LOW PRESSURE BURIED PIPE DISTRIBUTION SYSTEMS FOR SURFACE IRRIGATION

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Abstract

Findings of research work into the use of buried pipe distribution systems for surface irrigation are detailed, based on a literature review, field evaluation of existing systems in south Asia and field work on existing buried pipe systems in Bangladesh.

The extent and history of the use of buried pipe distribution systems is detailed in chapter two, along with trends in the upgrading and development of buried pipe systems. The comparative performance of buried pipe systems and open channel alternatives is discussed. Measurable benefits from buried pipe systems include reductions in seepage losses and a lower land take by the distribution system. Systems which are lower in cost than most lined channels are documented for some south Asian systems.

Although low pressure pipe systems vary widely in design they can be classified as open, closed or semi-closed with regard to the method of pressure control, and as gravity or pumped supply with regard to the source of the driving head. These definitions along with consideration of the methods of regulating pipe distribution systems and the choice of the operating and control system, form part of the framework and classification for buried pipe systems presented in chapter three. Pipe systems in India, Bangladesh and Thailand, visited as part of the research work, are described and evaluated within the individual case studies set out in chapter four, along with summaries of the standard features of each of the pipe systems.

Situations in which buried pipe systems are to be preferred over open channel systems depend on soil texture, topography, the nature of the water supply, system cost and particular social and environmental factors. Recommendations on pipe system selection are detailed, covering the choice of the type of buried pipe system, the method of regulating inflow discharge to the system, the operating and control system and the choice of layout and pipe material. Recommended design procedures are detailed for the preparation of a preliminary pipeline layout, along with specific hydraulic design procedures for each of the types of buried pipe system. Particular emphasis is given to the analysis of water hammer and pressure surge in closed pipe systems, and to the determination of the size and spacing of pressure control structures in open and semi-closed pipe systems.

Limited cost information on systems built in south Asia, is presented and discussed both in terms of unit and system capital costs, and also with regard to the impact of higher transit efficiency on per hectare costs. Bangladesh data from existing buried pipe systems are presented which establish measurable reductions in seepage losses and land take by the distribution system.

Low pressure buried pipe systems are considered to represent a neglected opportunity for upgrading surface irrigation systems, and it is hoped that this research will improve awareness of the types of pipe system and their suitability for different situations, and so encourage practitioners to consider buried pipe systems alongside more traditional open channel alternatives.

Declaration of Originality

I certify that I am responsible for the work contained in this thesis, that the original work is my own except as specified in acknowledgements or in footnotes, and that neither the thesis nor the original work contained in it has been submitted to this or any other institution for a higher degree.

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Glossary of Abbreviations and Acronyms

AC	asbestos cement pipe
BADC	Bangladesh Agricultural Development Corporation
BARI	Bangladesh Agricultural Research Institute
BIADP	Barind Integrated Area Development Project, Rajshahi, Bangladesh
DTW	Deep Tubewell
DTW II	IDA Deep Tubewell Project II, Bangladesh
ENGREF	Ecole Nationale du Génie Rural des Eaux et des Forêts.
FCL	Field channel length
GTZ	German Agency for Technical Cooperation
HHP	Howard Humphreys and Partners
HTS	Hunting Technical Services
IDA	International Development Agency (World Bank)
IDTP	Indo-Dutch Deep Tubewell Project, Uttar Pradesh
m^3/s	cubic metres per second
Mm^2	million square metres
MMP	Sir M MacDonald and Partners
MMI	Mott MacDonald International
ODA	Overseas Development Administration, UK
SCP	Société du Canal de Provence et a'Aménagement de la Région Provençale.
STW	shallow tubewell
TADP	Tangail Agricultural Development Project, Bangladesh
UPTP II	Uttar Pradesh Deep Tubewell Project II, India
uPVC	unplasticized polyvinyl chloride

CHAPTER 1. Introduction

1.1 Scope of Thesis

Buried pipe distribution systems for surface irrigation have been installed widely, with large numbers of systems operating in the USA, India and China. Pipe systems and their components in general have been described in a wide range of publications, for example by Jensen (1980) and Michael (1978). However little work has been completed evaluating the performance of existing buried pipe systems and compiling world wide experience of their use. Low pressure buried pipe systems are usually considered within a discussion of surface irrigation systems in general, and few publications document methods and procedures for system selection, design and construction.

Benefits to buried pipe systems are noted and acknowledged by a number of authors including Campbell (1984), Cunningham (1986) and Gisselquist (1986). Campbell (1984) when reviewing the introduction of buried pipe distribution systems on tubewells in Uttar Pradesh, states that experience there "indicates that the efficiency of the delivery to the field with open channels is very considerably less than with buried pipe (at least 35% less)", but the major economic benefit of the pipe system is a "higher level of agricultural development (including a move to higher value crops) which results from the greater reliability of irrigation supply".

Inspite of the clear advantages and benefits provided by buried pipe systems, their adoption outside of specific parts of the USA, India and China, has been limited and slow, while even within these countries buried pipe systems currently account for only a small proportion (refer to section 2.2) of all surface irrigation distribution systems.

In the absence of significant documentary evidence of pipe system performance and of standard approaches to their selection, design and construction, it is thought that many designers lack the confidence and awareness to consider buried pipe systems as an option instead of the more traditional surface channel systems.

The main hypothesis is that there is considerable scope for extending the use of buried pipe systems, and that new design approaches, pipe materials and resource constraints, provide an impetus for re-evaluating their use in surface irrigation systems.

In addressing this hypothesis the aims of the research work, reported within this thesis are three fold:

i) To develop a framework for defining pipe systems, including systematising their classification and standardising the nomenclature associated with their component parts.

ii) To review the design and performance of buried pipe systems as they have been constructed, and identify reasons for their less than widespread adoption.

iii) To identify and quantify the measurable benefits of pipe systems, and define their specific advantages over open channel alternatives.

The development of a framework for defining and classifying pipe systems, coupled with the findings of the performance review of existing pipe systems, allowed recommendations to be made with regard to pipe system selection, design and construction and these recommendations form the basis for chapters 5 and 6 of this thesis.

1.2 Research Methodologies

The research work on which this thesis is based was undertaken as part of work funded by the Overseas Development Administration, UK. While some of the results of this work have been published by this author (van Bentum and Smout 1990, and van Bentum and Smout, 1991a) or are forthcoming (van Bentum and Smout, 1992) and are referenced within this thesis, considerable as yet unpublished material is also included.

The research work, in addition to a review of the literature concerning buried pipe systems, included field visits pipe systems in south Asia and field research work conducted on eight buried pipe irrigation systems over a period of two years in Bangladesh.

The review of literature sought to compare buried pipe systems with more traditional lined and unlined open channel systems. Both published and unpublished material was examined, with a particular focus on documentation of field experience of local irrigation practitioners with the design, operation and construction of pipe systems.

Following on from contacts made during the literature search and review, field visits were undertaken to buried pipe distribution systems, utilising important innovations in design and operation, in a number of south Asian countries, including India, Bangladesh and

Thailand. Data from the field visits have been used to compile the case studies presented in chapter 4.

The Bangladesh field research work undertaken by staff of the Bangladesh Agricultural Research Institute, examined the performance of eight pipe systems distributing water from deep tubewells, in the Tangail District of Bangladesh. The work aimed to quantify specific benefits such as reduced transit losses, reduced land take for the distribution system and real advantages for operating and maintaining the system. Results from this work have been published by Rashid et al (1992).

1.3 Distribution Networks for Surface Irrigation Schemes

1.3.1 Introduction

In order to consider and discuss irrigation systems it is essential that commonly agreed definitions are used. Although the definitions and terminology outlined below are far from universally adopted, they are generally accepted and advocated by the International Commission on Irrigation and Drainage and so will be used for the terms of this thesis. Definitions and terminology developed for the components of the irrigation scheme and their function apply both to open channel systems as well as to pipe or conduit systems.

Bos (1985), describes four levels of organisation within an irrigation scheme, namely primary or main, secondary, tertiary and quaternary (sometimes known as field level). It is the irrigation system at the tertiary and quaternary level with which we are concerned when considering buried pipe distribution systems, although the use of low pressure buried pipelines in the primary and secondary parts of irrigation systems is described by Galand (1989) and Merriam (1987a). The American Concrete Institute (1990) documents the use of cast-in-place concrete pipe for secondary and primary level conveyance of irrigation water at low pressure.

Two important concepts in regard to irrigation distribution systems, are the distinction between conveyance, distribution and field application and the definitions of units of command area within an irrigation scheme.

The movement of water through an irrigation system, from its source to the crop, can be regarded as three separate operations, namely conveyance, distribution and field application (Bos, 1985).

The command area of an irrigation system is defined by Bos (1985) in terms of area units of different size, with each a subset of the other. In ascending order these are quaternary or block, tertiary, secondary or lateral, and finally scheme or project area. A schematic presentation of the more general terminology is detailed in figure 1.

A short summary of the alternative technologies used to distribute water within both the tertiary and quaternary distribution systems is given in sections 1.3.5 and 1.3.6 respectively, along with terminology associated with commonly used application methods in section 1.3.7, with the aim of clarifying the range of choices available within surface irrigation systems.

1.3.2 Command Area Definitions

Bos (1985), defines the quaternary unit as "the area that can be irrigated efficiently by one man if he were to receive a continuous flow through a discharge structure." In almost all cases water will be used consecutively by several farmers. The tertiary unit is a group of two or more quaternary units and receives water from the conveyance system (part of the system above the tertiary outlet) through one off-take structure. Similarly the secondary unit is an area comprising two or more tertiary units and receives water from a main canal or conduit through one (division) structure.

The overall project area can be considered as the area where irrigation is available and to which water is supplied from the water source through one diversion structure from the water source.

1.3.3 Conveyance and Distribution

Conveyance is defined, in general irrigation texts (James 1988), as the movement of water from its source through the main and sublateral or secondary canals or conduits to the tertiary offtakes or distribution system. Distribution involves water movement through the tertiary and quaternary canals or conduits to the field inlet. The final stage is field application where the water moves from the field inlet through the field system and via the application method to the crop.

In most cases the distribution system will begin at the point of water entry to the tertiary unit. The tertiary unit will almost always be less than 100 ha and usually more than 10 ha in area. Where the irrigation stream is too large it may be necessary for this to be broken down between several blocks, but in many cases the irrigation stream can be used consecutively by different landholders.

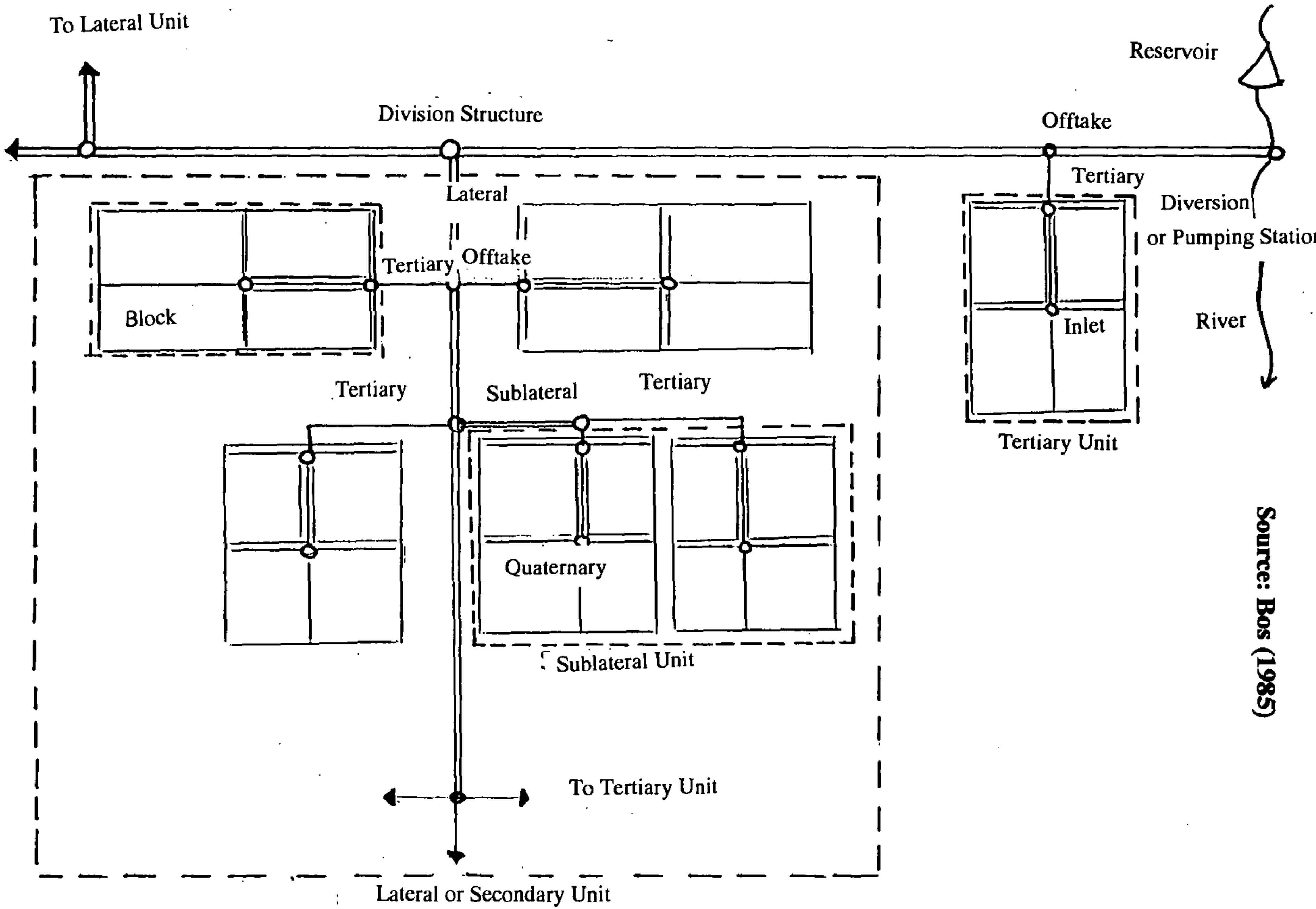


Figure 1.1 Schematic Presentation of Irrigation System Definitions

Source: Bos (1985)

1.3.4 Irrigation System Efficiency

In the same way that the movement of water within an irrigation system can be described as the combination of conveyance, distribution and field application so too overall scheme efficiency can be considered as the product of the conveyance, distribution and field application efficiencies.

In order to more precisely discuss efficiency within a distribution system and more particularly within the tertiary unit of an irrigation scheme, the overall distribution efficiency can be divided into two components, transit efficiency and field distribution efficiency. Transit refers to the passage of water within the pipeline system or open channel to the outlet or offtake, while field distribution comprises the passage of water within the final section of usually earth channel leading to an individual farmer's plot.

1.3.5 Tertiary Level Distribution

As already noted the tertiary distribution system begins at the point of water entry to the tertiary unit, which is typically an area of land in the region of 40 to 100 ha in area, comprising two or more quaternary units. The flow arriving at the quaternary unit, termed the delivery stream, will be defined by the particular flow rate which the farmer can practically handle given the application system he or she is using, for example 30 l/s for basin irrigation, while it may be 2-8 l/s for a hose attached to a hydrant. The inflow to a tertiary distribution system will either be equivalent to the delivery stream or a multiple of the desired delivery stream, necessitating division of flow within the system, or at the outlet.

The tertiary distribution system may comprise a network of open earthen or lined channels, buried or surface pipes or a combination of these.

Earthen Channels

Earth channels have been the traditional choice ever since irrigation began, for the distribution of irrigation water within the tertiary unit. While earth channels composed of well compacted low permeability material may exhibit low seepage losses, continued high distribution efficiency depends on regular and adequate maintenance.

Lined Channels

Lining has traditionally been the strategy chosen when modernisation and improvement of old earthen canals is to be carried out. The range of lining alternatives in use is wide, ranging from low permeability clay or earth layers, through plastic membranes and asbestos sheets to hard surface linings such as concrete or brick (Deacon 1984).

1.3.6 Quaternary Distribution Systems

Although in some cases lined channels and buried pipe systems extend to the quaternary level, supplying water to individual landholdings and individual furrows in some orchard developments (Galand, 1989), it is more usual for a quaternary distribution system to comprise earth channels, or movable surface pipes or hoses.

i) Earth Channels

Quaternary level earth channels tend to be constructed with less care than their tertiary level equivalents (Goldsmith, 1989). This appears to reflect both their often temporary nature (constructed on an annual basis) and the relatively long length of such channels for which each irrigator is usually responsible. Where attention is given to adequate compaction and shape, seepage losses can be substantially reduced.

ii) Surface Pipes

Movable surface pipe, composed of aluminium or ultra violet resistant PVC. The full flow is delivered to the individual plot or field with pipes only being shifted between irrigations, and not while water is flowing.

iii) Surface Hoses

Flexible surface hoses will generally be of smaller diameter than surface pipes allowing water to be redirected to different field plots without interrupting the flow of water. Flow rates are generally low (2-10 l/s) and such hoses are more often used to irrigate horticultural crops. Reference is made to the use of hoses on buried pipe systems in both China (Dept. Sci. Tech. China, 1990) and the Kallada Irrigation Scheme in south India (Campbell, 1986).

iv) Gated Pipes

Gated pipe, typically made from aluminium or uPVC, comprises a closed pipe or tube with regular controllable orifices (gates) located along its length, designed to coincide with a particular furrow spacing. Gated pipes are specifically designed to be used at the outlets of buried pipe systems for delivering water to individual furrows, and have tended to replace the traditional header ditches with siphon pipes.

Galand (1989) reports the very rapid increase in the use of gated pipe in the USA, with more than 360,000 hectares in California alone, and indicates the growing interest in the technique among irrigators in southern France. In both countries gated pipe is considered attractive because of the lower labour input and higher field efficiencies possible compared with header ditches. Typical design and construction principles are described by Watts and Smith (1985), Eisenhauer (1990) and Kruse et al (1980).

1.3.7 Field Application Methods

Surface irrigation, or gravity irrigation as it is sometimes called because gravity is used to spread the water, includes three main field application methods, namely, basin irrigation (including bedded basins), border strip (borderdyke) and furrow (including corrugations).

Other less important techniques which are sometimes mentioned are wild flooding and contour ditch irrigation (James, 1988). With each of these methods, open channels, buried pipe and surface pipe distribution systems can and are used to distribute water.

For each surface irrigation application method described below different methods of utilising buried pipe systems for water distribution are detailed.

i) Basin

In basin irrigation the field to be irrigated is divided into areas separated by narrow earth banks (called bunds, levees or earth checks). During irrigation the basin is filled with water, which is then allowed to sit and infiltrate. Walker (1989) notes that the uniformity of land levelling is critical to the efficiency achieved, as the irrigation is related to water depth and not time.

Irrigation uniformity will improve where the time taken to cover the basin is reduced, and this will depend on the size of the basin, the irrigation stream which can be handled, and crop characteristics as well as the nature of the soil surface.

The ponded method can also be applied to sloping and non-level fields, when the area is flooded, water is held until the desired depth is infiltrated (a function of time) and then drained. Water can be diverted into basins from buried pipe systems by a number of techniques including:

-earth channels from alfalfa valve outlets
-hand held flexible hoses from hydrant takeoffs for small plots
-surface pipes or hoses from alfalfa type valve outlets

ii) Furrow

Furrow irrigation can be termed a moving water technique and runoff or equivalent at the lower end is necessary to achieve good application efficiencies. Water is run in small sloping channels constructed down or across the prevailing slope. Walker (1989) concludes that while furrow lengths may be fixed by landholdings and field sizes, the optimum furrow length depends on many factors including, soil type, land slope, furrow dimensions, infiltration rate, delivery stream and land grading. Poorly graded land will require short furrows.

High water use efficiencies can be achieved with careful design, land grading and operation, including cutback of the furrow irrigation flow and reuse of runoff water. Many of these pose difficulties for farmers in developing countries, particularly as the formation of furrows themselves normally requires the use of a tractor. Nevertheless, furrow irrigation represents a controlled form of irrigation which is suitable for many row crops such as maize and cotton and which can be practised by many farmers with reasonable efficiencies. Walker (1989) also details techniques for the design and evaluation of furrow irrigation systems.

Water can be diverted into furrows from open canals or buried pipe systems by a number of techniques including:

- -header ditches with cuts in the bank, for alfalfa valve outlets
- -header ditches with siphons (over bank) or spiles (through bank) from alfalfa valve outlets
- -surface gated pipe or hose from alfalfa valve type outlets
- -individual risers supplying one or more furrows directly
- -multiple outlet valves for example, pot hydrants
- -individual outlets actuated by a system called cablegation or transirrigation, which is an automated system of outlet control described in more detail in section 2.9 (Galand, 1989)

iii) Border Strip

In border strip irrigation the area to be irrigated is divided into strips sloping away from a header ditch or riser outlet. Adjacent strips are separated by narrow earth banks (bunds, border ridges or levees) and there should be no slope across the strip. Efficient water use depends on careful design of the border strip length which is quite long and related to a number of variables including soil moisture deficit, delivery stream, rate of recession, land slope and soil infiltration rate among others. Border strips require better land grading than furrows with particular emphasis on the strip being flat across its width.

In theory there is an optimum strip length for the particular land slope, soil type, delivery stream and crop to be grown. Design and construction principles are detailed in many texts, including a recent publication by Walker (1989).

Some of the particular techniques used to distribute water to border strips from buried pipe distribution systems include:

- header ditches supplied from alfalfa valves with water distributed using siphons, sills or cuts in the ditch wall.
- alfalfa valves in the head of each border strip

CHAPTER 2. Buried Pipe Distribution Systems in Surface Irrigation

2.1 Introduction

In this chapter the recent history and current extent of buried pipe systems is explored along with trends in the design and construction of piped surface irrigation systems, to outline the importance of buried pipe systems. Data on the performance of lined and unlined channels are compared with field measurements and observations from Bangladesh buried pipe systems.

Both qualitative and quantitative benefits and advantages of buried pipe systems are discussed, drawn from the literature, and field research work. A summary of the different low pressure pipe materials in use is given.

Short definitions of pipe system layouts and typical buried pipe systems are also included by way of introduction, along with a discussion of current trends in the upgrading and development of buried pipe systems.

2.2 The Extent and History of their Use

2.2.1 The Importance of Buried Pipe Systems in Surface Irrigation

Although precise statistics on the proportion of surface irrigation using buried pipe distribution systems do not exist, reasonable estimates can be made based on data concerning world irrigation and known areas of pipe systems in some of the major irrigating countries of the world.

Field (1990), based on data from a number of FAO and World Bank publications, reports the total area of world irrigation at around 256 million hectares, with 94% of this being surface irrigation. Even if the area of micro-irrigation and sprinkler irrigation is now higher than indicated, because of the age of the data sources (1987 and 1988), surface irrigation clearly remains the dominant method of irrigation. Estimated areas of the different types of irrigation for both developed and developing countries of the world are summarised below in Table 2.1.

