components for a given area or soil profile.
Water budget (water balance)	Accounting of in- and outflow of water components for a given area or soil profile.
Water charge (water rate, irrigation rate)	A charge levied on the beneficiaries for supplying irrigation water. It may be based on or cover one or more of the following: (i) O&M expenses; (ii) depreciation charges for the whole or part of the project and O&M expenses; (iii) other criteria which may cover, exceed or not cover the working expenses and interest on investment.
Water control	The physical control of water by measures such as conservation practices on the land, channel improvements, and installation of structures for reducing water velocity and trapping sediments.
Water conveyance and delivery efficiency	The ratio or percentage of the irrigation water delivered at the irrigation plot to the water diverted from and measured at the source of supply.

Water duty	Design criteria where water requirements of a given area are expressed.
Water level gauge (flood meter)	An instrument for measuring the water level or the height of a flood (flood meter).
Water resources appraisal	Assessment of, with the help of observed data or other known procedures of calculation, an overall picture of the extent (in time and space) and dependability of water supplies (surface and ground) and the character of water of a river basin, region or country on which an evaluation of the opportunities for its control and utilization is to be based.
Waterlogging	State of low land in which the subsoil water table is located at or near the surface with the result that the yield of crops commonly grown on it is reduced well below the normal for the land; or, where the land is not cultivated, it cannot be put to its normal use because of the high subsoil water table.
Watershed management (river basin management)	Planned used of watersheds (river basins) in accordance with predetermined objectives.
Water users association (WUA)	Association of water users combining both governance and management functions (they are not the owners of the infrastructure.
Wild flooding (free flooding)	Field ditches are run along the contours. There are no rigid design criteria for this method and at best it does not give a very even application.
Working capital	Rather than distributing the profitable results from a budget among the users in totality, it is preferable to have in the balance sheet of the group a sufficient sum to provide against emergencies and to replace equipment. On the accounting level, this reserve is obtained by the progressive cumulation of depreciation accounts or with a provision for maintenance. The latter can be moduled according to the nature of equipment and life expectancy. Where lacking sufficient reserves, the group can resort to borrowing, followed by raising users' fees.

CHAPTER 17: Irrigation equipment supply database - IES



Irrigation Equipment Supply (IES) is a database that seeks to establish a list of irrigation equipment services worldwide. IES is developed as part of FAO's mandate to provide information on irrigation.
Prospective beneficiaries of IES are those who need to locate information on irrigation equipment at regional or country level. Information is given on:

- Suppliers/Manufacturers;
- Equipment; and
- Standards.

IES is located on the WEB:

http://www.fao.org/waicent/faoinfo/agricult/aglw/ies

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