Table 2.2, shows estimated areas of buried pipe distribution systems, compiled during this research. In respect of the area of low pressure pipe systems, USA has clearly the largest area at 7.3 million hectares (Baudequin et al 1990) followed by China ((Dept. Sci. Tech. China, 1990) and India. These area estimates are based on known areas of development with an allowance for some private investment outside government control, and are likely to underestimate the area of low pressure pipe systems. Although buried pipe systems in their varied forms comprise nearly 43% of all surface irrigation in the USA (Baudequin et al 1990), when taken in a world context they currently account for less than 5% of the total world irrigation area. Thus still in some ways pipe systems could be considered an American specialisation, though the situation is quickly changing.

Table 2.1. Summary of World Irrigation Areas ('000 ha)

System	Developing Countries	Developed Countries	Totals
Surface (ex BPDS)	180,255 (97%)	46,628 (68.6%)	226,883 (89.5%)
Sprinkler	1,500 (0.85%)	12,592 (18.5%)	14,092 (5.5%)
Microirrigation	200 (0.15%)	1,000 (1.5%)	1,200 (0.5%)
Low Pressure Pipes (est)	3,685 (2%)	7,740 (11.4%)	11,425 (4.5%)

Source: Field W. 1990.

Table 2.2 Estimates of Individual Country Areas of Buried Pipe Systems

Developing Countries	('000 ha)	Developed Countries	('000 ha)
China	2,500	USA	7,310
India	1,000	France	200
Bangladesh	10	Japan (est)	60
Africa	100	Australia	40
Nepal	5	Spain, Port.	130
South-east Asia	20		
South America	50		
Totals	3,685		7,740

Source: van Bentum and Smout, 1991a.

2.2.2 Trends in Surface Irrigation

While surface irrigation remains the dominant type of irrigation, the demand for greater water use efficiency, driven by higher unit water costs and water resource constraints has led to a shift in emphasis particularly in developed countries towards sprinkler and micro-irrigation technologies. Pimley and Fischer (1990) ascribe this change to the poor efficiency performance of labour intensive surface irrigation using inexpensive water.

Plusquellec et al (1988), also argue that one of the driving forces for sprinkler and trickle irrigation development has been the interest and investment on the part of private sector manufacturers of irrigation equipment. They state that "surface irrigation with little opportunity for marketable hardware has aroused only limited interest from the private sector."

In individual countries however the conversion from surface to sprinkler and micro-irrigation has been occurring at markedly different rates.

Melamed (1988) describes the eightfold growth in area under micro-irrigation in Israel since 1948 from 30,000 ha to 240,000 ha, as being related to high labour costs and the marginal value of water given advanced crop production systems and high yields, and highlights the acute water resource constraints that have motivated this investment.

Pimley and Fischer (1990), detail the most recent irrigation development investments by the U.S. Department of the Interior's Bureau of Reclamation in high pressure sprinkler systems with virtually on-demand operation, such as the Navajo Indian Irrigation Project in New Mexico. They conclude that the trend towards high-cost automated sprinkler irrigation systems is driven by a desire to improve water use efficiency. Surface irrigation is considered to be inefficient, because the high cost of labour coupled with inexpensive water encourages farmers to adopt water application patterns which are convenient for farm operations rather than for more efficient water use.

The move from surface systems to sprinkler and micro-irrigation systems, although providing valuable savings in labour, requires corresponding improvements in yield and crop value to cover the associated higher capital and energy costs (where pumping is required). These have been realised in higher income countries, such as those mentioned above, with their higher labour costs. However for the majority of small holders in developing countries growing staple crops with existing surface irrigation schemes and low labour costs, returns can seldom justify the capital expenditure associated with such a change. Their need remains for more reliable irrigation which can respond to their changing water needs.

Merriam (1987c) argues that buried pipe distribution systems represent an intermediate capital and operating cost solution between lower cost earthen channels and higher cost sprinkler and micro-irrigation systems and significant improvements in distribution efficiency can be achieved provided adequate flow capacity is provided in the pipe system, to allow flexible demand and arranged schedules to be used.

Pimley and Fischer (1990) in discussing the renewed interest in pipe systems, note that irrigation accounts for more than 80% of water use in the USA. They also conclude that to meet the increasing water demand, projects are being forced to use pipe to transport water, and that the question being asked by planners is ' Have you considered a pipeline for a distribution system?'

2.3 Early Buried Pipe Distribution Systems

The existence of simple buried pipe systems in some southern European countries is considered more than probable from as early as the 1920's and 1930's, however no formal documentation, or published references to such systems have been obtained.

Coles (1991), describes very early low pressure pipe systems installed on orchards in southern Africa, operating since the 1920's but unfortunately published documentation of these systems has not been sourced. These open pipe systems (see section 3.3 for a definition of open) used hand rammed nonreinforced concrete pipe with mortar joints, with the design based on keeping the maximum operating pressure to less than 2 m.

The first well documented use of buried pipe in distribution systems (rather than for conveyance) for surface irrigation, was in California during the 1940's. Pimley and Fischer (1990), describe the U.S. Department of the Interior's Bureau of Reclamation "designing and constructing a pipeline water distribution system for Coachella Valley County Water District" in 1946. Reasons given for installing the pipe system included the opportunity for higher crop yields, and the increasing value of water.

The system was an open pipe system (refer to section 3.3) designed to operate very much like the canal distribution system it replaced, with open stand structures functioning in the same way as check drop structures in surface canals.

Significant improvements to the scheme were made in subsequent years including the provision of reservoir and in canal storage and a central control system. Merriam (1987a) however, describes continuing surging and on-farm water supply problems on the scheme which he attributes to the 24 hour duration, limited rate schedule for water delivery.

During the 1950's the Bureau re-evaluated their buried pipe systems and began to use higher quality rubber ring jointed concrete pipe which allowed for higher operating pressures, and eliminated the need for open stand structures on many schemes. Pimley and Fischer (1990) describe two schemes built under this regime, Delano-Earlimart Irrigation District, and

Westlands Water District and give the reason for the shift to these systems as being the reduced maintenance and lower labour requirements for scheme operation compared with the mortar jointed low pressure pipe.

In the less developed countries of the world, not including China and India, buried pipe systems can still be considered to be in their infancy. Most pipe systems have been developed with considerable public assistance (Cunningham 1986; HHP/HTS 1988; Merriam 1985; and MMP 1989c) and more wide spread adoption will not only depend on finding solutions to technical problems but also addressing social, environmental and economic issues.

2.4 Performance of Open Channel Alternatives

One of the important reasons for the renewed interest in buried pipe systems is the evidence of poor performance, high cost and short life of open channel alternatives (detailed in the following section), coupled with the need to raise levels of agricultural productivity on the current area of irrigated land. Although constraints on irrigated production levels include technical problems, social, organisational and management issues are also seen as pivotal to any successful intervention to improve their performance. Campbell (1984) concludes that pipe systems, apart from saving water and land, (refer to section 2.6) also reduce right-of-way problems, and assure flow delivery at the design flow rate to the furthest irrigator with a minimum of losses and unauthorised diversions en route.

Because the majority of irrigation seepage losses occur in the watercourse channels which have lower flows and greater hydraulic radii than their parent main system channels (Goldsmith 1989), buried pipe systems by reducing water losses at the tertiary level (refer section 2.6.2 for data on seepage reductions) provide opportunities for significantly improving overall scheme efficiency in large irrigation schemes.

2.4.1 Earthen Channels

Old earthen irrigation channels in permeable soils can lose considerable quantities of water through seepage, leading to low transit efficiencies. Rashid et al (1990a) measured seepage rates on unimproved and improved compacted tertiary earthen channels in rural Bangladesh as averaging 5.6 and 6.2 m^3/s per million square metres (Mm^2) respectively for channels with a wetted perimeter of 0.8 m. Goldsmith (1989), in fieldwork carried out in Punjab India, reported losses in earthen channels of 1.8 to 3.7 m^3/s per Mm^2.

Important determinants of the magnitude of seepage losses in earthen channels appear to include soil texture, the level of compaction during construction, the presence of animal burrows and root holes, the level of maintenance and the level of the water table (Rushton et al 1992).

Although earthen channels are generally considered to have much lower construction costs compared to lined alternatives (refer to chapter 7 on costs), Goldsmith (1989) concluded that earth channels can become clogged with weeds so reducing their water-carrying capacity and increasing the expenditure required on maintenance, compared with lined channels.

Water which is lost due to seepage can create water logging problems and if the groundwater is saline, this can lead to salt intrusion into the soil. Goldsmith (1989) acknowledges that in one study, losses from the irrigation canals have caused the water table to rise close to the land surface, creating the risk of areas becoming unproductive due to secondary salinisation.

2.4.2 Lined Channels

Deacon (1984) reviewed a wide range of alternative lining techniques and usefully categorised alternative lining options into three groups, namely exposed rigid linings, exposed non-rigid linings and buried membrane linings.

He concluded that exposed rigid linings "can display very low seepage rates as well as being very durable". While laboratory studies generally bear out the potentially low seepage rates, field work often shows a rapid deterioration in the performance of rigid linings. Goldsmith and Makin (1989), describe field measurements of lined distributaries in the Punjab, where loss rates were shown to be similar to those of the earthen channels they replaced some years earlier. They distinguish between new channels and those more than four years old of which "the poorest had loss rates higher than those measured in unlined channels." They attribute the major cause of these high seepage losses to the development of cracking, where as little as 0.01% of crack area in the section can raise seepage rates to 60-90% of the unlined situation.

They cite problems of poor quality construction and maintenance as significant contributory factors in poor performance. High levels of performance will however depend on increased investment in maintenance, and this is frequently many times more than was envisaged and is currently being collected in water charges (Goldsmith, 1989). Rushton et al (1992), report interim results on a numerical model study of losses from lined canals. The work attempted to define seepage from a section of lining in relation to the relative permeability of the aquifer underneath the canal. This allowed seepage variations from the same canal through different seasons to be modelled. Field verification and testing of the mathematical models developed is required before drawing any conclusions on the value of the work conducted to date. Estimation of aquifer permeability in the field is likely to provide problems for calibrating any models.

While reductions in seepage losses will normally result from lining, if only because of the smaller canal section, the magnitude of these reductions will depend on adequate standards of construction and maintenance, and will be much lower then potential laboratory measured seepage rates would suggest.

While expected seepage loss reduction is a major reason for lining canals, other important reasons are decreasing the transit time for water distribution, maintaining the integrity of the canal section, reducing land acquisition problems, preventing erosion, easing cleaning and increasing canal capacity on flat slopes.

2.5 Description of a Typical Buried Pipe Distribution System

A typical buried pipe distribution system receives water from a canal, reservoir or pump and distributes this over a command area of 10 to 100 ha via a loop or branch layout of pipes to a number of outlets. Each outlet supplies water to one or more quaternary distribution systems, which comprises either earth channels or surface pipes or hoses. The pipeline is buried and the only above ground structures are outlets and associated outlet distribution structures, air vents, surge risers or structures directing the water into the pipeline at the head. A typical loop buried pipe distribution system is illustrated schematically in figure 2.1 (MMP, 1989d). Definitions of standard structures, based on their function are given in section 3.4.

Most low pressure pipe systems have until recently been constructed from nonreinforced concrete pipe but uPVC pipe materials are now increasingly being used (Cunningham 1986; Jain 1991). In some rare situations for reasons of cost and availability, asbestos cement pipe is sometimes used (Plusje 1981; WAPDA 1989). Pipe diameters range from as small as 150 mm for uPVC pipe (Republic of Indonesia, 1990) up to 600 mm for the larger concrete pipes (Merriam 1990). Low pressure pipe systems with larger diameter pipes exist but tend to be secondary conveyance pipelines rather than tertiary distributaries (ACI 1980).

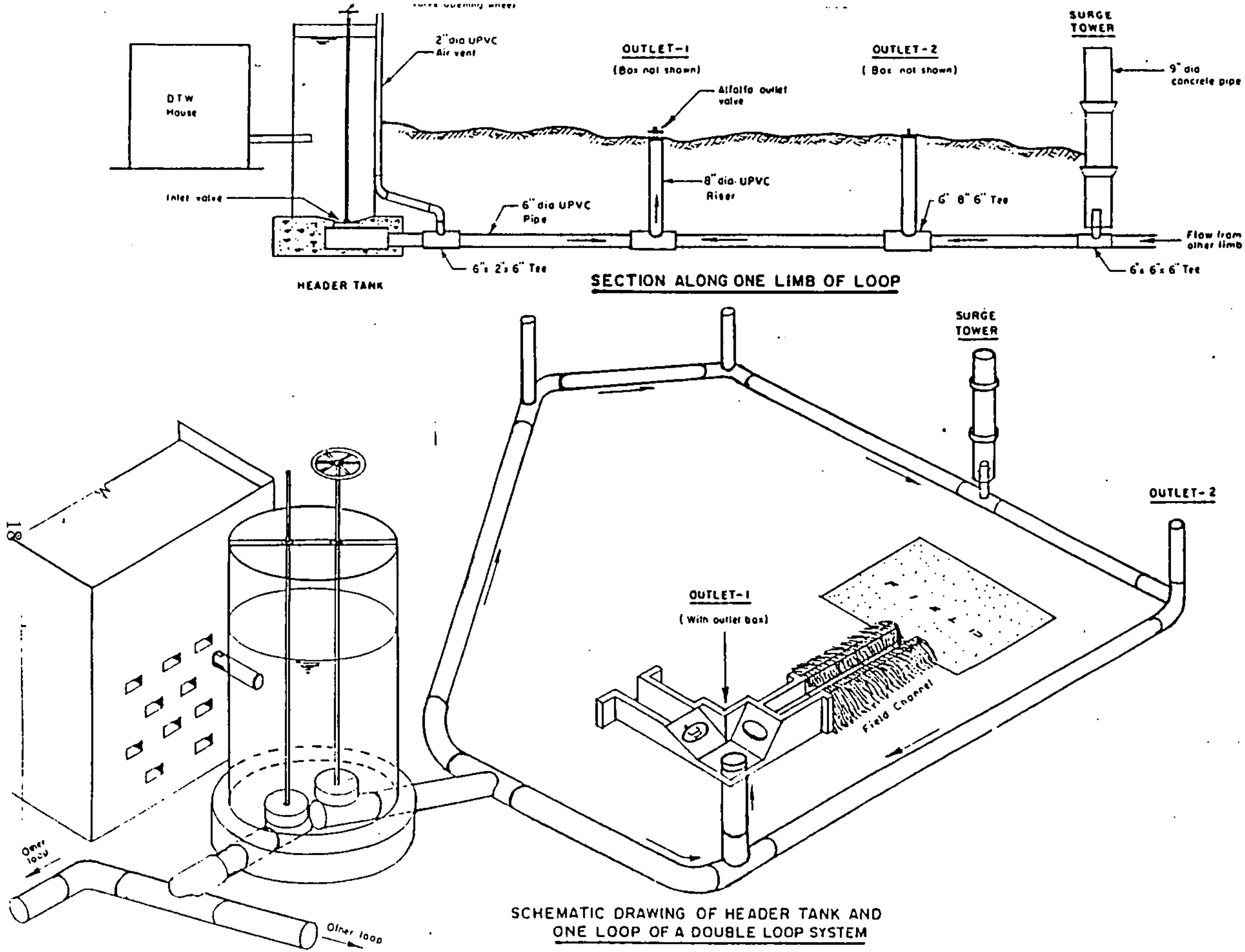


Figure 2.1 Typical Loop Buried Pipe Distribution System

Source: Sir M MacDonald and Partners (1989d)

2.6 The Benefits and Advantages of Buried Pipe Systems

The benefits ascribed to buried pipe systems can be usefully divided into qualitative improvements in the delivery of water and operation of the irrigation system, and quantitative savings in land, water and system costs.

Although pipe distribution systems are often quoted as having lower seepage losses, there are few documented measurements of distribution and transit efficiency for existing buried pipe systems. The data on water losses and land savings described below, are based on limited field work completed in Bangladesh and data collected in south Asia. While the general conclusions relating to pipe system costs are indicated below, reference should be made to chapter 7 for a more detailed discussion of pipe system costs compared to open channel systems.

Qualitative benefits described below represent the conclusions of irrigation practitioners familiar with both open channel systems and operational buried pipe systems. Future research work may be able to quantify and establish the significance of some of these benefits particularly in respect of improvements to the environment.

2.6.1 Qualitative Benefits

General

Apart from the economic benefit of pipe systems enabling a higher level of agricultural development (growing of high value crops) because of the potentially greater reliability of irrigation supply, already alluded to (Campbell, 1984), other important qualitative benefits include:

-larger delivery streams allowing for quicker and more efficient field application.
-reduction in the disruption to existing crops and any existing irrigation system, resulting in fewer delays in obtaining agreement of the layout and alignment of the pipe system.
-effectively reducing the distance between the farmer and the water source, as represented by the tertiary offtake or tubewell and therefore decreasing the magnitude and importance of tail-end problems and water stealing.
-elimination of the need for expensive raised embankments and aqueducts to convey water across drainage features, gullies or depressions.
-enabling the rapid shifting of irrigation water from one part of the command to another during periods of fluctuating or low demand.
-savings in water, which can be significant enough to enable the selection of a lower pumping duty, resulting in both capital cost and operating cost savings.

Environment

Although little quantified information has been found on the environmental and health impact of buried pipe distribution systems, the documented savings of agricultural land, reduced water losses and elimination of suitable habitats for disease vectors will all have a positive impact, compared to open channels.

In a world context this may be important in influencing the incidence of diseases such as schistosomiasis and malaria, particularly where the whole distribution system is piped, and irrigation is a recent introduction to the area.

Where irrigation systems are also used for domestic water supply the reduced opportunity for contamination of the water supply once in the pipe system, will result in a measurable improvement in water quality and therefore a reduction in the incidence of water borne ill-health. MMI (1990b) describes the impact of piping an earlier open channel irrigation distribution system, on access to water for domestic purposes. While good quality water becomes available at locations far from the water source, water is less accessible as discharge from the pump immediately enters the pipe system.

Finally improved distribution efficiencies lead to reduced environmental degradation due to water logging. In addition to creating habitats for disease vectors, water logging can result in localised soil salinity and reductions in crop yield (Goldsmith and Makin 1989).

Disadvantages

Although the apparently higher capital cost is the main reason for the non-adoption of buried pipe systems a number of other disadvantages have been noted, including:

- the fixed nature of the pipe system layout and outlet positions, which cannot be easily changed
- unauthorised water use is more difficult to identify because the flow of water is hidden through most of the distribution system
- the trenches dug during pipeline installation disrupt irrigation and cropping practices, often restricting system construction to short periods during the year
- successful pipe system construction and maintenance requires skilled labour not always available in the village command
- the pipe system represents a new more complex technology for the smallholder farmer to operate
- unfamiliarity of the irrigation engineer and technician with design and construction of

pipe systems.

2.6.2 Quantitative Benefits

i) Introduction

The three main quantifiable benefits of buried pipe systems over their open channel alternatives are:

1. Reduction in water transit and distribution losses
2. Reduction in the land area taken up by the distribution system
3. Reductions in the maintenance and operating costs of the irrigation system

While the reduction in seepage losses and land take is discussed in some detail below, reference should be made to chapter 7 for a detailed discussion of pipe system costs.

ii) Reduced Seepage Losses

While seepage loss reductions are often quoted for buried pipe systems, limited data have been obtained on actual measured system performance. Data obtained by Rashid et al (1992) are summarised in Table 2.3, and were the result of extensive seepage loss measurements over two years on eight buried pipe systems which had been operating for at least four seasons. Although the data are considered reliable, there is considerable variation in the performance of different pipe systems, which the researchers attribute to differences in the pipe material, jointing and construction techniques used. Losses were measured by estimating inflow discharge to the pipe system, based on calibration of pump speed against discharge, subtracting measured outflow from the pipe system, and averaging the loss over the length of water filled pipeline in operation, with losses assumed to also occur in pipe sections where no water is flowing.

The work completed by Rashid et al (1992) agreed with the more limited measurements conducted by Ray (MMI 1990b), suggesting that losses in buried pipe systems were at best 5% and at worst 15% of losses measured on the typical earth channel systems they replaced. The work of Goldsmith and Makin (1989) would suggest that given the poor performance of many lined channel systems, similar differences could be measured in the transit efficiencies of lined channels and pipe systems.

In measuring seepage losses on buried pipe systems, Rashid et al (1992) attempted to pinpoint the source of the leakage and establish strategies for trying to improve the performance of pipe systems. A distinction was made between pipe leakage through the body of the pipe and through the joint, and losses associated with structures such as outlets. The results of the work are discussed in a little more detail in the following section while the data are summarised in Table 2.3.

Pipe Body

Drawing on data on the number and location of pipe leaks detected and repaired during the period of the study, Rashid et al (1990), concluded that on average, some 40% of the leaks occurred from the pipe body, though this proportion included schemes where poor quality pipe had been installed. The majority of schemes however had no more than 1 or 2 leaks per 100m of pipeline per year (Rashid et al 1992).

Establishing reasons for the pattern of leakage was complicated by the mixture of pipe materials, and construction and jointing systems used on the study schemes. They concluded that the high leakage rate occurring in the East Kutubpur scheme (20.4 leaks/100m) was probably due to:

-the use of poor quality handmade pipe
-the use of poor quality materials
-the use of short or broken pipe
-inadequate curing of pipelines and structures

Seepage loss measurements by Ray (MMI 1990b) were carried out on a scheme where pipe sourced from private pipe suppliers had been used, though regular load and hydrostatic pressure tests had been completed by way of quality control. Brod (MMI 1990a) documents the routine manufacture of non-reinforced concrete pipes by machine spinning with failure rates of less than 5% when the pipe was tested to hydrostatic pressures of 1 to 2 bars.

Even with close supervision of manufacture, curing and installation of buried pipe, an average of 1-2 leaks /100m of pipeline occurred, though this still provides a very substantial efficiency improvement over earth channel systems.

Rashid et al (1992) also noted that on pipeline sections exposed to high operating pressures (near the header tank) and pipelines running beneath roads, leakage occurred with a much higher frequency.

Structures

Observation in the field suggests that seepage from structures associated with the pipe system generally occurs where there is damage to above ground structures such as pressure towers and outlet valves. Koluvek (1970) also suggests movement or settling of structures after construction can be an important source of damage to pipelines leading to seepage loss.

Visual observation of systems in south-Asia showed that apart from damaged and broken outlet valves, very few structures exhibit seepage losses after one season of operation. Observations suggested that the magnitude of seepage losses from outlet valves in particular, depends on the number of leaking valves in the system, the pipe layout (branching or loop) and the success or otherwise of attempts made by irrigators to seal the valve when not in operation.

Measurements and visual estimates of outlet seepage losses, made by Brod (MMI 1990b and Rashid et al 1990a) are in the range of 0.4 to 0.6 l/s per leaking outlet valve. While one leaking outlet valve would represent only 1% of the pump discharge, this rises quickly with the number of valves leaking. Rashid (1992) indicates that on average 40% of valves are leaking, so that on an average pipe system with 10 to 12 outlets pressurised at one time, typically 4 or 5 outlets could be expected to be leaking, adding 2-3 l/s to total system losses. Header tank measurements of seepage losses are considered a little unreliable given the possibility of measured water losses being confused with water which is leaking back into the well via the pump discharge pipe. Rashid et al (1992) also noted the high frequency of failure of air vents (1 in 5) constructed from vertically moulded hand made pipe. For detail on the performance of pipe manufactured under different techniques, reference should be made to Appendix A which describes different pipe materials and manufacturing methods.

Joints

While Rashid et al (1992) found that at least 60% of all the leaks were from the pipe joints, they also conclude that the hand made spigot socket and tongue and groove pipe used in TADP schemes, was inferior because of high porosity of the pipe wall, and inadequate curing. This was confirmed by Georgi (1989) when describing the problems encountered with vertical mould manufactured pipe. TADP experience as reported by Georgi (1989), with alternative joint systems such as tongue and groove and spigot socket, must be considered unreliable because of the poor curing and compaction of hand made pipe. Reference should be made to van Bentum and Smout (1992) for a full discussion of different jointing methods and their performance.

The plane ended pipe joint, chosen for its low cost and ease of installation, (MMP 1989a) though prone to leakage, can provide acceptable levels of performance, where careful construction and installation is carried out. The higher leakage rates, measured by Rashid et al (1992) on pipe sections close to header tanks or pressure towers, seem to indicate however a low operating pressure threshold for this joint.

Overall Pipeline Losses

In summary pipe system losses can be said to vary widely and depend on the quality of pipeline construction, particularly for nonreinforced concrete pipe, the length of the pipeline connected to the operating outlet and the unit seepage losses occurring mostly at the joints.

Measured values of seepage losses already quoted for Bangladesh, which include losses through leaking outlets on the test line, apply only to plane ended concrete pipe with simple mortar joints. While it is probable that the standards of concrete pipe manufacture and installation on pipe systems in the USA, would result in lower seepage losses, no data have been sourced. While Merriam, (1985 and 1990) reports low rates (unquantified) of joint leakage from concrete pipelines built in Sri Lanka and India, using tongue and groove mortar jointed pipe on machine manufactured pipe, no field measurements are reported.

iii) Reduced Land Take

Although the saving of land due to the installation of buried pipe systems is often quoted, there is little information quantifying the net saving. Rashid et al (1992) give data for channel area measurements taken on three buried pipe systems, with gross and percentage areas given for the before and after pipe system situations. The limited data do indicate that the area covered by channels per hectare of the command area declines significantly, and the percentage saving ranges from 0.46% to 2.4% (average 1.2%) of the original gross command. While this area may appear small (0.48 ha on a command of 40 ha), in some intensively settled areas very high land values, such as for example Rs 500,000/ha in coastal Kerala, India, can make this a valuable saving (Campbell 1984). In some of the Bangladesh schemes, the land freed up by the pipe system had yet to be reclaimed for agricultural use three years after the installation of the pipe system (van Bentum and Smout 1991a).

Of more significance than the actual cost saving, may be the avoidance of major right-of-way and land acquisition problems which can at best slow and at worst, severely hamper any irrigation development.

iv) Lower Cost

The comparative costs (capital, maintenance and operation) of buried pipe systems and open channel systems are discussed in detail in chapter 7. Several of the major conclusions are set out below to indicate the nature and magnitude of the cost benefits available.

Capital

Costs of buried pipe systems built in Bangladesh, Nepal and Indonesia, using a range of pipe materials, are from 2-3 times the cost of earth channel systems with water control structures, but consistently less than any of the hard surface lining systems considered. On a unit length basis, and considering the value of land saved, pipe systems cost from 10% less than low cost ferrocement lining as used in Indonesia (Republic of Indonesia, 1990) to 50% less than the cost of brick lining systems as built in Bangladesh and Nepal (Gisselquist 1986; and GDC 1987). Although earth channel systems are considered low cost (some 10 to 20% of the cost of a buried pipe system), when the land take and required water control structures are included, system costs range from 30 to 50 % of comparable nonreinforced concrete pipe systems.

When the higher distribution efficiency of pipe systems is taken into account so that the cost of the water supply (in this example a deep tubewell) is spread over a larger area then pipe system costs on a per hectare basis become comparable to earth channel systems and are 50% of those for brick lined channel alternatives (GDC 1987; van Bentum and Smout 1992).

Maintenance Costs

While lower annual maintenance costs are attributed to buried pipe systems in general (Campbell 1984), and higher pressure pipe systems in particular (Pimley and Fischer 1990), no data comparing annual maintenance costs between different alternative distribution systems have been identified.

Rashid et al (1992), recorded seasonal repair and maintenance expenditure on three buried pipe systems for two seasons. The data are too few to make any significant conclusions particularly as most of the expenditure on each of the three tubewell systems was associated with the maintenance of motors on the deep tubewells and not with repairs to the pipe system and above ground structures. Estimates of the number and cost of joint and structure repairs carried out since pipe installation could provide a more realistic picture of maintenance costs.

Table 2.3 Summary of Performance Data on Buried Pipe Systems, Bangladesh

Parameter	Range	Average	Remarks
TADP Systems			
Conveyance loss in pipeline (lps/100m)			
a) Tank test	0.1-1.2	0.33	4.3% of earthen channel
b) inflow-outflow	0.35-1.4	0.69	9% of earthen channel
Conveyance loss in earthen channel by inflow-outflow (lps/100m)	5.9-9.4	7.69	22% of pump discharge per 100m of channel
Leaks on pipeline			
a)Total	2-48	19	40% of leaks in bodies (Except at E.Kutubpur: 360 nos)
b)per 100m	0.11-2.2	0.9	60% of leaks in joints (Except East Kutubpur 20.4/100m)
Outlet Valve Leaking			
a)Total	3-36		Mostly design and manufacturing faults
b)Percent	14-72	42	
BPDS maintenance cost (Tk/ha)			
i) 1989-90	5-127	54	18% of earth channel (Tk 300)
IDA DTW Systems			
Conveyance Loss in pipeline (l/s/100m)	0.3-1.36	0.73	very similar to TADP loss measurements
Earth channel losses (l/s/100m)			
a) Unimproved earth channel	4-8	6	Average of 3 schemes
b) Compacted earth channels	5-9	7	Average of 4 schemes
Outlet valves leaking			
a) Total	3		Data relates to one pipe system only
b) Percentage	20		

Source: Rashid et al, 1992. and MMI 1990b.

Note: Tk = Taka: 38.4 Tk = 1 $, 1991.

2.7 Alternative Pipe Materials and Methods of Manufacture

Low pressure buried pipe distribution systems are made from a wide range of pipe materials including, precast or cast-in-place nonreinforced concrete pipe, thin walled asbestos-cement, or plastic pipe including smooth walled and thin walled uPVC pipe materials.

Non-reinforced concrete pipe materials have been successfully used for buried pipe distribution systems since the early 1920's (Coles, 1991) and have been widely used for pipe systems in the USA (Pimley and Fischer, 1990). While non-reinforced concrete pipe is strong in compression, it has weaknesses when subjected to tensile forces. Koluvek (1970) while acknowledging that reinforced concrete pipe is a superior pipe material, concludes that such pipe is too expensive for irrigation distribution systems in the USA.

Nonreinforced concrete pipes are still however widely used in low pressure pipe distribution systems, but usually for situations where operating heads do not exceed 10 m, and are normally less than 4m (Merriam 1990). Non-reinforced concrete pipe can be manufactured by a wide range of simple techniques including:

A.Mechanised vertical moulding techniques.
B.Hand rammed vertical moulding.
C.Machine spinning
D.Hand spinning
E.Cast-in place manufacture

The more commonly used joint systems include mortar jointed plane ended pipe (MMP, 1989b), tongue and groove pipe with a mortar joint (Merriam, 1990) and spigot and socket pipe with a mortar seal or rubber gasket (Koluvek, 1970). Indian, American and British standards provide general specifications, although for irrigation use the American Society of Agricultural Engineers' standard provides the most relevant recommendations (ASAE S261.7, 1989).

Until quite recently the main plastic pipe material used for irrigation was smooth walled rigid uPVC pipe. More recently new thin walled corrugated uPVC pipe materials have been used for low pressure irrigation applications (Jain 1989). Opportunities presented by these new pipe materials are discussed in more detail in Appendix A.

Although claims for asbestos cement pipe of long life and low maintenance costs demonstrated by many years of field experience, are cited (Univ. Cal. 1977), few buried pipe systems built using asbestos cement have been identified. Plusje (1981) however reports on a pipe system built in Bogra, Bangladesh, where construction difficulties, seepage problems from ill fitting joints and high installation costs discouraged repetition of the use of asbestos cement pipe. Asbestos cement pipe has long been used for non-pressure sewerage and stormwater applications in the UK and Europe (Everite 1986).

The pipe materials outlined above are detailed more fully along with relevant references in Appendix A. Various low pressure pipe materials are illustrated in photo plate 2.1.

2.8 Pipe System Layouts

2.8.1 Introduction

Buried pipe systems may comprise either a branching or loop layout, or a combination of both. Although in theory loop pipelines offer considerable advantages in terms of hydraulic performance by sending the flow down two pipelines instead of one they have not been widely adopted, for reasons outlined in section 5.5.

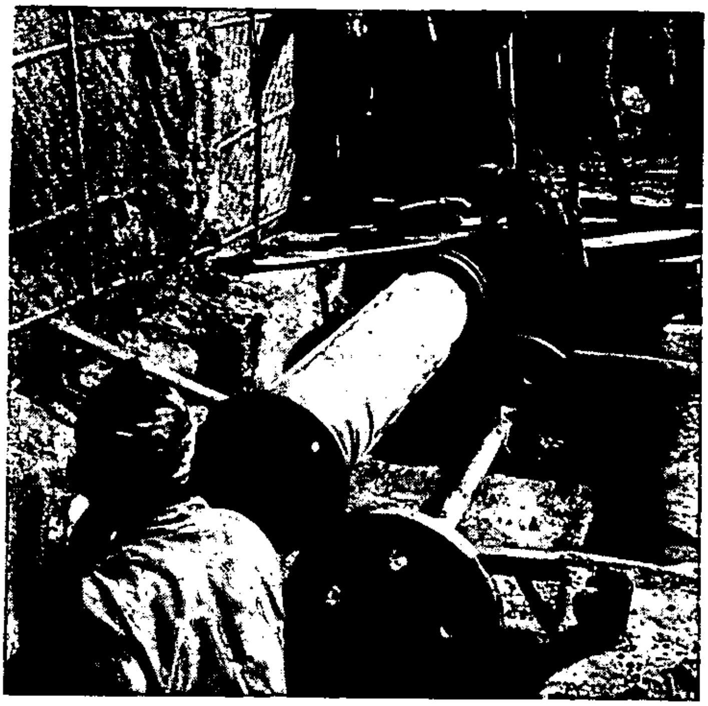
Only closed pipe systems or closed parts of systems can utilise loop pipelines within their network. Open or semi-closed systems however can include loops as part of a closed pipe section, ie. where both ends of the loop close on a single connected section of pipe and each part of the loop is hydraulically connected.

2.8.2 Branching Pipe Systems.

A branching pipe system comprises an interconnected network or tree of pipes originating at the water source. Each pipe is linked to the next at one end, while the other end is blanked, so that water effectively flows only in one direction, away from the water source, to outlets on each of the branches.

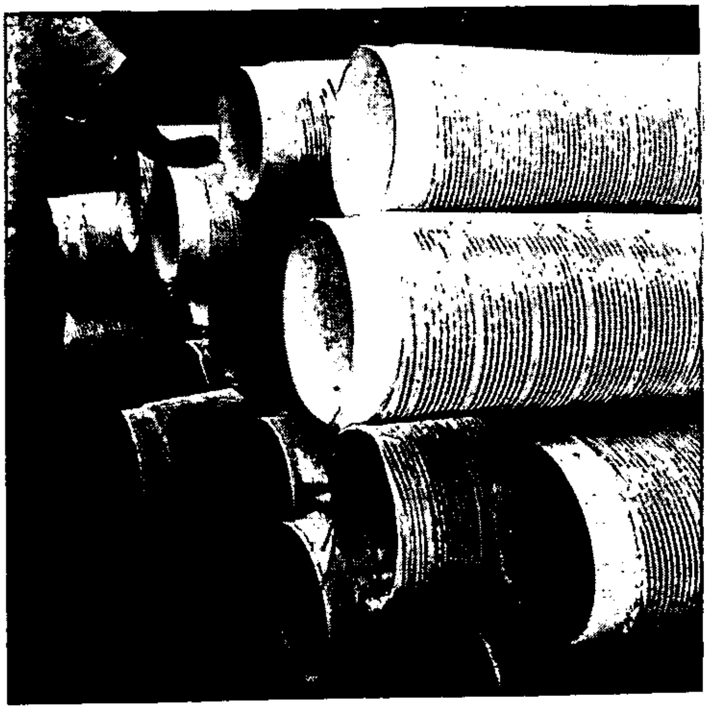
Branch systems require larger diameter pipe than equivalent loop systems, because they must take the entire outlet discharge in one pipe. Most pipe systems use branching pipe systems, particularly where the layout of outlets is complicated by intricate patterns of land ownership.

Photo Plate 2.1 Typical Low Pressure Pipe Materials



Nonreinforced concrete pipe Manufactured by spinning (Bangladesh)

Rigid uPVC Pipe (IDTP, India)



Spirally wound corrugated uPVC pipe (Haryana, India)

Tongue and groove nonreinforced concrete pipe (Gadigaltar, India)

2.8.3 Loop Layouts.

In loop systems the flow is split between the two halves of the loop with the split depending on the relative lengths and diameter of the pipe comprising the respective arms of the loops.

A schematic drawing of a uPVC loop system and pressure tower with bottom valve control, as built in Bangladesh, is shown in figure 2.3 (MMP, 1989d) while figure 2.2 shows a double loop layout of a typical uPVC pipe system as built in Uttar Pradesh (Cunningham, 1986).

2.9 Trends in the Upgrading and Development of Buried Pipe Systems

While in developing countries reducing the cost of existing buried pipe systems is an important part of the strategy of encouraging buried pipe systems to be more widely adopted, in higher income areas of the world, the demand for higher water use efficiency, coupled with a drive to reduce labour inputs has encouraged investment in technology to improve the efficiency of existing buried pipe systems. Pipe systems are perceived as a lower capital and energy cost alternative to the conversion of surface irrigation systems to sprinkler and micro-irrigation systems (Merriam 1987c).

In parallel with this has been the development of new thin walled corrugated plastic pipe materials for use in gravity drainage and sewerage applications, which can potentially be utilised in low pressure situations (Riblok Aust. 1990).

Buried pipe systems are seen as a medium cost alternative for the rehabilitation of traditional irrigation systems (Manuellan 1988). Galand (1989) and Renault (1990), describe research and development effort in France and the USA, focussing on the development of technologies which provide surface irrigation systems and particularly existing buried pipe distribution systems with efficiencies and delivery performance similar to that of alternative sprinkler and micro-irrigation systems. Many of these technologies (the most widely adopted are described below) are as yet not well known outside their countries of development.

Technologies which have moved beyond the experimental phase include:

i) Gated Pipe

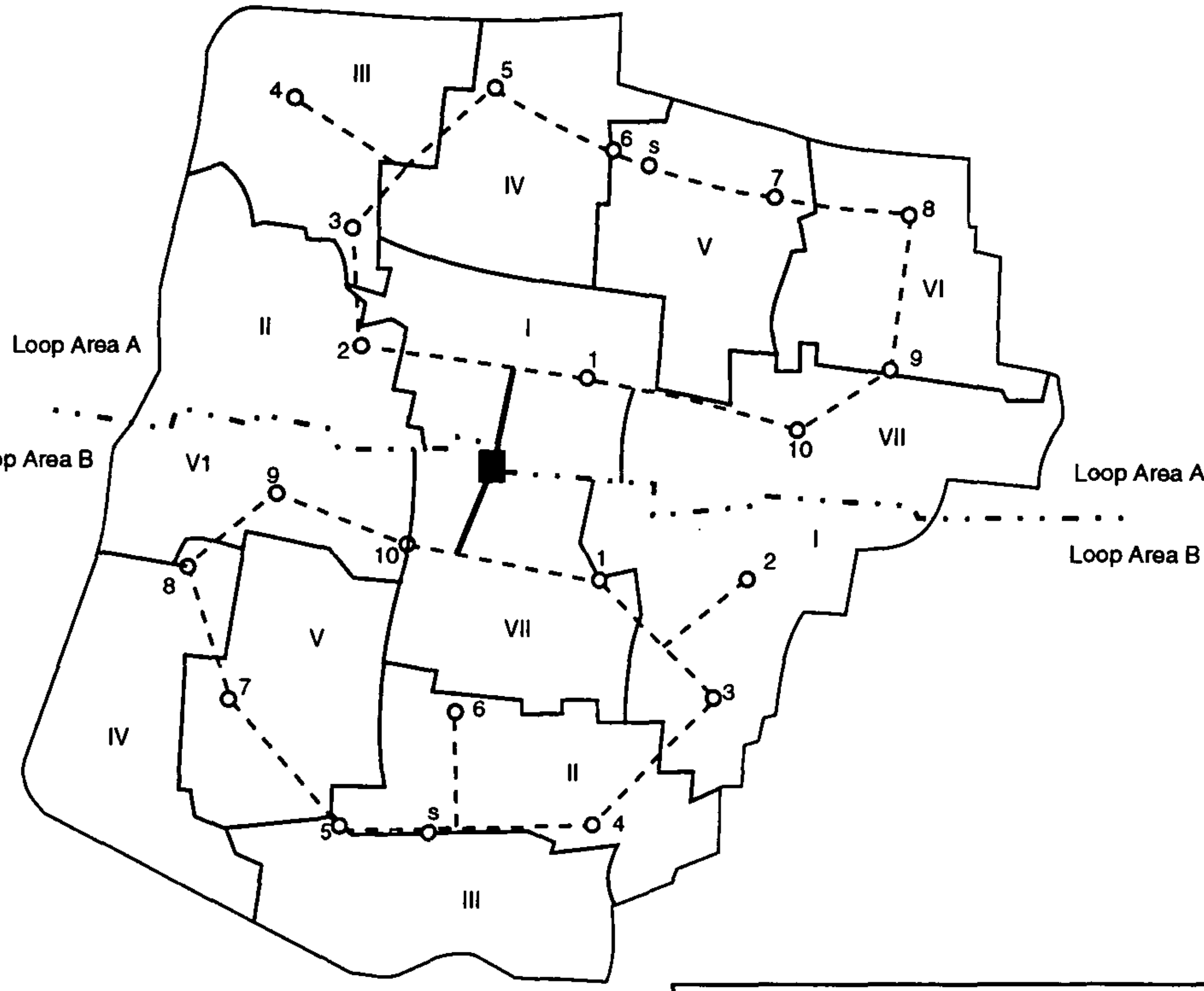
Gated pipes, described by Booher (1974), are portable pipelines used to distribute water from low pressure outlets to individual furrows, via small shutter controlled orifices regularly located along the pipe and facing the furrows. The pipe is normally

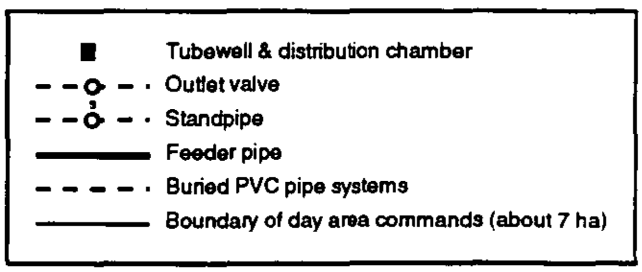
Figure 2.2 Loop Layout on Uttar Pradesh Based Systems

IMPROVED PUBLIC TUBEWELLS

Schematic layout for a distribution system for typical improved standard tubewell command
(150 m³/h serves 100ha through a two loop systems)

Source: World Bank (1983)

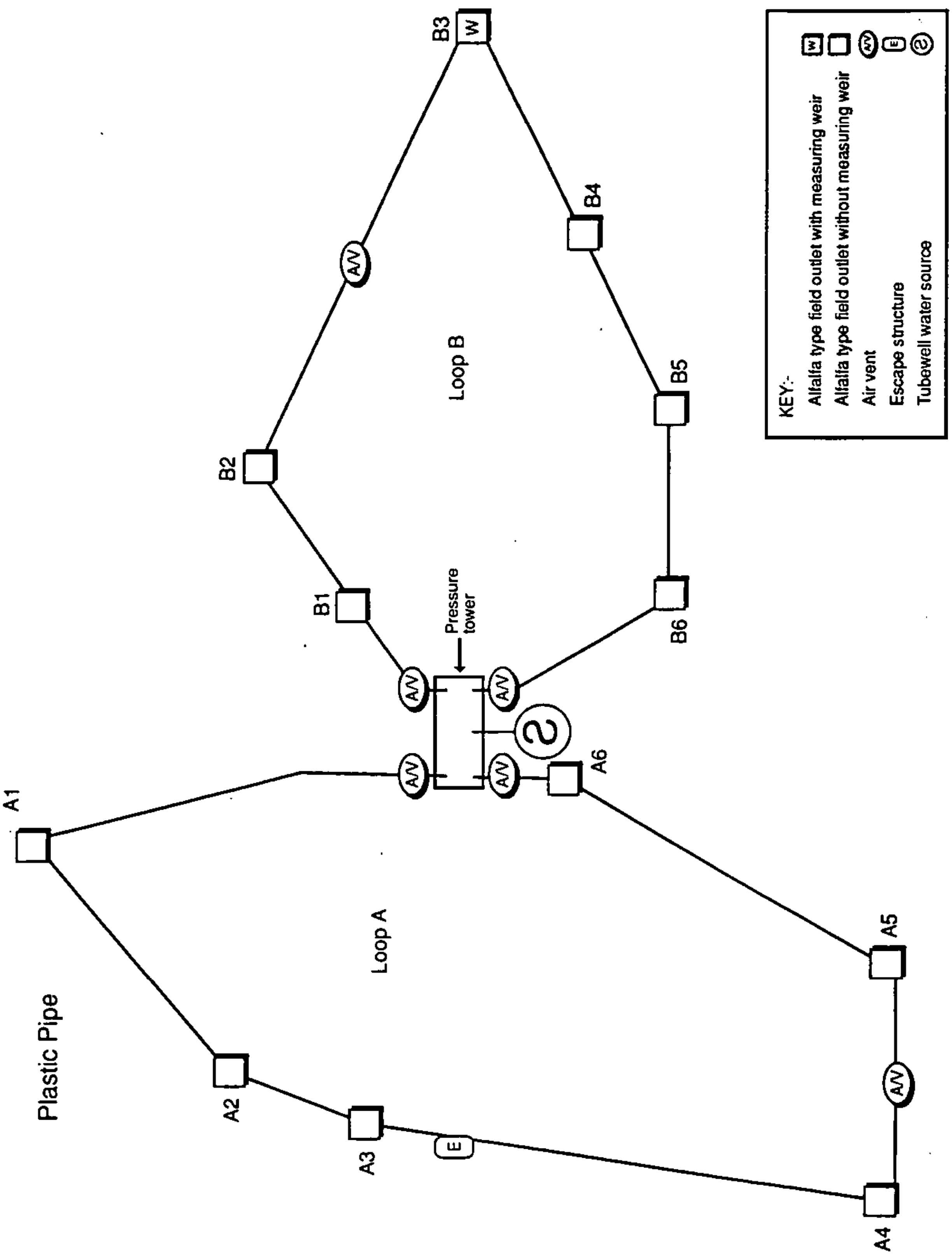




Area day commands	Symbol	Irrigated by outlet number	
		Loop A	Loop B
Monday	I	1.2.3	2.3
Tuesday	II	2.3	3.4.5
Wednesday	III	3.4.5	4.5
Thursday	IIV	3.5.6	7.8
Friday	V	1.6.7	5.6.7.9.10
Saturday	VI	7.8.9	9.10
Sunday	VII	1.9.10	1.6.10

Figure 2.3 Double uPVC Loop Layout as Built in Bangladesh

Source: Sir M MacDonald and Partners (1989d)



composed of uPVC with special flexible joints for easier handling but is on occasion made from aluminium. This technology has tended to replace the traditional earth channel and siphons, and in California is now estimated to cover some 360,000 ha (Baudequin et al 1990).

ii) Layflat Tubing

Both Galand (1989) and Booher (1974) describe flexible butyl rubber or ultra violet resistant PVC tubing used as "gated pipe", which was developed in order to enable machinery access to fields after irrigation. The tubing generally has flexible hose sleeves of small diameter through which water is released. Flow control is achieved by folding and clamping the sleeve, so allowing streams to be cut back or stopped.

iii) Cablegation or Transirrigation

An automated system of outlet control developed in France and the USA, utilising a cable which is attached to a plug drawn down a sloping gated or buried pipe. The progress of the plug allows flow to occur from different groups of gates or risers, with the period,of flow determined by the plug speed. The technique, developed in 1980, is known as "cablegation" in the USA and "transirrigation" in France and is described in more detail by Renault (1988).

iv) Surge Irrigation

A technique developed for use with furrow irrigation whereby the irrigation supply is intermittently pulsed, at the outlet from the buried pipe system, to create a rapid advance of the water front down the furrow by means of a series of surges. Water is delivered to the furrow from either gated pipe or individual furrow risers, and pulsing is achieved using a pulse valve which directs flow to either of two pipelines consecutively. Galand (1989) estimates that by 1988, pulse or surge irrigation was already being practised on more than 150,000 ha in the USA alone.

v) Commutative Valve

Renault (1988) reports the development by Neyrtec and the Société du Canal de Provence, of a simple time activated valve which allows for the transfer of irrigation supply from one irrigation line to another on completion of the allotted period of irrigation. The extent of the use of this device is not however reported.

vi) Large On-Farm Streams

Merriam (1987d), sets out the advantages of providing a larger supply flow which is available at potentially variable rates. He concludes that this would enable the setting of all the furrows or border strips in a block at one time, and allow for cutting back of the delivery streams when necessary. His contention is that this can greatly reduce the labour required and can appreciably increase uniformity and efficiency. The larger supply is achieved by having a reservoir, often on-farm, which can deliver a large, variable supply and large capacity pipe system. No more equipment is required other than gated pipe and the usual buried pipe with outlets. A return flow system by returning runoff to the reservoir at the upper end helps achieve higher water use efficiencies and reduce drainage problems.

While certainly worthy of consideration, it is the author's belief that such variable supply systems are better suited to the large farm holdings, typically found in western industrialised countries, such as the USA.

CHAPTER 3. Framework for Classification and Definition of Buried Pipe Systems

3.1 Introduction

This chapter details a classification developed for pipe systems in general, and for low pressure buried pipe systems in particular. The classification is based on the maximum design operating pressure experienced within the system. Because medium and high pressure (refer to section 3.2) are generally not used for distributing water in surface irrigation systems, they are not considered in this discussion.

Classification of low pressure buried pipe systems in particular considers the method of pressure control (open, closed and semi-closed) and the origin of the supply pressure (gravity, pumped or mixed). Definitions are also given for the component structures of a pipe system based on their function within the pipe system.

Low pressure pipe systems are further classified in relation to the methods chosen for regulating the inflow discharge to the pipe system and the system of operating and controlling the pipe system.

The choice of operating and control system, involves a design choice of the method of regulating inflow discharge to the pipe system, as well as the type of control structure at the inlet and head of the pipe system. Alternatives are described for both gravity and pumped supply systems. The final part of the chapter considers the way in which a pipe system is operated, termed the mode of operation. Along with definitions, the advantages and disadvantages of each alternative mode of operation are also outlined.

3.2 Definition of Low, Medium and High Pressure Pipe Systems

3.2.1 Introduction

The classification which follows is based on consideration of the pipeline design working pressure, and though it is drawn from definitions and terms used by Merriam (1987b) and Baudequin et al (1990), it differs by considering only low pressure systems. Clearly the range of pipe system operating pressures is a continuum, and any classification must be considered somewhat arbitrary. However 10 metres was chosen as the division between medium and low pressure, because field visits to systems in south Asia (van Bentum and Smout, 1992) indicated that few pipe irrigation systems with operating pressures in excess of 10 m, use surface irrigation application methods. Operating pressures between 10 and 20 m appear typical for micro-irrigation systems including trickle irrigation and low pressure sprinkler methods, where pipe systems extend to individual sub-plot and even plant level.

The definitions are considered useful because they encompass the wide range of pipe materials and irrigation operating pressures currently found.

Pipeline Design Working Pressure

The design working pressure is defined as the sum of the static and dynamic pressures within the pipe system including an allowance for any transient pressure surges, associated with such events as water hammer. Outlet operating pressure is not considered within the definition, although for surface irrigation this will usually be from 1 to 5 m, depending on the field distribution and application method used. The design working pressure will usually be a maximum at the head of a pump supply pipe system or at the extremity of a steep gravity pipe system.

3.2.2 Low Pressure Systems

Low pressure systems are defined as buried pipe systems where the maximum design working pressure is less than 10 m. This will include the majority of pipe systems distributing water for application by surface irrigation methods.

Maximum Pipe Pressures

Although the maximum design working pressure is set at 10m, in most cases it will be considerably less than this. The actual maximum allowable pipe pressure will depend on the pipe material used, the method of pipe manufacture and the pipe jointing system used during construction. Table 3.1 details maximum allowable pipe pressures for pipe materials commonly used in buried pipe systems, with the values based on guidelines presented in specific standards (ASAE A376.1 1989 and ASAE S261.7 1989), as well as field experience from Bangladesh (MMI 1990a).

(i) uPVC (Unplasticised polyvinylchloride).

For low pressure uPVC pipe materials, standard specifications (ASAE S376.1, 1988) detail that:

-the maximum surge pressure should not exceed 30% of the rated pipe pressure
-the total of maximum operating pressure and pressure surge should not exceed the rated pipe pressure

Standard manufacturers data on pipe pressure ratings assume a water temperature of 23°C, and where higher temperature water is conveyed the pipe's design pressure should be derated. Typically for a temperature of 44°C this would mean a halving of the pressure rating of the pipe, though generally water significantly warmer than 23°C is uncommon.

Values for derating, applicable to some plastic pipe materials are detailed in ASAE S376.1 (1989), however reference should also be made to literature from the particular pipe manufacturer. Maximum allowable pressures given in Table 3.1, allow for pressure surge at no more than 30% of the rated pipe pressure.

Care should particularly be taken when specifying thin walled uPVC pipe materials for low pressure applications, as only a few manufacturers currently specify a pressure rating for their pipe (Jain, 1991). Most thin walled and corrugated pipe materials are recommended only for non-pressure applications (HPPA 1989). New tests and specifications are considered necessary if these materials are to be used with confidence in low pressure applications.

(ii) Nonreinforced concrete.

For nonreinforced concrete pipes standard specifications (ASAE S261.7, 1989) detail that the maximum operating pressure including pressure surge should not exceed 25% of the hydrostatic test pressure for mortar jointed pipe and 35% of the hydrostatic test pressure for rubber gasket jointed pipe. Although nonreinforced concrete pipes routinely test successfully to pressures between 1-2 Bar (kg/cm^2), the cement mortar joint will not withstand these pressures and hence system operating pressures need to be down rated to take account of this (MMI 1990a).

3.2.3 Medium Pipe Pressures

Medium pressure systems are defined as buried pipe systems where the maximum design working pressure is between 10 and 20 m. Within this group will be included most micro-irrigation systems, where working pressures in excess of 10 m are often required to overcome friction losses in long pipe networks, filtration facilities at the headworks and automatic valving.

Table 3.1. Recommended Maximum Pipe Pressures

Pipe Material	Recommended Max Operating Pressure	Max Allowance for Surge (m)
Concrete		
Cast-in-place concrete pipe	2-5 m	included
Hand spun plane ended concrete pipe	4-5 m	included
Machine spun tongue and groove concrete pipe	5-8 m	included
Machine tamped tongue and groove or spigot socket pipe	5-10 m	included
uPVC		
Thin walled uPVC pipe (est)	7 m	3 m
2.5 kg/cm^2 Rigid smooth walled uPVC pipe	<18 m	8 m

Source: ASAE S376.1 (1989) and ASAE S261.7 (1989) and pipe manufacturer's data from Jain, 1991.

3.2.4 High Pipe Pressures

High pressure systems are defined as buried pipe systems where the maximum design working pressure is more than 20 m. This will include most sprinkler irrigation systems, except low pressure mini-sprinkler systems.

Thus low pressure pipe systems are considered to be those with maximum design working pressures below 10 m. This will include most pipe distribution systems for surface irrigation, although higher quality uPVC pipe materials will allow medium design working pressures to be used.

3.3 Classification of Low Pressure Buried Pipe Systems

3.3.1 Introduction

Although low pressure pipeline systems come in many forms they can be usefully classified on the basis of pressure control into closed, semi-closed, and open systems, and on the basis of the origin of the supply pressure into gravity, pumped, or mixed systems.

The classification of low pressure pipe systems given below is drawn from definitions and terms used by Merriam (1987b) and Baudequin et al (1990), though neither author sets out the relevant definitions in full. This section also seeks to clarify the confusion apparent in some general irrigation texts. For example, James (1988) defines open and closed in relation to whether the system is open to the atmosphere or not, whereas the distinction relates to the provision of overflow stand pipes to dissipate excess pressure head, by a free fall of water.

3.3.2 Method of Pressure Control

i) General

In a similar way to open channel systems, low pressure buried pipe systems can be used in steep command areas, provided some mechanism for dissipating excess pressure head is provided to keep design working pressures to less than 10 m, and maximum pipeline velocities to less than 1.5 m/s (refer to section 6.4.2). Two different methods of dissipating excess pressure are used in low pressure pipelines.

In open pipe systems, overflow stand pipes, which function like drop structures on open channels, are provided to dissipate excess head. Head is lost when water falls over the baffle in the stand, to a lower level on the downstream side. Alternatively in semi-closed pipelines, the overflow stands are replaced with float valves, with the pressure reduction achieved by friction loss through the float valve. Where no pressure dissipation is required to keep the maximum design operating pressure below 10m, the pipe system is termed closed.

As well as defining the type of pipe system, the method of pressure control also strongly influences the regulation of the pipe system, and this is discussed in detail in section 3.5.

ii) Open Pipe Systems

By utilising overflow stand pipes to dissipate excess pressure head, open pipe systems divide the pipeline into two or more hydraulically disconnected pipe sections with discontinuous hydraulic grade lines, and overflow stand pipes acting as the boundaries. Because operating pressure cannot be transmitted between the different pipe sections, open systems are difficult to regulate and differences between inflow at the head of the system, and discharge from an outlet on a lower pipe section, result in operational spillage from the overflow stand between them.

Pimley and Fischer (1990) describe the problems associated with the operation of open pipe systems, and in particular the need for continual adjustment to balance inflow and outlet discharges to reduce operational spillage. Merriam (1987c) strongly advocates the conversion of existing open pipe systems to semi-closed ones to improve their operating characteristics, save labour and permit upgrading of operating schedules. Open pipe systems which are still in operation are described by Merriam (1987a) in the USA and Baudequin et al (1990) in France. A schematic diagram of an open pipe system is shown in figure 3.1 (based on

Baudequin et al 1990).

iii) Semi-Closed Pipe Systems

In semi-closed pipe systems float valves are used instead of overflow stand pipes to dissipate excess head on sloping command areas. The float valves not only allow the whole pipeline to be hydraulically connected but also enable higher pressure rated pipe to be used, often reducing the required number of pressure control structures. Merriam (1987b) considers that semi-closed pipe systems combine the best features of both open and closed systems. The ability of closed systems to automatically respond to flow and pressure changes downstream is retained, so reducing the operational spillage and complex operation. The low operating pressures of open pipe systems are also retained allowing the use of lower cost pipe and equipment. This avoids the disadvantage of large pressure variations in closed systems where flow rates are changing.

Pipe systems of this type are little documented, and so assumed to be not very widespread. One reason may be the relative obscurity of the design and performance of the float valve. Construction and operation of semi-closed pipe systems is described in Sri Lanka (Merriam 1985), USA (Merriam 1987a) and India (Merriam 1990).

iv) Closed Pipe Systems

In a closed pipe system there is no requirement for the dissipation of excess head and the entire pipeline is hydraulically interconnected. Closed pipe systems can develop the maximum pressure resulting either from pumping or the difference in elevation. Note that closed pipe systems can be open to the atmosphere where the operating pressures allow above ground structures to extend above the hydraulic grade line.

Merriam (1987c) notes that closed systems will have the greatest variation in pressure, so that stable pressure and flow rates become difficult to obtain where freedom to alter outlets is unrestricted.

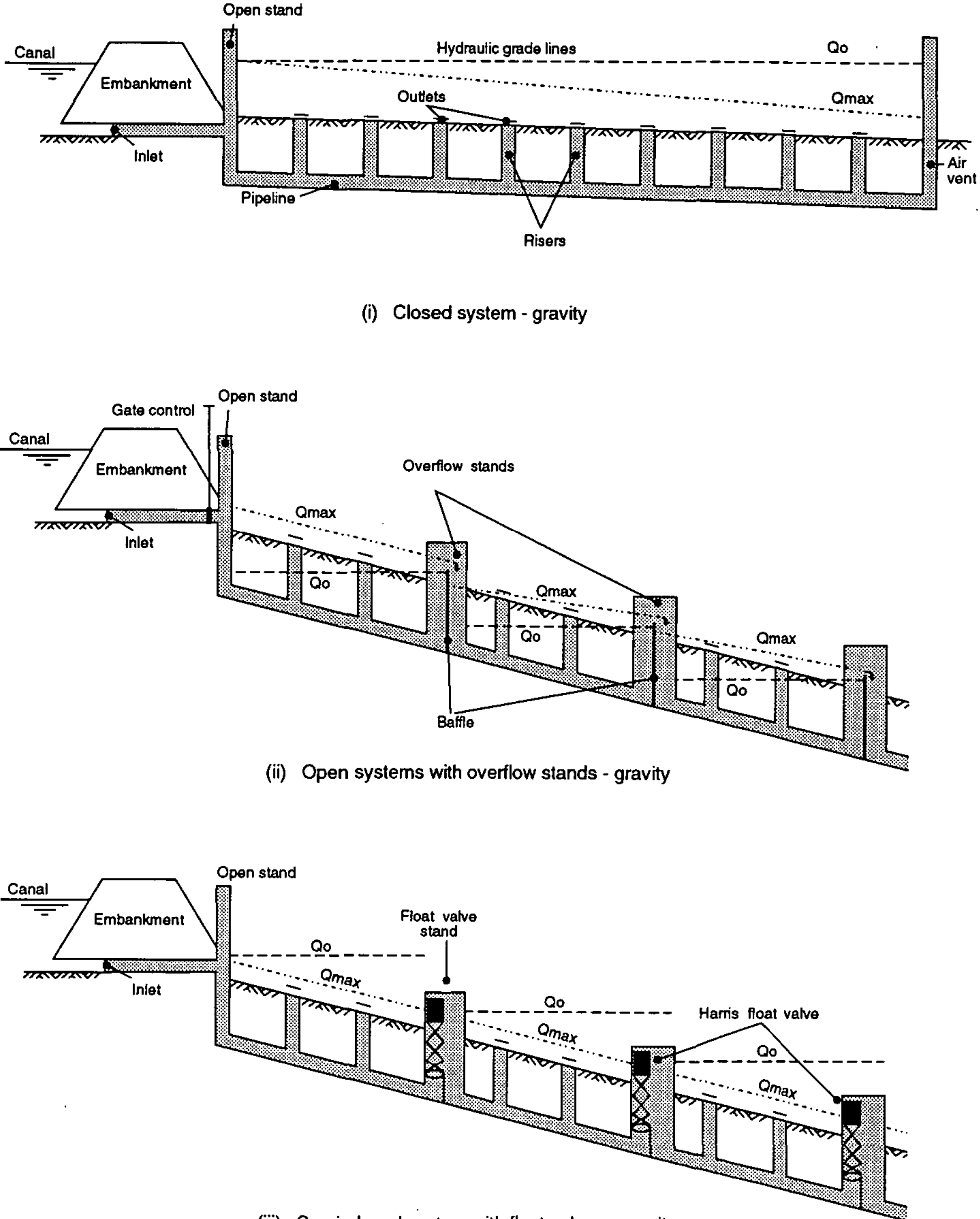
Because these systems, which are the most common, allow changes in demand to be sensed at the water source, automation of the water supply is possible. Systems of this type are widely reported throughout the world with large numbers having been built in India (World Bank 1983), Bangladesh (Gisselquist 1986, 1989) and China (Dept. Sci. Tech. China 1990).

Schematic illustrations of closed pipe systems under both gravity and pumped supply are shown in figure 3.2 (based on Baudequin et al 1990).

Figure 3.1 Schematic Illustration of Pipe Systems under Gravity Supply

Source: Baudequin et al. (1990)

Flow = Q

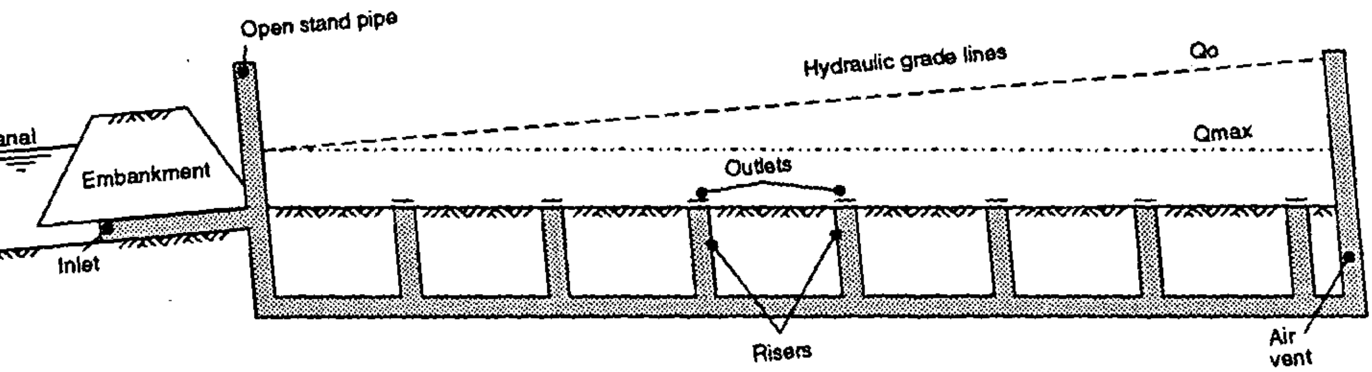


(i) Closed system - gravity

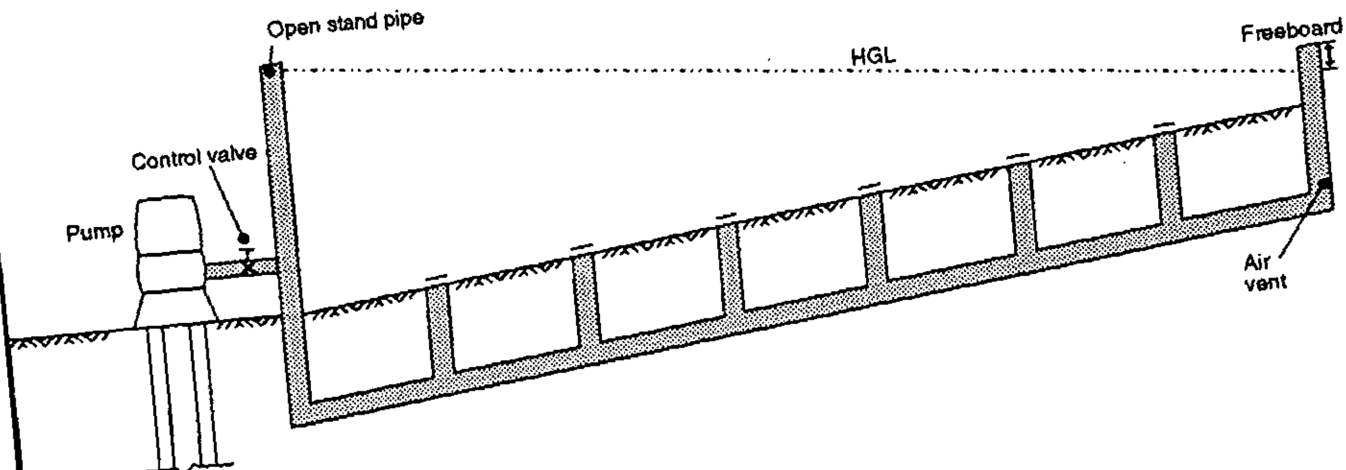
(ii) Open systems with overflow stands - gravity

(iii) Semi-closed system with float valves - gravity

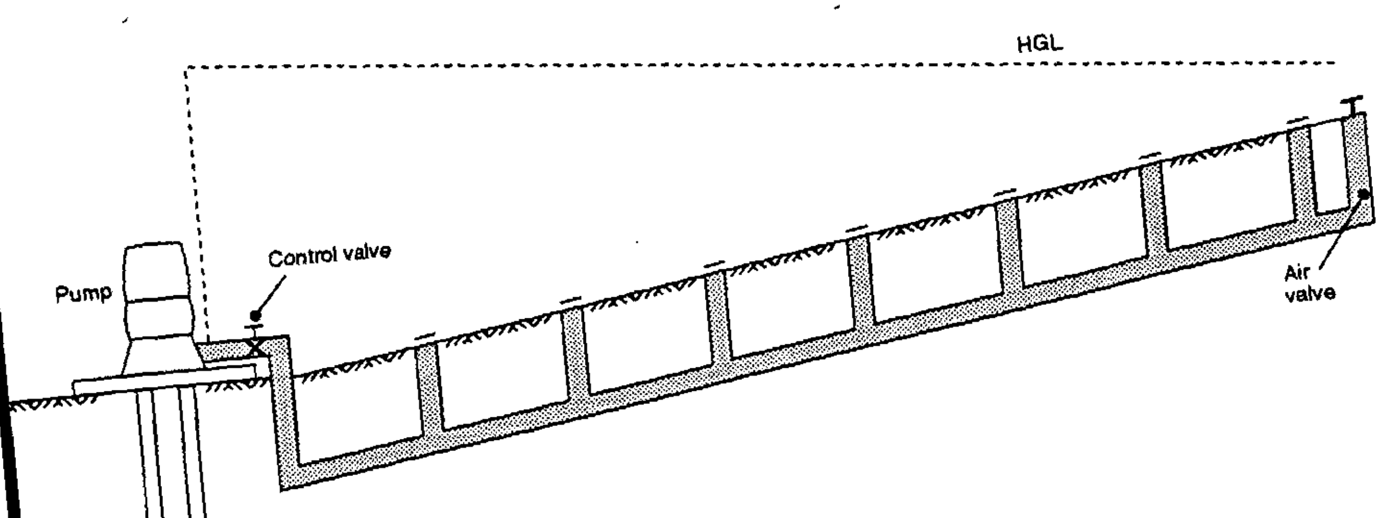
Figure 3.2 Schematic Illustration of Closed Pipe Systems



(i) Closed system - gravity



(ii) Closed system - pumped



(iii) Closed system - pumped (with air valve)

3.3.3 Origin of the Driving Head

i) Introduction

In addition to classifying pipe systems on the basis of their hydraulic control characteristics it is valuable to make a further distinction on the basis of the origin of the driving head required to overcome friction losses.

ii) Gravity Supply.

If the available head is adequate to distribute water over the entire command area by gravity, then the system can be termed gravity supply. Systems of this type in the USA are described by Merriam (1987a), and by Baudequin et al (1990), while Merriam (1985), describes a gravity supply system in Sri Lanka.

In some situations the water source may be higher than the area to be commanded but the head difference is too small to allow for operating a pipe system without provision of a small booster pump or selection of a very expensive pipe system utilising large diameter pipes.

iii) Mixed Gravity and Pumped Supply

Where the available head allows gravity supply to part of the command area, but requires pumping to the remainder, a mixed system could be used to reduce the pumping costs involved with a total pumped supply. Care must be taken to ensure that the two different systems are compatible in terms of control and operation.

Where the gravity portion of the scheme supplies water to the pumped section, a closed or semi-closed pipeline can be provided to enable automation of the pump and demand sensitive operation of the entire system. Systems of this type have been built in the USA and are described by Baudequin et al (1990).

iv) Pumped Supply

Systems under pumped supply include those utilising groundwater, those where available head is inadequate to overcome pipe friction losses and situations where the topography is rising away from the water source.

All tubewell based systems are defined as pumped supply. In other situations where a gravity fed surface distribution system is to be replaced at the tertiary level by a buried pipe system, then with very flat command areas pumping may be required to overcome pipe friction losses. The cost of providing and operating a pump even if low lift must be balanced by considerable operational and performance advantages from the use of a pipe system. In situations where farmers use individual pump sets to lift water from surface water courses to their field channels such as in Egypt (EWUP Fort Collins 1983), pipe systems can rationalise the investment in pumps, by enabling one pump to supply a number of farms. Pilot pipe systems of this type in Egypt, are described by Hydraulics Research (1990c). Tubewell based pumped supply pipe systems exist widely in south Asia, and are described in detail in India (IDTP 1988), Bangladesh (MMP 1989a), Sri Lanka (Merriam 1985) and Thailand (HHP/HTS 1988).

3.4 Definition of Component Structures on a Buried Pipe System

Despite the wide range of buried pipe systems in existence, only a limited number of structures are necessary, though designs, construction methods and materials used for each structure vary widely. Definitions for each of the structures set out below, relate to the function of the structure within the pipe system and are independent of the construction methods or materials used. While outline definitions for some of the structures mentioned are drawn from James (1988) and Koluvek (1970), most of the material is the result of field observation and interpretation by the author during visits to over thirty pipe systems in four south Asian countries.

3.4.1 Pumpstand and Header Tank

A general term for any stand pipe structure open to the atmosphere connecting the water source (for example a tubewell pump) to the underground pipe network. The structure will extend from ground level to a height required to provide the necessary driving head in the pipe system. A number of specific types of pumpstand or header tank are distinguished, and defined below. These include pressure towers, head riser pipes, low head pumpstands and elevated tanks.

i) Pressure Tower

A particular type of pumpstand where the water level is forced to rise to the design driving head inside the structure. Flow to the pipe system may be via the floor or through internal or external satellite stands. The internal diameter of the structure is usually sufficient to allow for the installation of valves or satellite stands inside the tower.

ii) Head Riser Pipe

Small diameter vertical stand pipe, between the water source and the underground pipe network, setting the maximum delivery head. It is equal to or larger in diameter than the underground pipe, acts as an air vent and surge riser, but provides no storage or room for the installation of a control valve.

iii) Low Head Pumpstand

Short open stand structure used to connect the pump to the pipe system where the driving head is at or just above ground level. The pump normally discharges freely into the stand.

iv) Elevated Tank

Raised tank (usually on columns) supplying one or more separate pipe networks via individual head riser pipes. The tank usually incorporates some mechanism for flow division, and pump regulation can be automated where desired.

3.4.2 Stand Pipe Structures

Any upright chamber or cylinder, open to the atmosphere and connected to the pipeline network. They may house gates, valves or be positions for dissipating excess head in open stand structures. Typical stand pipe structures defined below include overflow stands, float valve stands and gate stands.

i) Overflow Stand.

An open stand structure connected to a pipeline in an open pipe system, at a position where excess head is to be dissipated. Water falls from the upstream side of the stand over a baffle to a lower water level on the downstream side, so effecting a drop in system pressure.

ii) Float Valve Stand.

Open stand structure within a semi-closed pipe system, housing a float valve which permits dissipation of excess head or pressure within the pipe system. The valve is fitted at the entrance of the upstream pipe section to the stand structure. The float valve and stand serve to hydraulically connect, the upstream and downstream pipe sections.

iii) Gate Stand

An open stand structure connected to the pipeline system whose function is to house gates or valves for the control of water flow to different pipe branches.

iv) Surge Riser/Air Vent

A vertical open stand provided to reflect the pressure waves developed during water hammer so reducing the magnitude of the pressure surge. It is connected directly to the pipe system, rises to a height above the maximum level of the hydraulic grade line, and will also function as an air vent during normal operation.

3.4.3 Air Vents or Valves

i) Open Vent

Vertical pipe connected to the pipe network which allows for the release of air during pipeline filling and normal operation. The pipe can be as small as 50mm in diameter and rises above the hydraulic grade line for flow to the critical outlet. Used where the release of air is necessary but water hammer is not considered a problem.

ii) Air Valve

One way valve allowing release of air but not water from the pipeline. Suitable for situations where open vents are not practical, for example where the height of the hydraulic gradeline is beyond the practical height for a vertical pipe.

3.4.4 Riser

The section of pipe connecting the underground pipeline to the outlet valve at the field surface. It is usually of the same or smaller diameter than the underground pipeline.

3.4.5 Outlet Valve

The adjustable exposed portion of the pipe system which when opened allows delivery of irrigation water. A number of different types of valve exist though the most common consists of a valve or plate mounted on a pipe riser and known as an alfalfa valve.

3.4.6 Hydrant

An above ground attachment, either permanent or portable, fitting over an outlet valve (usually an alfalfa or orchard valve) which allows for additional control of irrigation water. Used as a means of connecting the outlet to above ground pipe or hose.

3.4.7 Outlet Distribution Structure

The structure built around the outlet valve to control the discharge of water to the field distribution system, which may comprise open channels, surface pipes or hoses.

3.5 Methods for Regulating Pipe Distribution Systems

3.5.1 Introduction

The method of regulating the pipe distribution system is defined as the way in which inflow discharge into the pipe system is balanced with outlet discharge. Pipe systems may be self-regulating in the case of semi-closed systems or possess either manual or automatic methods of regulation in the case of pumped supply systems.

Manual regulation is the only real alternative on gravity open pipe systems, while on semi-closed and closed gravity supplied systems self-regulation is possible provided sufficient water and pressure is available, to allow for outlet discharge up to the limit of the pipeline's design capacity.

For pumped supply systems the method of regulation includes both the method of balancing inflow and outlet discharge as well as a choice between automatic and manual pump control. In all situations the aim is to avoid unnecessary spillage of water.

Recommendations on the selection of the method of regulation for different buried pipe systems are given in section 5.3.

3.5.2 Open Pipe Systems

The inflow discharge to all open pipe systems must be regulated manually by the operation of in-line gates or valves, if excessive operational spillage at the overflow stands is to be avoided. Both Pimley and Fischer (1990), and Merriam (1987a), describe the careful setting and resetting of control valves required within the system. Open pipe systems can be simply converted to semi-closed systems providing on-demand operation by the installation of float valves, and Merriam (1987a) describes the potential benefits of converting the Coachella Valley Scheme in California from an open to a semi-closed scheme.

Open systems with manual regulation are reported in a number of locations in western USA (Baudequin et al 1990, Pimley and Fischer 1990), as well as in southern Europe (Baudequin et al 1990) and southern Africa (Coles, 1991).

3.5.3 Gravity Supply Semi-Closed and Closed Systems

In gravity supplied semi-closed and closed pipe systems the inflow to the pipe system will be self-regulating provided sufficient water and head is available, and structures are provided to cope with the pressure surges created by sudden changes in flow. The inflow to the pipe system may still be restricted, for operational reasons, by the use of gates, while the maximum outlet discharge will be limited by the design capacity of the pipe system.

Where desired the driving head can be maintained at the head of a pipe system against a background of varying canal or reservoir water levels by the provision of constant water level control gates or devices, such as those manufactured by Neyrtec, and described by Goussard, (1987).

3.5.4 Pumped Supply Semi-Closed and Closed Systems

Introduction

The choice of regulation method for pumped supply systems though differing for electric and diesel motor driven pumps, can generally be made from one of four methods detailed below. Only with electric motor driven pumps will automation of pump operation be possible and then practically only with the provision of a storage reservoir or tank at the head of the pipe system.

Methods of Balancing Pump Supply and Demand

i) Altering the pump speed and hence discharge to more closely match the irrigation demand.

With diesel engines this is possible as engine speed can frequently be varied in the range between nominal speed and 50 percent below, with only a small reduction in efficiency (Discussions with Bangladesh engineers). Morton (1989) reports this practice as commonplace in tubewell based systems in Bangladesh.

Electrically driven pumps generally have fixed speeds of 1500 and 3000 rpm based on fixed electric motor speeds. Although variable speed electric motors are available they are more expensive and considered less reliable.

ii) Altering the number or setting of the outlets which are operating, to suit the pump discharge.

This method would normally be used with most pipe systems. Systems are designed to be operated with a set number of outlets open and formal or informal rotations are used to achieve a balance between inflow and outlet discharge. Pipe systems in China (Dept. Sci. Tech. China, 1990) and Indonesia (Republic of Indonesia, 1990) are examples of systems where pumps are directly connected to the pipe system, via a head riser pipe, and other methods of balancing pump supply and demand are not available.

iii) Alternate switching of the pump off and on, either manually or automatically to achieve a desired line pressure or water level in a control reservoir.

Labye et al (1988) describe automated methods of regulating electric pumps which rely on water level or line pressure sensing. Storage in a reservoir or tank must be adequate to allow for normal operation without excessive pump cycling which would lead to failure of electrical or mechanical components. Diesel engine driven pumps should not however be stopped and started frequently in this way.

iv) Selecting one or more pumps from a set, to match the demand flow rate.

This method is restricted to larger schemes with a wide range in possible operating demand which can justify the investment in a set of pumps. Although this system has been used on pipe systems in Egypt (EWUP Fort Collins, 1983), it is not likely to prove a practical alternative for most smallholder irrigation schemes.

Operation of several outlets simultaneously on the same pipe liner (option ii) cannot be recommended, in the absence of a low pressure regulator to provide more constant flow rates when pressures vary over the range 0.2 to 1.2 Bar (2-12 m). Renault (1988) makes reference to the development by ENGREF of a special low pressure discharge regulator, and suggests a prototype of the device would be ready in 1989, however no reference to the use of such equipment in the field has been identified.

The choice of the method of pump regulation needs to take into account the skill level of the irrigators who are to operate and maintain it, and the resources available for carrying out any repairs. Wherever automatic regulation is provided, Labye et al (1988) make reference to the need for manual regulation, with the necessary protection, in the event of failure of the automated system. In most developing countries the difficulties of maintaining automated systems, obtaining spare parts and the need for flexibility in supply, will mean manual regulation is preferred.

For more detail on the range of alternative manual and automated methods of pump regulation for pipe systems reference should be made to Labye et al (1988).

3.6 Operation and Control of Buried Pipe Systems

3.6.1 Introduction

The term operating and control system has been coined to describe the design choice of the method of regulating inflow to the pipe system and the type of control structure at the inlet and head of the pipe system. It depends on the number of outlets which are designed to be operated at one time and whether the inflow discharge is divided at the head or lower down the system. The alternative operating and control systems available for pumped supply systems are illustrated schematically in Figure 3.3.

This differs from the mode of operation, which relates to a choice of how water is to be distributed within a particular pipe system design.

For pumped supply pipe systems important considerations include the ratio of the optimum outlet discharge to the inflow discharge which will establish the number of outlets to be operated at one time, whether accurate flow division is required and the method of pump regulation to be used.

For gravity supply pipe systems important considerations include the maximum design operating pressure, and whether secondary manual gate control or automatic water level control is desired.

For both gravity and pumped supplied systems alternative operation and control systems are outlined below. This is by no means an exhaustive list and other practical alternatives may well exist.

3.6.2 Pumped Supply Systems

i) Pump Connected Directly to the Pipe Network (refer to figure 3.3)

This type of operating and control system is typical of pipe systems using uPVC pipe materials, which allow maximum design operating pressures to approach and even exceed the threshold of 10m. The higher operating pressures compared to non-reinforced concrete pipe, enable flow velocities to be increased so facilitating a reduction in pipe diameter and a possible reduction in the pipe cost.

Pressure relief valves, or pressure sensors to switch off the pump, should be provided to protect the pipe system from excessive line pressures. In all systems of this type visited, which included closed pipe systems built in Thailand and described by HHP/HTS (1983), manual operation is practised. Automation only becomes practical on very small electric pump supply systems using a pressure vessel and preset pressure sensors.

ii) Pump Connected via a Head Riser Pipe to the Pipe Network (refer to figure 3.3)

Because water at the inlet to the pipe system can rise no higher than the practical height of the head riser pipe, maximum operating pressures are typically restricted to less than 5 m, thus avoiding the need for special pipeline pressure protection. Systems of this type are described as having been built in Indonesia (Republic of Indonesia 1990) and China (Dept. Sci. Tech. China, 1990).

iii) Pressure Tower with Distribution by Bottom Valve Control (figure 3.3)

In this system water is discharged into a vertical large diameter open stand, called a pressure tower. The diameter is such as to enable inlet valves to two or more pipeline networks to be installed in the floor of the tank. This system allows inflow discharge, to be distributed to one or more parts of the distribution system while shutting off those sections which are not operating. This assists in reducing seepage losses on unused pipe branches, which are more a problem on nonreinforced concrete pipelines. Matching of inflow discharge and outlet discharge is usually regulated manually, by varying engine speed in the case of diesel motor installations or by altering outlet valve positions and settings with electric motor driven pumps.

The volume of the header tank provided is not usually large enough to allow for automation by probe control without risking excessive pump cycling. Systems of this type are described by MMP (1989d, 1989e), Georgi (1989) and Gisselquist et al (1986) as having been built in Bangladesh and India.

iv) Pressure Tower with Top Water Division (refer to figure 3.3)

In this system water rises to the upper portion of the pressure tower, and enters separate pipe networks via satellite risers arranged either inside or outside the main pressure tower. The system allows for inflow to the pipe system to be divided in differing proportions between two or more pipe networks. As the flow is reduced before entering the buried pipe system, a reduction in the size of pipe is possible, leading to a saving in capital costs.

In Bangladesh, systems with both internal and external satellite towers have been built and are reported by Rashid et al (1992) and MMI (1990a). The internal satellite stands include provision for shutting the supply to any of the networks by closing an alfalfa valve at the head of each of the pipe networks. Repair to the internal satellite stands or valves is however difficult given the very limited space (Rashid et al (1992).

Photo plate 4.12 shows several designs which have been built in Bangladesh on the IDA DTW II and TADP Projects (Georgi, 1989 and MMP, 1989a).

An alternative design, used on pump lift irrigation schemes in central India, replaces the satellite towers with outer chambers built as an integral part of the tank (van Bentum and Smout 1991). Weirs set in the walls, between the inner tower and outer chambers, each connected to separate pipe networks, allow for the division of water to each pipe system. In-line gate valves installed at the head of each pipe network are provided, for flow regulation and shutoff. One of these pressure towers is illustrated in photo plate 4.1.

v) Elevated Tank Supplying Separate Pipe Networks via Individual Riser Pipes (refer to figure 3.3)

The elevated tank allows for both top water level division of flow and provides the necessary storage volume to enable automation of pump control. Inflow to the pipe distribution system is via vertical riser pipes connected to separate pipe networks. As with the pressure tower and top water division, the reduction in the inflow discharge to each pipe network allows for a reduction in pipe diameter, and a resulting cost saving. Although all the elevated tank systems visited were automated (IDTP, 1989), in all cases manually regulation is also possible.

Automation is generally achieved using probe controls to switch electric motor driven pumps off and on, and systems of this type have been built in Uttar Pradesh, India (Cunningham, 1983). Elevated tanks of a similar design have been built under the Bhairawa Lumbini project in southern Nepal, although stop logs are used for division of inflow discharge between up to four different pipe networks (GDC 1987) instead of the two loop networks common in Uttar Pradesh systems.

3.6.3 Gravity Supply Systems

i) Open Pipe System with In-line Valve Control

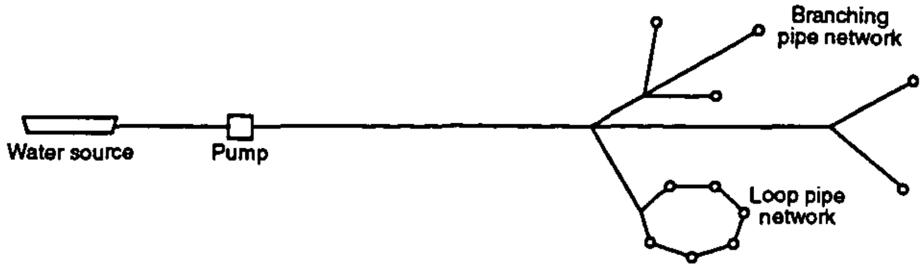
On open pipe systems, the intake, inflow discharge and the combined outlet discharge must be balanced. Both Pimley and Fischer (1990) and Merriam (1987a), describe the repeated adjustments, which need to be made to balance flows and avoid excessive spillage at the overflow stands, in USA built open pipe systems. Because any adjustments must be repeated whenever changes in outlet valve settings are made, open pipe systems operated in this way are considered labour intensive, though still less so than open channel systems.

ii) Semi-Closed or Closed Pipe System with Manually Gated Inflow

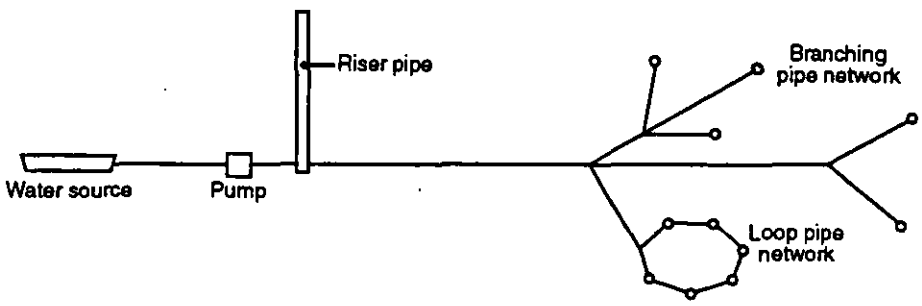
A gate, at the inlet to a pipe system, allows for shutting of inflow to the pipe system or for reducing the maximum inflow to below the design capacity of the pipeline. Provided water is available, inflow to the pipe system will automatically balance the outlet discharge upto the design capacity of the pipe system.

Systems of this type, which draw water from major canals, have been built and in use for many years in California and several western states of the USA (Baudequin et al 1990). The Gadigaltar scheme reported by Merriam (1990) in Madhya Pradesh, India is a more recent example of this type of system and uses manually operated screened inlet gates, at the head of each pipeline offtake from the main supply canal. One of these screened outlets is shown in photo plate 4.4.

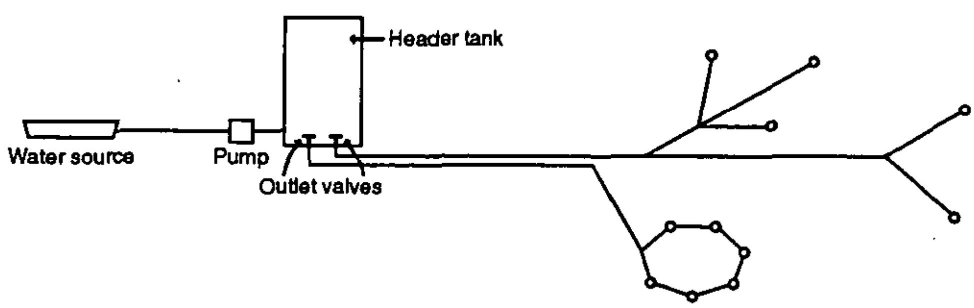
Figure 3.3 Schematic Illustration of Operating and Control Systems for Pumped Supply Systems



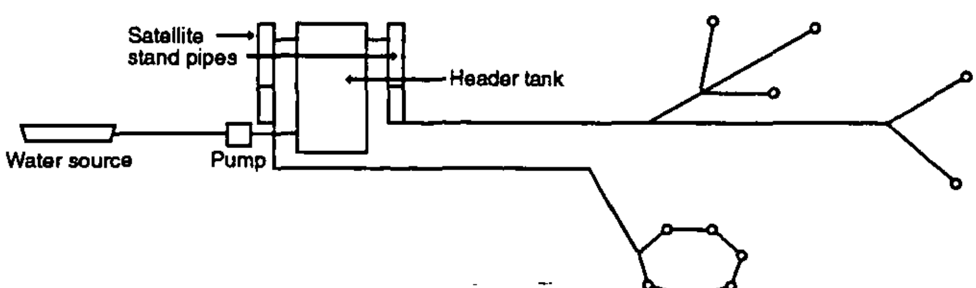
(i) Water source directly connected to the pipe system



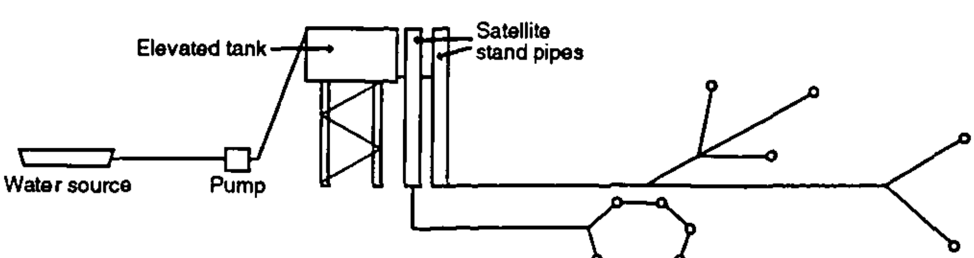
(ii) Water source connected via a head riser pipe



(iii) Pressure tower with bottom valve control



(iv) Pressure tower with top water level control



(v) Elevated tank supplying separate pipe networks

iii) Semi-Closed or Closed Pipe System with Automatic Water Level Control from the Intake

In the situation where the level of the water source fluctuates then it may be desirable to install a structure to maintain a near constant controlling water level at the head of the pipe system. This will usually involve the installation of automatic water level sensing gate or device on the intake to pipe system. Provided sufficient water and head is available, the system can be operated on-demand.

Installation of this type of control together with the upgrading of open pipe systems to semi-closed by the installation of float valves, has been a feature of recent improvements to buried pipe distribution systems in the USA (Merriam, 1987a).

3.7 Modes of Operation for Buried Pipe Systems

The mode of operation is used to describe the way in which actual water distribution occurs within a pipe system which has been constructed. For any design of pipe system, and combination of system hardware, there will be a number of ways of operating the system, though one mode will frequently provide the most optimal and equitable supply.

For the purpose of this discussion the inflow to the pipe system is termed the inflow discharge or pump discharge Q_i, flow from an outlet is termed outlet discharge Q_o, and the flow in the farmers field channel is called the field discharge Q_f.

The mode of operation depends on the ratio of the design inflow discharge Q_i, to the field discharge which can be used efficiently by each farmer Q_f. In most small basin irrigation schemes this field discharge flow Q_f is considered to be of the order of 20-30 l/s, for quaternary earth channels. Thus where the inflow to the system is greater than 20-30 l/s then some method of flow division becomes essential, to enable two irrigators to share the discharge a one time.

Because the operating requirements for a pipe system will vary, for example between agreed rotations during periods of peak demand to indent systems of allocation when demand for water is low, choice of the mode of operation must take this into account. The choices available will in part be determined by the selection and arrangement of structures within the system.

Recommendations on the mode of operation suitable for each type of buried pipe system are detailed in section 5.7.

The four predominant modes of operation are described below.

Mode A

One irrigator takes the full inflow discharge through one outlet valve.

This mode of operation predominates where the pump is directly connected to the pipeline system and in situations where the inflow discharge Q_i, can be comfortably handled by the irrigator at the outlet, that is with flow rates of 20-30 l/s and less in earth channels at the quaternary level.

In this case the irrigator receives the full inflow discharge Q_i, whether appropriate or not, and where the flow is larger than that which the irrigator can efficiently handle, ($Q_i > Q_f$) then irrigation performance may be poor despite the good transit efficiency of the pipe system.

Mode B

The full inflow discharge is delivered to one outlet, where it is shared between two or more farmers by means of an outlet distribution structure.

This mode of operation is used where the inflow discharge is greater than can be comfortably handled by one irrigator. Operation in this way is possible on all pipe systems which are designed for the full inflow discharge to be available at every outlet. Distribution structures for flow division may need to be provided at each outlet at extra cost. This mode of operation gives farmers considerable flexibility in deciding the pattern of operation.

As this system requires that two or more irrigators agree to share water and irrigate simultaneously, it is seldom agreed to in situations where there is mistrust and a lack of cooperation, for example in some of the Bangladesh pipe systems described by Rashid et al (1992). In a few cases one irrigator may be able to use two field discharge streams Q_f, at the same time, delivering half to each of two plots.

Where cooperation between irrigators is poor or when irrigation demand is low, the tendency may be for one irrigator to take the full outlet discharge (Rashid et al 1992), and with quaternary field channels of inadequate capacity, overtopping and high seepage losses often result.

Many of the nonreinforced concrete pipe systems built in Bangladesh were planned to be operated in this way, however the system for provision of fuel and collection of water charges tended to hinder cooperation and rotational distribution (Rashid et al, 1991).

Mode C

In this case the inflow discharge is divided at the water source between two or more separate pipe networks.

Structures at the head of the pipe system (already described in section 3.6), such as the elevated tank or pressure tower with top water level division, enable water to be divided evenly or in proportion to the area to be irrigated, between different pipe networks. The pressure tower with bottom valve control, will also allow division of flow between different pipe networks but individual outlet discharge will depend on the position and number of outlet valves operating. Weirs and gated flow divisors allow flow division to different pipe networks in proportion to the area to be irrigated (van Bentum and Smout 1991a).

Where flow is divided in fixed proportions, this mode of operation assumes a division of the command area into smaller areas with similar cropping and irrigation demand patterns. Actual outlet discharge will depend on seepage losses within the pipe system, which when low, enable equitable irrigation distribution.

This mode of operation is provided for in the uPVC pipe systems constructed on a large scale in Uttar Pradesh, India (Cunningham 1983, and IDTP 1989). With low seepage losses, flow is evenly divided between two outlets, each operating on a different pipe loop. The system requires that at least one irrigator on each loop wishes to take water simultaneously.

Mode D

The inflow discharge is shared between several outlets on the same pipe network. Successful and equitable operation requires genuine cooperation between irrigators. In the absence of any flow limiter or low pressure regulator to ensure a near constant supply flow rate and pressure, without high friction losses, flow division will depend on the number and position of the valves in operation. Wide variations are possible in outlet discharges because of differences in the outlet operating pressures. Adjustments to flow can be made by throttling individual outlet valves or using gate stands to alter the division of flow between branches. These changes are however coarse and difficult to predict, and need to be repeated when a different combination of outlets is operated.

Recommendations can be made as to which valves should be operated in conjunction with one another to minimise the variation in outlet flows, but Bangladesh experience shows such advice may be ignored in the face of widespread mistrust (MMI 1990a).

In practice all pipe systems can be operated in this way but the uncertainty regarding the resulting outlet discharge makes it a less than ideal choice. Where flow division has not been provided for, and is advantageous, then this may be the preferred mode of operation available to the irrigators.

For both gravity and pumped supply pipe systems, recommended design modes of operation are listed below. For each system, alternative modes of operation are possible but many have significant limitations.

Table 3.2 Possible Modes of Operation for Gravity Inflow Pipe Systems

Operating Systems	Modes of Operation	
	Recommended	Alternatives
1. Open pipe system with in-line valve control to each pipe network	A, B, C,	D
2. Semi-closed or closed pipe system with manual gated inflow from reservoir or canal	A, B, C,	D
3. Semi-closed or closed pipe system with automatic water level control at the inlet	A, B, C,	D

Table 3.3 Possible Modes of Operation for Pumped Inflow Systems

Operating Systems	Modes of Operation	
	Recommended	Alternatives
1. Water source directly connected to the Pipe Network	A	D, B
2. Water source connected via a head riser pipe to the pipe network	A	D, B
3. Header tank or pressure tower with bottom valve control	D, A	B
4. Header tank or pressure tower with top water level control	C	D, B
5. Elevated tank supplying separate pipe networks each with an individual stand pipe	C	D, B

CHAPTER 4. Case Studies of Buried Pipe Systems

4.1. Introduction

The following case study descriptions are developed from data collected during field visits to buried pipe systems in south Asia. As well as highlighting particular design, construction and operating features, an assessment of performance is made where possible and suggested design and operating improvements are made. Photographs of structures within the schemes taken during the field visits, are referenced where appropriate and shown at the end of this chapter.

4.2. Data Sources

Field notes, photographs and survey information obtained during the visits were supplemented with relevant reports, maps and standard structure designs where available.

4.3 Vindhyasini Akkadselarge Lift Irrigation Scheme

4.3.1. General Features and Location

This lift irrigation scheme is one of many in the state of Maharashtra, India, built for smallholder sugar producers, by their local cooperative sugar factory, with outside consultant design and construction expertise. The scheme is located in Dhule district, near Shahada in northern Maharashtra, and covers 1620 ha owned by 1000 smallholder farmers in the four villages of Chiloma, Kurukwade, Dhamane and Bamni.

Water is raised from the nearby Tapti River using three 225 kilowatt electric motor driven pumps, delivering a total of 1100 l/s, a distance of 1600m. The water is delivered to a header tank at the inlet to the pipe system via two 800 mm diameter reinforced concrete pipe rising mains.

The scheme command area slopes gradually, from where water is delivered in Chiloma village, through Kurukwade and Dhamane villages, to Bamni village at the bottom of the scheme command, a distance of approximately 3 kilometres.

Scheme summary data is based on data for one pipeline within one of the villages of the scheme.

4.3.2. Background to the Irrigation Scheme

Construction of the scheme by staff of the sugar cooperative, using contractors was completed in 1986, although the scheme design was provided by a consultant based in southern Maharashtra. The cooperative with its own staff of engineers is responsible for maintenance and improvement of the scheme, on behalf of the small holder farmers.

The low pressure pipe system comprises the secondary and tertiary levels of the irrigation scheme.

4.3.3 Water Source, Crops Grown and Methods of Irrigation

The availability of irrigation water and abstraction rules vary through the year. Three growing seasons are distinguished, kharif or rainy season (June to September), followed by the rabi (October to February), and finally the short summer (March to May). Summer river abstractions are sufficient only to irrigate the sugar crop which is set at 30% of the gross scheme area.

Sugar cane is the primary cash crop and the reason for the profitability of the pumped lift scheme, though the area planted to cane is set at a maximum of 30% of an individual farmer's holding. During both kharif and rabi additional water is available to irrigate other crops, including cotton and chilies during kharif and wheat, gram, sunflower and sorghum during the rabi season.

4.3.4. Design Criteria

The scheme is effectively designed to irrigate 500 to 600 ha of sugar cane through the dry summer period with a scheme flow of around 1000 l/s or less depending on river water levels.

The needs of the sugar cane and the relatively deep soils present have led to the adoption of a three week fixed rotation, though this is varied on occasion for the irrigation of other crops. Except during the rainy season, water supply is limited, restricting the choice of crops during the rabi period to lower water requirement crops such as wheat, gram and sorghum.

Water is supplied to each of the four villages and to individual blocks within the village on the basis of the area irrigated. Water is supplied continuously to each block with irrigation staff rotating water among the land owners within each block.

4.3.5 Pipe System and Structures

The pipe system operates as an open pipe system with different sections of the pipe system hydraulically disconnected. The two intermediate header tanks provide for the dissipation of excess head on the gravity mainline (see photo plate 4.1, pumped lift irrigation scheme). Where inflow discharge to any of the secondary pipelines is in excess of field discharge, then valve adjustments must be made if overflow at the outlet is to be avoided.

The rising main discharges the full flow into the main header tank, which comprises a central tank surrounded by outer chambers each receiving water via connecting weirs and supplying water to individual pipe lines radiating from the head tank.

The quantity of water delivered to the villages below each header tank is set by the relative length of the weir crests. Design flows in each part of the system are given in figure 4.1 and are based on an irrigation design duty of 0.68 l/s/ha.

When first constructed each header tank or distribution tower supplied four or five reinforced cement concrete pipelines in a branching layout. Each pipeline comprised two or more branches and extended a distance of 1500 to 2000 m from the header tank. The pipelines supplied simple open concrete stands, which directed water to tertiary earth channels via screw capped or flange covered orifices in the wall of the stand. These standpipes served command areas of around 40 ha or more, and are illustrated on photo plates 4.2 an 4.3.

More recently the concrete pipe system has been extended using uPVC pipe to deliver water to outlet command areas of 6 to 12 hectares. No air vent or pressure surge structures were provided on the main or secondary pipelines. To control flow to each of the secondary pipelines, in-line steel gate valves are provided, and one of these is illustrated in photo plate 4.4.

4.3.6 Method of Regulation and System Operation

Water is delivered continuously to each distribution pipeline at a fixed flow related to the area served. The sugar cooperative employ channel operators who control the water allocation and operate the valves directing water to different outlets in consultation with the farmers.

Applications in addition to the standard allocation for the set area of sugar cane are made to the channel operators.

4.3.7 System Construction

For the gravity mainline and distributary pipelines from each of the header tanks, plane ended reinforced concrete pipe was used in sizes ranging from 1000 to 250 mm. Collar joints were constructed using a packing comprising coconut fibre and damp cement, finished with beads of 1:3 mortar. When laying pipes in soft material, locally available shattered and weathered rock called "mooram" is used as base material.

4.3.8 Social and Environmental Issues

The buried pipe system has allowed the limited surface water resource to be shared efficiently, under strict water allocation rules set by the government water authority, and has relieved the pressure on the over pumped hard rock groundwater resource. Deep percolation losses from irrigation with the river water will help to maintain low soil salinity levels, which tend to buildup under irrigation practised with the relatively saline groundwater.

The remarkable feature of the scheme is the high degree of organisation and cooperation achieved through the sugar cooperative, driven in part by the cash crop returns offered, and very limited scope in the area for non-members to secure their own individual water supply.

4.3.9 System Cost

The estimated total system cost in 1986 local prices was Rs 16550 per hectare, and the construction was funded by a ten year loan for 95% of the cost at an interest rate of 10% with the remaining 5% required as a cash contribution.

In order to repay the loan and recover maintenance costs, the cooperative levies water charges on the basis of the crop grown and for a set amount of water per season. Water charges reflect not only the profitability of the crop but also its water requirements. 1991 charges were set at Rs 2220 per hectare (Rs 900 per acre) for sugar cane, Rs 890 per hectare (Rs 360 per acre) for cotton and chilies, Rs 400 per hectare (Rs 160 per acre) for wheat and Rs 250 per hectare (Rs 100 per acre) for sorghum.

For a single irrigation in excess of their entitlement, an irrigator will be charged an additional amount equivalent to the water charge.

4.3.10. Observations on System Design and Performance

As an open pipe system, operation relies heavily on fixed proportioning of the water supply at each of the pressure towers, in a similar way to fixed supply schedules in secondary canals of large surface irrigation scheme. The pressure tower structures are innovative in design, and economical in cost for a scheme of this size. The tertiary pipe system varies widely in its layout and the intensity of outlets, depending on whether or not new uPVC pipelines have been installed.

In-line gate valves and poorly maintained standpipes with side orifices, make precise control of flow within the tertiary unit difficult.

4.3.11 Scheme Summary

Scheme Name: Vindhyasini Akkadselarge Lift Irrigation Scheme
Scheme Location: Maharashtra, India.

Design
Type of Buried Pipe System: Open pipe system
Method of Regulation: Manual in-line gate valve
Operating and Control System: Pressure tower with top water level division
Pipe Layout: Branching layout
Mode of Operation: Mode B or D. Full inflow discharge shared at the outlet by two or more farmers, or between two outlets operating at the same time.
Structures Present: Pressure towers, In-line gate valves, Stand pipe outlets,
Pipe Material Used: Various diameters of collar jointed reinforced concrete pipe, 160 mm diameter rigid uPVC

Scheme Data
Total Scheme Area: 1620 hectares
Average land holding: 1.6 hectares (0.48 ha of cane)
Irrigation Water Duty: 0.68 l/s/ha
Length of Pipeline per ha: N/A
Average Outlet Command Area: 3 to 6 hectares
Total Scheme Cost $US/ha: 920 (1986)
Distribution system cost $US/ha: N/A
(Rs 18 per $US 1)

References Nil

4.4 Pipaldagarhi Lift Irrigation Scheme

4.4.1 General Features and Location

This lift irrigation scheme is one of many on the banks of the Narmada River in southern Madhya Pradesh, India. The scheme is one of several supported by the USAID funded Madhya Pradesh Minor Irrigation Project, providing irrigation to 300 farmers in six villages with a gross area of 895 hectares and a net irrigable area of 710 hectares. The scheme is designed to irrigate a maximum of 60% of the area in cotton, which is 426 hectares. The groundwater resources in the area are already oversubscribed and increasing in their salinity.

Water is lifted from the Narmada River via vertical turbine pumps mounted at the top of a 40 m high access well to keep the pump above flood level as the Narmada river experiences a very wide flow regime.

4.4.2 Background to the Irrigation Scheme

The scheme was built as part of a programme to evaluate alternative designs and operating regimes, with particular emphasis on improving the reliability and consistency of irrigation supply.

The philosophy behind the design and construction of the scheme, was to provide a predictable and reliable but restricted irrigation supply. Low irrigation intensities, on similar schemes in the area, it was thought were due more to unreliability of supply rather than the lack of flexibility inherent in fixed supply schedules.

4.4.3 Water Source, Crops Grown and Methods of Irrigation

As with most pump lift irrigation schemes the cropping system is concentrated on cash crop production, which in this case is cotton. During the kharif season the area envisaged for cotton is 60% of the irrigable area, that is 426 ha, while during rabi the area of cotton was intended to be reduced to 40%, with 20% of the area in wheat. The remaining area is either planted in a range of pulses or oil seeds or left fallow.

The cotton is irrigated using furrows supplied from in-field earthen channels, running from outlets on the buried pipe system.

4.4.4 Design Criteria

The design discharge for the scheme is 426 l/s, or 0.6 l/s/ha for the net scheme area of 710 ha. The low water duty per hectare is based on expectations of high transit and distribution system efficiencies. The pump discharge is distributed via concrete lined primary and secondary open channels, with offtakes at each block or "chak" which command an area of no more than 40 hectares. Within the blocks closed uPVC pipe systems distribute water to individual outlets serving 2-4 hectares owned by 1 or 2 farmers.

The flow delivered to each block is fixed in relation to the area served, so that for the maximum chak area of 40 ha, the available flow is assumed to be 18 l/s, where conveyance efficiency is 75% giving a continuous duty of 0.45 l/s/ha.

4.4.5 Pipe System and Structures

The tertiary level buried pipe systems comprise loop layouts of uPVC pipe ranging in size from 110 to 160 mm diameter, and rated to 40 m (4 Bar) head. The inlet of the pipe system comprises a proportional modular offtake from the secondary canal, connected by concrete pipe to a vertical stand pipe, a short section of concrete pipe with an in-line gate valve and then to a second standpipe which joins with the uPVC loop. Additional air vents comprising, 2.4 m high, 50 mm diameter galvanised steel riser pipes threaded on to uPVC saddles, are provided at high spots on the pipe loop, and one of these is shown in photo plate 4.5.

The outlets comprise uPVC risers capped with small 110 mm diameter alfalfa valves, surrounded by a masonry discharge box. In most outlets a simple v-notch weir is provided to give the farmer a visual check on the flow rate, while in the few outlets where the discharge is sufficient for two farmers to share, the distribution structure incorporates a flow division facility.

4.4.6 System Construction

Trench excavation for the pipeline was successfully carried by machinery, to a depth of 1m. In most loops, with trench excavation complete, pipe laying, jointing and backfilling were completed in one day. In all cases uPVC pipe was embedded in an envelope of sand, supposedly to extend pipe life. Pipes were jointed using solvent cement glue, and the joint left undisturbed for 10 min before lowering into the trench. Full working pressure was applied to the pipe system 24 hours after final backfilling.

4.4.7 Method of Regulation and System Operation

Management and operation of the scheme is decided at the beginning of the season, but usually takes the following general pattern. Water is supplied continuously to each block offtake, with the flow being determined by the block command area. Typically a rotation period of one week is adopted for supply to one farmer. As only a portion of the farmer's holding can be adequately irrigated at each turn, the individual farmer must decide which part of his land holding receives irrigation in each rotation. In small block areas, the system of proportional water allocation can result in small delivery flows, for example 24 hectares will receive 11.25 l/s.

4.4.8 Social and Environmental Issues

In a similar way to the first case study, the buried pipe system has enabled access to the limited surface water resource, under strict water allocation rules set by the government water authority, so relieving pressure on the over pumped hard rock groundwater resource. The pump lift in this instance is not so onerous, and farmers with access to the river bank have established their own private systems.

Deep percolation losses from irrigation with the river water, will help to maintain low soil salinity levels, which may tend to rise under irrigation practised with the relatively saline groundwater. Irrigation will also help to recharge shallow groundwater storage, important for dry season domestic and stock water supplies.

4.4.9 System Cost

Estimated total scheme cost was Rs 29200 per ha. While the use of uPVC pipe rated to 4 Bar pressure, increased the system cost, the low irrigation duties allowed the selection of relatively small pipe diameters. With the use of machinery for trench excavation, uPVC pipe system installation was rapid. This will have contributed to reducing the disruption caused to existing crops and agricultural activities.

4.4.10 Observations on System Design and Performance

The scheme design has kept conveyance and transit losses to a minimum, while small outlet commands means short field channel distances, to the furrow irrigation systems used. While the short rotation schedules and proportional continuous flow delivery, to each block offtake, may well help to improve the reliability of supply, on the smaller blocks the small delivery flows will inevitably increase the field application times and lower application efficiencies.

The apparently conservative water duties must be considered in the light of the very limited surface water resources, and as part of a strategy to spread the benefit of cash crop irrigation to as many land holders as practical. Though the scheme is clearly a pilot scheme, efforts could have been made to lower capital costs by using lower class uPVC pipe or locally manufactured nonreinforced concrete pipe, as well as avoiding the importation of special backfill material. The headworks arrangements could have been simplified with the provision of only one standpipe, with an alfalfa type valve instead of an in-line gate valve.

4.4.11 Scheme Summary

Scheme Name:	Pipaldargarhi Lift Irrigation Scheme
Scheme Location:	Madhya Pradesh, India.

Design

Type of Buried Pipe System:	Closed pipe systems
Method of Regulation:	Automatic proportional orifice with manual in-line gate valve.
Operating and Control System:	Self-regulating with manual in-line gate valve backup
Pipe Layout:	Loop layout
Mode of Operation:	Mode A. One irrigator takes full inflow discharge at one outlet.
Structures Present:	Proportional modular inlet, open stand pipe, air vents, alfalfa valve outlets, outlet distribution structures, in-line gate valve.
Pipe Material Used:	110 to 160 mm diameter, uPVC (4 Bar) pipe.

Scheme Data

Total Scheme Area:	710 hectares net
Average land holding	3-4 ha
Irrigation Water Duty:	0.6 l/s/ha gross
Length of Pipeline per ha:	40-50 m/ha
Average Outlet Command Area:	1.5 to 3 hectares
Total scheme cost $US/ha:	1622 (1990 prices)
Distribution system cost $US/ha:	N/A
(Rs 18 per $US 1)	

References — Nil

4.5 Gadigaltar Tank Irrigation Pilot Project

4.5.1 General Features and Location

The tank irrigation project is located in Madhya Pradesh, on the Undari River at Gadigaltar, not far from Khargaone. The scheme water supply from a dam on the Undari River, is released into a sloping main canal, 5.2 kilometres long, which terminates in a lower scheme reservoir. On the upper scheme area, a number of semi-closed pipelines draw water from the main canal, via gated gravity intakes. The lower reservoir supplies a level-top secondary canal, which in turn feeds several semi-closed pipelines, supplying water to individual farmer outlets.

The objective in design was to provide each farmer with a flexible rate supply up to a maximum of 30 l/s supplied to single outlet, with some restriction on frequency.

4.5.2 Background to the Irrigation Scheme

The scheme is a USAID assisted initiative to construct, operate and evaluate a buried pipe distribution system (using sloping and level top main and secondary canals) where the supply is under the control of the farmer water users, as part of the Madhya Pradesh Minor Irrigation Project. The concept is partly inspired by Merriam's work in the USA (1987a) and Sri Lanka (1985). The scheme replaces an earlier design for a traditional open channel distribution system using the same reservoir. Scheme construction began in mid 1990 and is due for completion in late 1992.

4.5.3 Water Source, Crops Grown and Methods of Irrigation

Water is provided by a reservoir built across the Undari River valley. Crops which are intended to be grown include cotton, cereals, oilseeds and pulses, but it is also hoped that with the flexible supply, intensive irrigation of vegetable and fruit crops will develop.

As some areas of the gross scheme command area have thin soils and slopes steeper than 3%, these areas have been excluded. While in some areas, small basin irrigation will be practical, most irrigation will be by furrow and border strip techniques.

4.5.4 Design Criteria

The net command area of the scheme is set at 1157 hectares, comprising 545 farms. The scheme is divided into two sections, an upper area of 496 ha supplied by 5 separate pipe networks from the sloping main canal, and a lower area, comprising 661 ha, below the intermediate reservoir, and irrigated by four pipeline networks supplied from the 1 kilometre level top canal.

The main canal has a design flow of 1.9 m^3/s, with the intermediate reservoir (capacity 10 ha.m) designed to store surplus main canal flow for irrigating the lower command area.

4.5.5 Pipe System and Structures

Five semi-closed pipelines draw water from the sloping canal through screened and gated inlets (shown in photo plate 4.4) to supply individual outlets, while on the lower area four semi-closed pipelines draw water from the level top canal.

The intermediate reservoir maintains the water level in the level top canal via two outlets, one manual gate and a second automatic Neyrtec water level control gate. Harris float valves are installed in open float valve stands (shown in photo plate 4.4) to dissipate excess head and keep operating pressures to below the allowable maximum for the concrete pipe of 5m. Air vents constructed from 50mm galvanised steel pipe are provided at any high spots within the pipeline, to prevent surge problems. With the float valve stands provided every 400 metres, additional surge riser structures were not considered necessary.

The pipelines are designed with flow capacity in excess of a continuous delivery rotation schedule, in order to allow several farmers to take their farm stream size when desired. The maximum stream size available at each outlet, provide with an orchard valve, is set by design at a rough maximum of about 20 l/s (0.7 cusecs). The design aimed to provide each farmer with a single outlet but in practice because of plot distribution, farmers will take water from two or more outlets. A typical outlet is illustrated during operation in photo plate 4.6.

4.5.6 System Construction

The scheme is still under construction although the tank, and associated outlet structures, main sloping canal and some of the upper zone pipelines are installed complete with outlets air vents and float valve stands.

The sloping and level top canals will be concrete lined canals, while all pipelines will use locally manufactured nonreinforced concrete pipe. Local suppliers have been contracted to provide machine compacted nonreinforced concrete pipe, which will be jointed using mortar. Initial load and hydrostatic pressure tests, carried out using locally constructed equipment, indicates that pipe will be suitable to withstand the 5m maximum design operating pressure. The equipment used to test pipe locally is shown in photo plate 4.7.

4.5.7 Method of Regulation and System Operation

The overall aim of the system is to reduce the irrigation related constraints to overall farm management. The system is intended to be operated on-demand, under an agreed irrigation frequency but with a restriction on the peak rate to be taken at any outlet. This is termed a "limited rate arranged schedule responsive to farmer needs."

Where several irrigators are taking water at one time there will be some variation in the outlet discharge each receives. The mechanism for recording water use and subsequent calculation of water charges is not clear. During periods of low demand it is also practical for only one irrigator to take water at any one time.

The use of semi-closed pipelines means the scheme is almost entirely self-regulating, and the only adjustment required is to regulate the draw-off from the main dam to the main canal. Regulation is carried out to ensure that the intermediate reservoir is filled for the start of each irrigation day.

4.5.8 Social and Environmental Issues

The steeply sloping command area would have posed considerable design problems for a traditional open channel distribution system. The semi-closed system will achieve very significant improvements in water efficiency, and reduce operational wastage to a minimum.

The successful local manufacture of concrete pipe, has demonstrated the opportunity for the successful use of low pressure pipe as an alternative to lined channels.

4.5.9 System Cost

Prior to construction the scheme was estimated to cost Rs 40350 per ha. The distribution system alone is estimated to be costing Rs 9770 per ha.

The estimate of total cost includes the earth dam, spillway and approach channel headworks which comprise 75% of the total scheme cost. If 50% of the headworks cost is taken and the full cost of the canals and pipelines the cost would be Rs 25078 per ha, and be comparable with the cost of the pumped schemes in case studies 1 and 2.

4.5.10 Observations on System Design and Performance

The semi-closed pipe system incorporates a number of control features not often seen in Indian irrigation schemes including the Harris float valves and Neyrtec water level control gate.

Scheme regulation could be assisted by linking a reservoir level sensor and flow sensor in the tail of the main canal to provide information on residual flows and storage fill to the main reservoir gate operator.

The scheme costs above do not include the cost of the float valves and orchard valves imported from the USA, nor the value of the technical assistance included in the design.

4.5.11 Scheme Summary

Scheme Name:	Gadigaltar Tank Irrigation Pilot Project
Scheme Location:	Khargaone, Madhya Pradesh, India.

Design

Type of Buried Pipe System:	Semi-closed pipe system
Method of Regulation:	Self-regulating with manual slide gate backup.
Operating and Control System:	Self-regulating with automatic water level control
Pipe Layout:	Branching pipe layout
Mode of Operation:	Mode D. The inflow discharge is shared between several outlets on the same pipe network.
Structures Present:	Canal orifice inlet, Harris float valves and stands, air vents, manual slide gates, Neyrtec water level control gate, level top canal, orchard valves, concrete outlet structure with v-notch weir.
Pipe Material Used:	150 to 750 mm diameter tongue and groove mortar jointed nonreinforced concrete pipe.

Scheme Data

Total Scheme Area:	1157 hectares net
Average land holding:	2-3 ha
Irrigation Water Duty:	l/s/ha gross
Length of Pipeline per ha:	50-60 m/ha
Average Outlet Command Area:	1.5 to 2.5 ha
Design Operating Pressure:	5 m
Total scheme cost $US/ha:	1614 per ha (1991 prices)
Distribution System Cost $US/ha:	390 (1991 prices)
(Rs 25 per $US 1)	

References — Merriam (1990); USAID (1990)

4.6 Tubewell Based Systems in Uttar Pradesh with uPVC Pipe

4.6.1 General Features and Location

Buried pipe systems using uPVC pipe to distribute groundwater from deep tubewells have been built widely throughout northern India, and particularly in the state of Uttar Pradesh. Schemes of the type described in this case study were visited in the vicinity of Lucknow and Varanasi.

Earlier deep tubewell development tended to compete with private development, but later investment has been targeted at areas, where there are few alternative water sources and groundwater supplies are difficult.

4.6.2 Background to the Irrigation Scheme

Schemes of the type described with buried pipe distribution systems have been under construction since the early 1980's. Construction has been supported through two phases of a World Bank sponsored tubewells project (Cunningham 1986), and the more recent Indo-Dutch Tubewell Project (IDTP 1989). The total number of improved public tubewell systems with buried pipe distribution systems is now approaching 5000 units which represents about 20% of all the public tubewells in Uttar Pradesh.

4.6.3 Water Source, Crops Grown and Methods of Irrigation

The tubewell draw on groundwater with pumping water levels in excess of 30 metres below ground level. Although a well yield of 40 l/s is considered ideal, where groundwater yields are low, schemes have been installed with a flow of as little as 30 l/s.

The typical cropping pattern assumed is sugar cane, paddy and some cotton grown in the rabi or wet season, from April to August, with wheat and pulses predominating during the kharif or dry season, from August to February. The objective of tubewell irrigation has been to increase irrigation intensities in both the rabi and kharif. It was hoped that the largest improvements would come from irrigation of the second cereal crop, as most of the rabi water requirements are satisfied by rainfall.

Typically, with the highly fragmented land holdings of populous Uttar Pradesh, basin irrigation is practised. Earthen distribution channels are usually permanent, because of the range of crops grown, though channel networks can be intricate and extensive.

4.6.4 Design Criteria

The typical system design aims for an irrigable command area of 100ha, with a well

The elevated tank comprising a concrete slab, on top of four reinforced concrete columns, with brick sides, is the most expensive of the system structures. The elaborate brick tamper proof chambers have proven difficult to build because of problems of curing given the requirement to transport water. Once constructed the chambers must be broken to carry out valve repair.

4.6.7 Method of Regulation and System Operation

The irrigation system is designed as two separate command areas, each served by its own pipeline. Electric pump operation is automatically regulated by probe control, so that inflow discharge matches outlet discharge. Provided at least one outlet on each pipe loop is open, the flow will be equally divided.

The system of operation devised for the pipe systems involves dividing each loop command area into seven day areas, each representing a day of the week. Each day area covering about 7 ha, would allocate water to the farmers in their area, on the basis of the land holding. A particular day area may take water from one, two of three outlets depending on plot location.

While average command areas indicate that 6 to 9 farmers may share one outlet, field observations indicate that in some highly fragmented commands, up to 20 farmers shared an outlet (26 farmers in one day area group). Agreeing irrigation schedules and water allocation in these circumstances, proved very difficult. The workload of monitoring water use and levying water charges, was frequently in excess of that intended for the part-time operators.

4.6.8 Social and Environmental Issues

The elevated tank has made equitable flow division a reality and significantly reduced the opportunity for unauthorised water abstraction, provided there are no serious leakages from the pipeline or outlets.

While serious water-logging is occurring around leaking outlets, the systems has demonstrated very significant improvements in transit efficiency.

4.6.9 System Cost

Costs of Rs 8500 per ha, have been quoted, though it is thought these costs significantly underestimate the real situation. The pipe systems have a much lower pipeline intensity (pipe length per ha), than systems built in other south Asian countries (Bangladesh and Thailand) which is reflected in the average outlet command areas, and longer field channel distances.

4.6.10 Observations of System Design and Performance

While automated pump control promised to reduce the operator workload, it has led to unnecessary pump operating expenditure in cases where outlet leakage is a persistent problem. The probe control itself has proved less than reliable, and in almost 50% of systems, manual operation appears the norm, because parts or servicing expertise is not available.

Because tamper proof outlets are so difficult to repair, persistently leaking outlets are a problem in many schemes, causing localised water logging, and unnecessary operating costs. Damage appears to be the result of poor scheme cooperation rather than deliberate vandalism. In common with other buried pipe schemes, outlet valves as the only moving part, wear rapidly and need to be carefully and durably manufactured, with installation which allows for easy repair and replacement.

While the buried pipe systems provide a more reliable irrigation supply, it would appear that in some cases the water supply is being overly stretched, creating water supply conflict. In situations where well yield is low, the wisdom of reticulating supply to the standard 100 ha command is questionable. Where the numbers of farmers is very large, or command areas highly fragmented so that more than ten farmers share one outlet, increasing the number of outlets and reducing outlet command size may have helped to reduce the difficulties of scheme operation.

The low levels of system performance, as noted by the estimated irrigation area achieved on each scheme, appear to reflect organisational problems and resource conflicts, rather than specific system design weaknesses.

4.6.11 Scheme Summary

Scheme Name:	Uttar Pradesh Tubewell Systems
Scheme Location:	Uttar Pradesh, India.
<u>Design</u>	
Type of Buried Pipe System:	Closed pipe system
Method of Regulation:	Automatic probe control with manual backup.
Operating and Control System:	Elevated tank with automatic pump operation
Pipe Layout:	Loop layout
Mode of Operation:	Mode C. The inflow discharge is divided at the inlet to the pipe system between two outlets on separate pipe networks.

Structures Present:	Elevated tank with probe control, alfalfa valves, masonry tamper proof outlet structure, surge riser pipe, steel riser pipes.
Pipe Material Used:	200 and 150 mm diameter uPVC pipe rated to 2.5 Bar (25 metres)

Scheme Data

Total Scheme Area:	100 hectares net
Average land holding:	0.6 ha
Irrigation Water Duty:	0.4 l/s/ha
Length of Pipeline per ha:	35 m/ha
Average Outlet Command Area:	3 to 5 ha
Design Operating Pressure:	5 m
Total scheme costs $US/ha:	472 (1988? prices)
Distribution system costs $US/ha:	N/A
(Rs 18 per $US 1)	

References — Cunningham (1986); IDTP (1988): World Bank (1983); Kolavalli and Shah (1990).

4.7 Tubewell Based Systems in Tangail District, Bangladesh.

4.7.1 General Features and Location

The buried pipe systems described below, have been constructed since 1985 in Tangail District of Bangladesh, with funding assistance from the German government. The pipe systems are constructed together with deep tubewells, in areas where alternative surface and shallow groundwater are very limited. Tangail district experiences difficulties in securing sufficient irrigation water, to enable intensive cropping during the dry season period of November to February.

The command areas of the deep tubewell schemes constructed are typically flat to undulating with elevation changes not exceeding 3 m. The soils are fine textured silts and clays and are relatively free draining.

4.7.2 Background to the Irrigation Scheme

The aim of the schemes was not only to improve irrigation distribution efficiencies, but also to encourage local manufacture of the pipe and system components, in an attempt to generate new employment.

The pipe system was modelled on initiatives undertaken in the 1970's in northern India, when buried pipe systems using nonreinforced concrete were being installed.

4.7.3 Water Source, Crops Grown and Methods of Irrigation

Groundwater is pumped using diesel motor driven centrifugal pumps, from pumping water depths varying between 20 to 30 m in screened wells which are from 80 to 100 m deep.

The schemes are designed to enable dry season irrigation of a range of crops including rice, vegetables, pulses and other cereals, all grown using basin irrigation techniques. The basins are supplied either from earth field channels, which are rebuilt on an annual basis or through neighbouring basins.

While dry season irrigation of rice has become popular, diversification into vegetable and other cash crops has been slower, and dependent on establishing markets for the produce outside the area.

4.7.4 Design Criteria

The schemes were designed to distribute the pump discharge of 40 to 46 l/s to a command area of 30 to 40 ha. The high irrigation water duty provided of 1.1 l/s/ha, reflects discharge of 40 l/s. The water is discharge into an elevated tank, from which flow is divided into two loop uPVC pipelines, which each distribute 20 l/s to alfalfa valve outlets. With the numbers of outlets on each loop ranging from 9 to 12, typical outlet command areas range from 4 to 5 hectares.

4.6.5 Pipe System and Structures

The elevated tank as the link between the tubewell and the distribution system, serves a number of functions. Primarily it allows for the precise division of the inflow discharge into the two loop pipelines, while also providing a buffer storage for the control of the electric motor driven pumps automatically via probe controls, so that inflow to the pipe systems is matched to outlet discharge. The inside of an elevated tank with probe control, and external view of the tank and pumphouse are illustrated in photo plates 4.8 and 4.1.

Water enters the two loop pipelines via vertical steel riser pipes, which also act as surge risers and air vents for each of the loops. Typically one additional surge riser is provided on each loop, to allow dissipation of the pressure wave developed during rapid valve closure. The small pressure rise resulting causes water to spill from the surge riser, but is well within the pressure rating of the pipe material used. A typical uPVC pipe surge riser is illustrated in photo plate 4.5.

The outlet valves are standard alfalfa valves which are enclosed in special tamper proof brick surrounds. Outlet distribution structures, depending on design allow water to be directed using earth bunds to either two, three of four different earth channels. A two channel outlet is illustrated in photo plate 4.9. In some cases in-field drop structures are provided to prevent erosion and one of these is shown in photo plate 4.10.

The size of the outlet command suggests that the nominal maximum field channel length from outlet to plot is more than 150 m, although the actual length along field boundaries may be up to 200 m.

4.6.6 System Construction

The loop pipelines are manufactured from uPVC pipe of 2.5 Bar (25 metre) pressure rating which is solvent cement jointed at site. The trenches are excavated by hand and backfilled with in-situ material. The pipelines are tested once the loop is complete, though the incidence of leaking joints appears very low. Thinner walled uPVC pipe cannot be used, because of the stiffness required for handling, storage and jointing. Alternative corrugated uPVC pipe materials have as yet not been evaluated.

the high water requirements of rice grown in the dry season. On the typical pipe system 20 outlets would be installed to serve some 40 to 60 irrigators.

Farmer holdings vary widely but generally average 0.7 ha. Because of the degree of land fragmentation in the command areas, a typical outlet can serve from 3 to 15 irrigators. A typical farmer's holding will be divided into 3 plots.

4.7.5 Pipe System and Structures

While the Tangail Agricultural Development Project (TADP), initially experimented with the use of vertical mould hand compacted nonreinforced concrete pipe, most of the pipe used in the schemes was nonreinforced concrete pipe spun by hand.

Water is delivered from the deep tubewell to the pressure tower. Water then flows from the pressure tower via valves set in the floor of the tower, to two or three branching pipelines. The valves in the pressure tower are standard alfalfa valves but water flows in the opposite direction to the situation at the outlet. Water moves from above the plate, past the valve into the pipeline. Valves on three pipe branches in the floor of a pressure tower are illustrated in photo plate 4.4.

Early pipe system designs provided an air vent/surge riser, adjacent to every outlet. Later systems now have vents constructed from the same pipe as the pipeline at a minimum spacing of 200 metres. A typical surge riser/air vent is shown in photo plate 4.5.

In some systems, check structures were provided to prevent the pipelines from emptying between irrigation events, as water drained back down the wells, past the foot valve. A number of types of outlet distribution structure were evaluated over the years of the project including the simple concrete surround illustrated in photo plate 4.3, before a simple earth surround was adopted. An alternative outlet built by the IDA DTW project is illustrated in photo plates 4.2 and 4.9 with provision for flow division at the outlet.

4.7.6 System Construction

Trench excavation is carried out by hand, with locally manufactured pipe jointed using a simple mortar band. Careful installation, jointing and backfilling are essential if leakage of the pipeline is to be minimised. A locally occurring mineral termed 'kauchi', provides the aggregate for any concrete used in pipe manufacture, and it has proven superior to the broken brick chips used in other parts of Bangladesh.

The pressure tower is typically constructed to a height of 3 m, from prefabricated nonreinforced concrete rings of 1 m diameter, transported to site. The rings are placed on top of a cast concrete floor incorporating the required number of valves and network pipelines. Vibration of the pump discharge pipe is isolated from the tower using flexible packing material in the joint. The typical multi-ring pressure tower is illustrated in photo plate 4.12.

4.7.7 Method of Regulation and System Operation

The pipe system is designed to provide the full discharge flow to any of the outlets. Although several systems were provided with top water flow division on the pressure towers, in most systems water is released into the pipelines from valves in the bottom of the tower. Pressure towers with top water level control via external and internal satellite stands are both illustrated in photo plate 4.12.

As the inflow discharge is greater than can be comfortably handled by one irrigator, flow needs to be shared between at least two irrigators. This is either achieved by delivering the full flow to an outlet, or more normally by operating two outlets simultaneously, usually on different pipelines. Any pipelines which are not operating are shutoff by closing the appropriate valve in the floor of the tower.

4.7.8 Social and Environmental Issues

The buried pipe systems have clearly helped to reduce the tail end problems experienced on many of the schemes.

The contribution of labour from the beneficiaries for excavation, portering and installation, was an alternative to the provision of a cash lump sum payment, and helped to develop a sense of ownership and responsibility for the scheme.

4.7.9 System Cost

Various pipe system cost estimates are quoted but the most recent give prices for the distribution system alone. These range from Tk 160 to Tk 200 per m of pipeline. For a buried pipe system of 1800 m an average cost would be Tk 324,000 or Tk 8100 per ha for a 40 ha command area. Including a deep tubewell costing around Tk 500,000, total system cost would be Tk 824,000 or Tk 20600 per ha.

4.7.10 Observations on System Design and Performance

The schemes have been particularly successful at encouraging the development of local pipe manufacturing and construction expertise. Despite problems encountered with a continuing high frequency of leakage on some systems, the pipe systems have very considerably improved the overall irrigation distribution efficiencies and resulted in water becoming available some distance from the tubewell.

The disappointing overall performance of the irrigation systems, as measured by the intensity of irrigation achieved, seems to have more to do with the poor level of cooperation among scheme members and the high operating cost of the diesel engine driven pumps.

While the pipe systems have considerably reduced potential seepage losses, the absence of any accurate method for flow division is a major drawback. With uncertainty about the equity of flow division and low levels of cooperation among scheme members, operation frequently involves the full inflow discharge being taken by one irrigator at one outlet. Although pump speeds are often lowered to reduce the pump discharge, outlet discharges are still often in excess of the field channel capacities leading to overtopping and high seepage losses.

4.7.11 Scheme Summary

Scheme Name:	Tangail Agricultural Development Project
Scheme Location:	Tangail District, Bangladesh

Design

Type of Buried Pipe System:	Low pressure closed pipe system
Method of Regulation:	Manual regulation, via pump speed control
Operating and Control System:	Pressure tower with distribution by bottom valve control.
Pipe Layout:	Branching pipe system
Structures Present:	Pressure tower, air vents/surge risers, alfalfa outlets with earth bund surround.
Pipe Material Used:	nonreinforced concrete pipe (hand spun)

Scheme Data

Total Scheme Area:	30 to 50 ha
Average land holding:	0.4 to 1 ha
Irrigation Water Duty:	1.1 l/s/ha
Length of Pipeline per ha:	
Average Outlet Command Area:	2 to 3 ha
Design Operating Pressure:	4 metres
Distribution system cost $US/ha:	231 (1991 prices)

Total scheme cost $US/ha:588 (1991 prices)
(Tk 35 per $US 1)

<u>References</u>

Georgi (1989); Gisselquist (1986); Gisselquist et al (1989); MMI (1990a): MMI (1990b); MMP (1989a); Rashid et al (1990a); Rashid et al (1990).

4.8 Sukhothai Groundwater Project, Thailand.

4.8.1 General Features and Location

The pipe systems described below were constructed to distribute water from deep tubewells in the Sukhothai region of northern Thailand. The irrigated area comprising some 100 plus schemes is estimated at 5,600 ha, with schemes inevitably bounding one another.

The very flat slopes and opportunity for tubewells to be positioned at higher elevations within the commands, meant closed pipe systems were feasible. The pipe systems can be described as low to medium pressure systems, with the high pressure (8 Bar) uPVC branching pipe system directly connected to the pump, and operating pressures at the well head of approximately 10m.

4.8.2 Background to the Irrigation Scheme

Sixteen years have elapsed between initial scheme design and final project completion, and in that time considerable experience has been gained world wide in the design and operation of buried pipe distribution systems.

Project implementation, by the Royal Irrigation Department (RID), took much longer than anticipated because of problems over the procurement of the pumpsets. However the project has succeeded in pioneering groundwater development for irrigated agriculture in Thailand, as well as introducing new irrigation management and extension techniques.

4.8.3 Water Source, Crops Grown and Methods of Irrigation

Although groundwater resources are considerable in the area, the high concentration of irrigation systems in one area, has necessitated some restriction on the level of abstraction. Based on the topography the irrigated area has been divided into upland and lowland. In the flatter lowland areas, where rice is the main crop, though pulses such as soyabean are becoming more popular, basin irrigation is practised with water distributed by earth channel or through neighbouring basins.

In the upland areas, where mostly border strip and some furrow irrigation is practised, water is supplied to the field by siphon from earth header ditches. Crops grown here have been more mixed and included pulses, some cereals, cotton and sugar cane.

Although target cropping intensities of 200% for the lowland areas and 265% for the upland areas were envisaged for full project development, the main aim was to ensure the main wet season crops. The adoption of basin irrigation of soyabean in the lowland areas instead of the proposed second rice crop has however created some operational problems which are outlined below.

4.8.4 Design Criteria

Because of the requirement that the established pattern of land ownership remain unchanged, the only practical layouts were complex branching pipelines. Additionally the project was committed to providing one outlet for each farmer in order to simplify scheme operation and management.

Based on sustainable well yield estimates of 55 l/s, the nominal command area was set at 55 ha. In practice well yields were lower than hoped for and varied widely from 25 to 60 l/s, serving command areas of 45 to 58 ha.

4.8.5 Pipe System and Structures

The branching pipe system comprised 8 Bar rigid uPVC pipe connected to the pump well head via a short section of above ground steel pipe. The steel pipe included elaborate flow protection and control equipment. In addition to an air release valve and a gate valve near the pump, an in-line flow meter, butterfly valve and branch to a surge tank were provided. A high pressure relief valve was also provided before the pipe entered below ground and branched to the different parts of the command. In-line gate valves were provided on each of the main pipe branches in order to direct water only to the pipeline in use.

No additional air valves or surge risers were provided in addition to the structures at the headworks. The outlets comprised a locally manufactured alfalfa type valve in a concrete box surround with a single sharp crested horizontal weir, and one of these is shown in photo plate 4.6. Earth field channels, like those in photo plate 4.10, needed to be large and well graded.

4.8.6 System Construction

Scheme construction was almost entirely carried out by staff of the Royal Irrigation Department, from the well head to the outlet. Farmers remained responsible for completing earth channel works. Any pipeline leakage appeared to be infrequent and usually appeared within the first year of operation.

The imported equipment provided for flow control and system protection was all installed by RID staff.

4.8.7 Method of Regulation and System Operation

The pump is generally attended by a single operator who is responsible for initially starting the pump, regulating the valves to direct water to the outlet taking water, and stopping the pump in the event of any problem. With the pump protection provided, automatic cutouts will operate if there is a problem with the electrical supply or excessive line pressures.

In the lowland areas it was always intended that one irrigator would take the full inflow discharge to the pipe system, from a single outlet riser box. Field observations suggest that earth channels are often poorly formed and field losses can be considerable, although the maximum field channel lengths are usually much less than 100 m. With the change to soyabean in the lowland area, the large delivery streams are no longer appropriate, and accurate light irrigation applications are very difficult to achieve.

In upland areas, the original design called for the supply to be shared between two farmers by balancing flow from two risers, and checking discharge through the weirs. Presently farmers are refusing to share the water both because of questions about the equity of flow division possible. A flow of 55 l/s can not be handled efficiently by a farmer applying water to a field plot via siphons, resulting in excess runoff on border strips and furrows, and a reduction in field application efficiency.

4.8.8 Social and Environmental Issues

Although technically the scheme can be considered successful, most of the benefits will rely on the performance of the water user associations established in each command. Improved application efficiencies depend on improvements to the farmer managed field channels and a willingness to share water from the scheme. The buried pipe systems are some of the first irrigation systems in Thailand to be responsible for the recovery of the operating expenses, and although problems exist on some schemes with large sums owed in unpaid power charges, considerable progress has been made.

The presence of large volumes of irrigation water in the lowland areas, has highlighted the need for improvements to the drainage system if soil deterioration is not to become a major problem.

4.8.9 System Cost

A typical system is estimated to have cost Baht 1,900,000 or Baht 38,000 per ha ($US 1460 per ha), for a 50 ha scheme. The distribution system represents about 20% of this cost, and is only 50% more expensive than the elaborate two story pump house provided in some of the schemes.

4.8.10 Observations of System Design and Performance

While the buried pipe system has enabled the precise delivery of water to individual farmer land holdings, changes in the cropping pattern have identified limitations in the flexibility with which the system can be operated. Again the absence of any precise method for dividing inflow discharge has been identified as preventing higher transit efficiencies feeding through to reductions in application inefficiencies.

Lower pressure pipe systems should have been feasible on the lowland command areas, and would have reduced both the capital and operating costs, by eliminating the need for the elaborate headworks and high cost uPVC pipe. Lower costs and more flexible operating systems will be keys to expanding the use of buried pipe systems within Thailand.

4.8.11 Scheme Summary

Scheme Name:	Sukhothai Groundwater Development Project
Scheme Location:	Sukhothai Province, Thailand

<u>Design</u>

Type of Buried Pipe System:	Closed medium pressure systems
Method of Regulation:	Manual
Operating and Control System:	Pipe system directly connected to the pump
Pipe Layout:	Branching layout
Mode of Operation:	Mode A. Full pump discharge taken by one irrigator at one outlet.
Structures Present:	Air release valve, surge tank, pressure release valve
Pipe Material Used:	Rigid uPVC pipe (8 Bar)

<u>Scheme Data</u>

Total Scheme Area:	40 to 60 ha
Average land holding:	1.5 to 3 ha
Irrigation Water Duty:	1 l/s/ha
Length of Pipeline per ha:	50 -70 m/ha
Average Outlet Command Area:	1.5 to 2 ha
Design Operating Pressure:	10 m
Distribution system cost $US/ha:	292
Total scheme cost $US/ha:	1460
(Baht 26 per $US 1)	

<u>References</u> HHP/HTS (1988)

4.9 Conclusions from the Case Studies

Although the pipe systems described, vary widely in their design and methods of construction, all succeed in bringing the irrigation supply closer to small holder irrigators distant from the water source more effectively than alternative open channel distribution systems. The pipe systems appear to facilitate the irrigation of small areas of diverse agricultural crops in a way that open channel systems do not.

While the performance of pipe systems, as measured by the area irrigated is still disappointing, in most cases this is due more to social and management problems rather than specific technical weaknesses. In several of the systems, simple design alterations could have partially solved the problems experienced and helped to improve levels of performance.

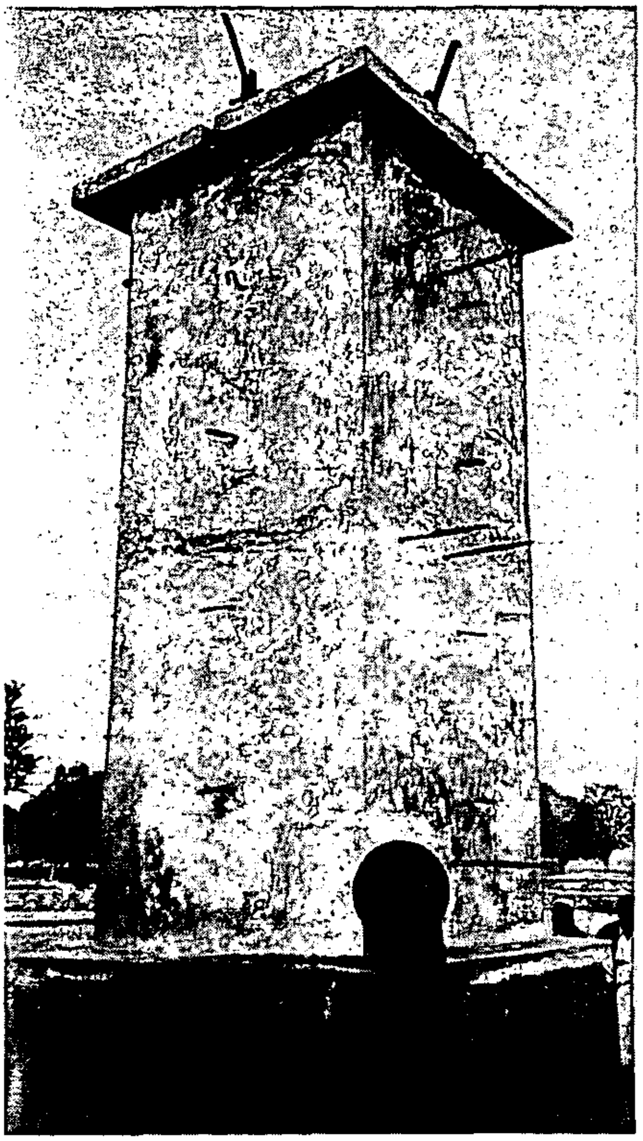
Two recurring problems were the low levels of cooperation among scheme participants, and the lack of precise flow division at the inlet to the pipe system. The absence of any precise method for dividing inflow discharge, prevents higher transit efficiencies leading to reductions in application inefficiencies, as the large delivery streams taken by individual irrigators overtop small field channels.

Whether buried pipe distribution systems reduce the level of cooperation required for operating distribution systems, when compared with open channel systems, will depend on the design of the system. Where pipe systems provide individual outlets for each irrigator, the need for cooperation is largely obviated (for example in the Sukhothai pumped supply system described in case study 4.8). However if large numbers of farmers (more than 20) are required to share the discharge from one outlet, cooperation will be essential to successful operation (such as in the Uttar Pradesh tubewell based systems described in case study 4.6).

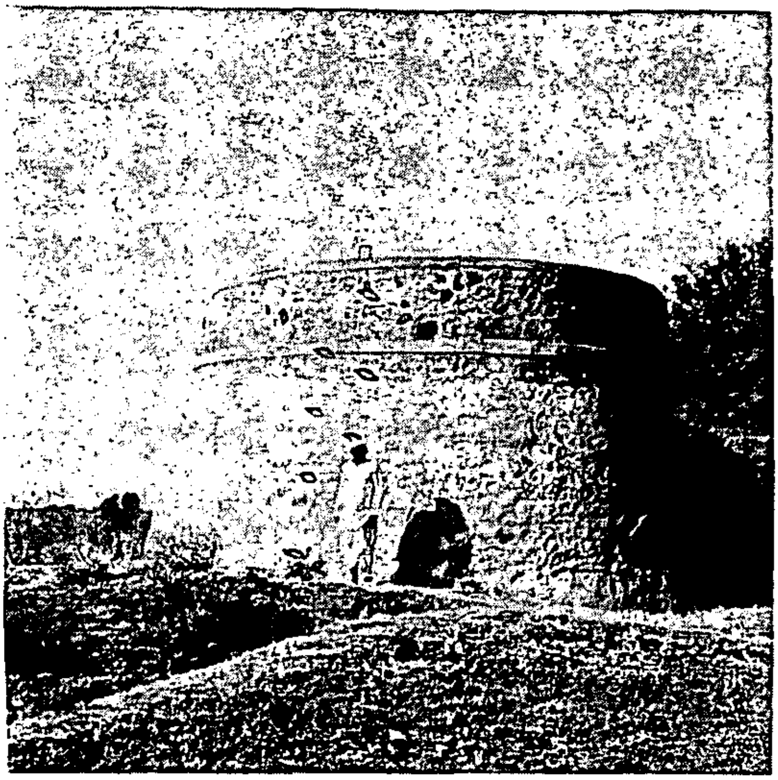
Because it is much more difficult to change the design of a pipe system once constructed compared to an open channel system, pipe systems need to be designed with a view to possible changes in the pattern of water demand and likely operating system.

Although buried pipe systems reduce transit losses, this will only be translated to overall efficiency improvements where earth field channels are relatively short and in good condition. While nonreinforced concrete pipe systems provide adequate performance at low cost, higher cost uPVC pipe systems can be installed much more rapidly and reliably.

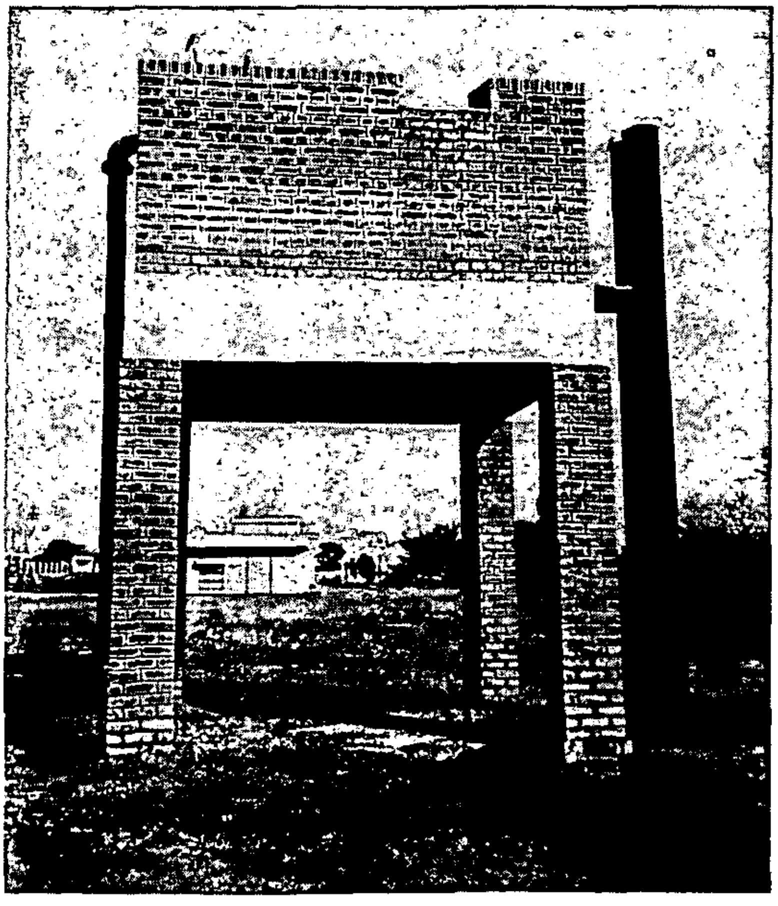
Photo Plate 4.1 Pressure Tower Structures



BIADP (Bangladesh)
Header Tank



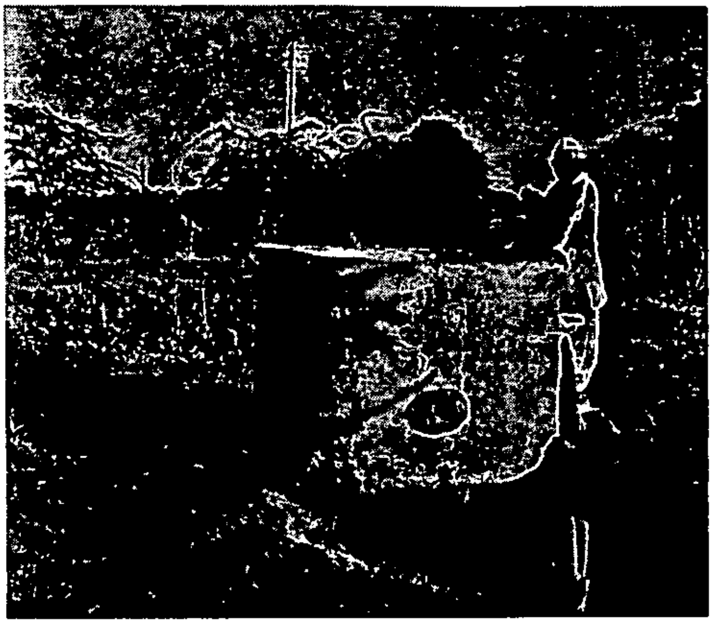
Pump lift irrigation scheme
(India)



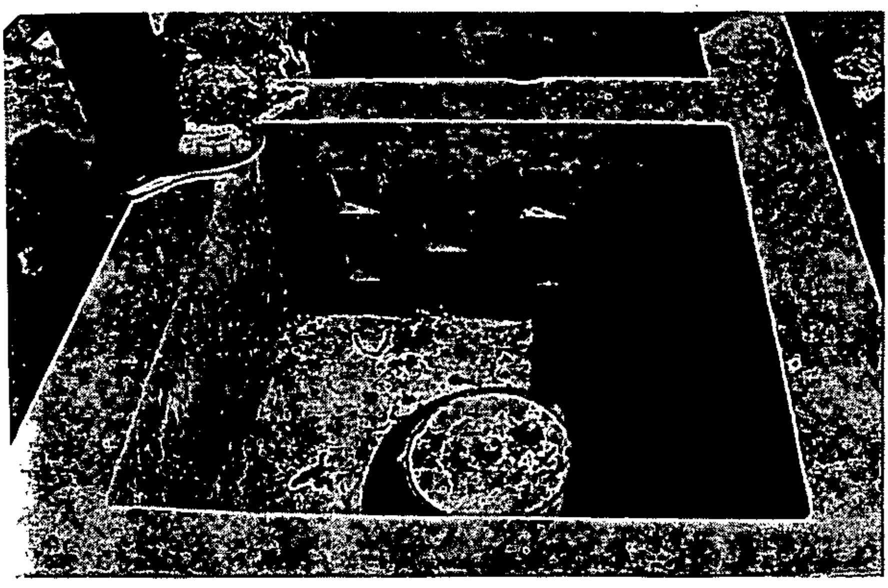
Elevated Tank (Uttar Pradesh, India)

Photo Plate 4.2 Outlet Types

Capped riser (India)

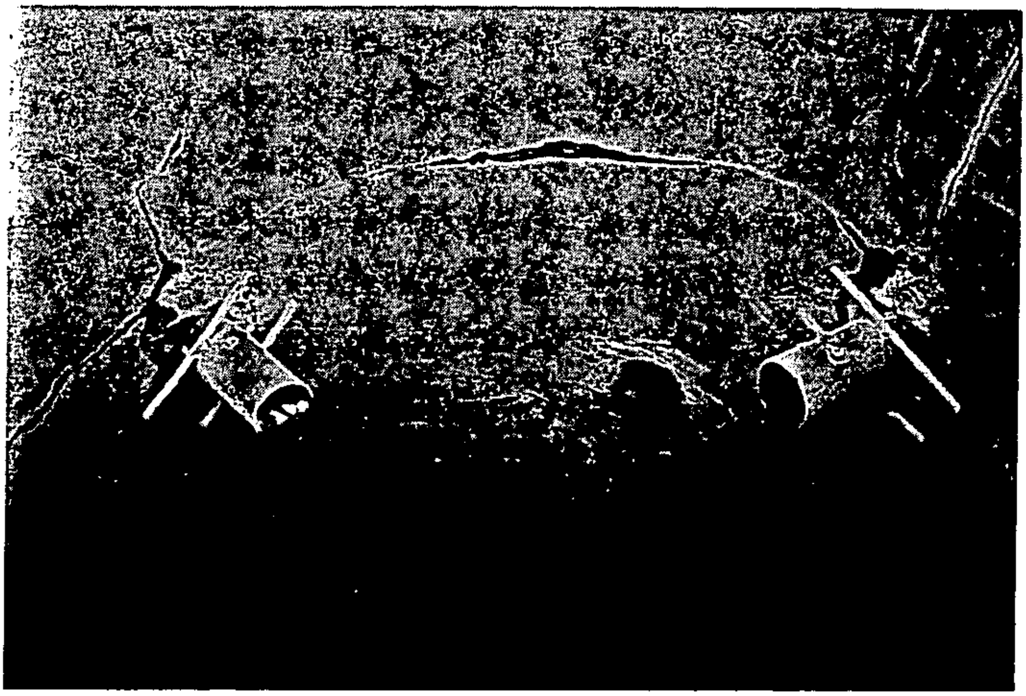


Open stand with side orifices (India)



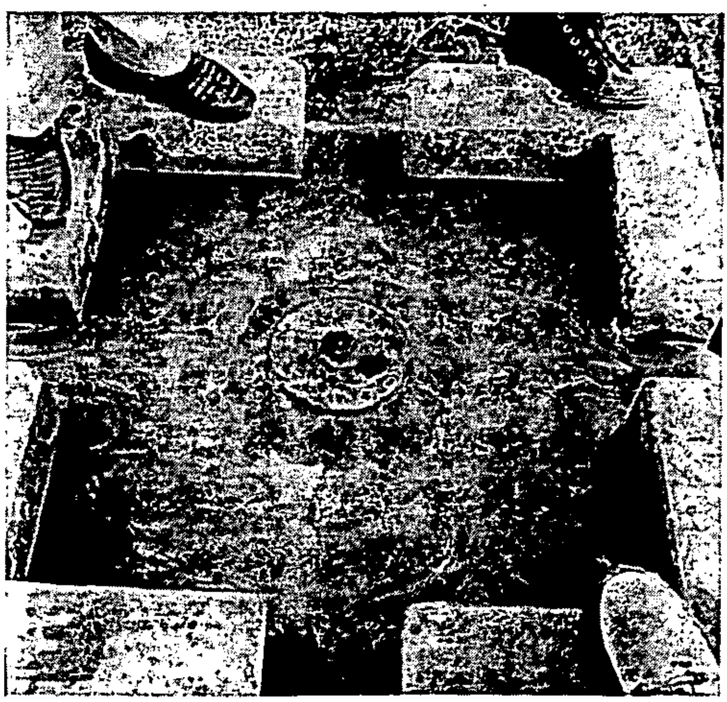
Alfalfa valve (IDA DTW II Project Bangladesh)

Photo Plate 4.3 Outlet Distribution Structures 1.



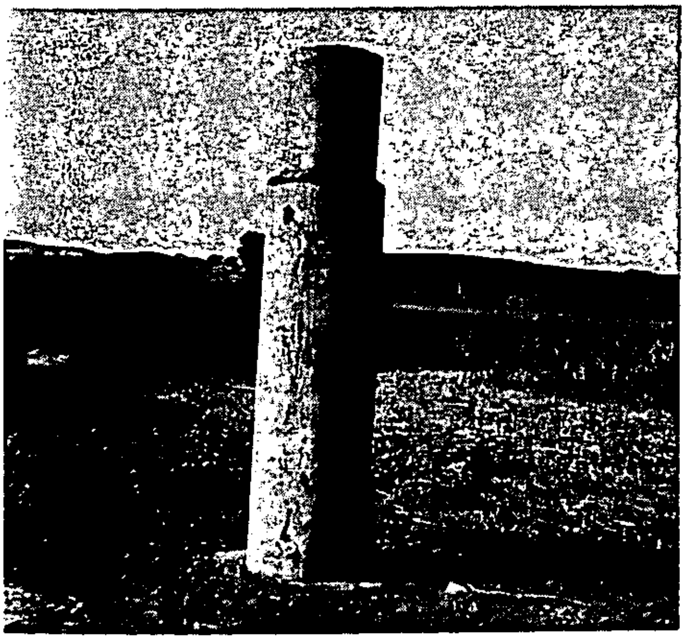
Open stand with side orifices

Concrete surround (TADP, Bangladesh)



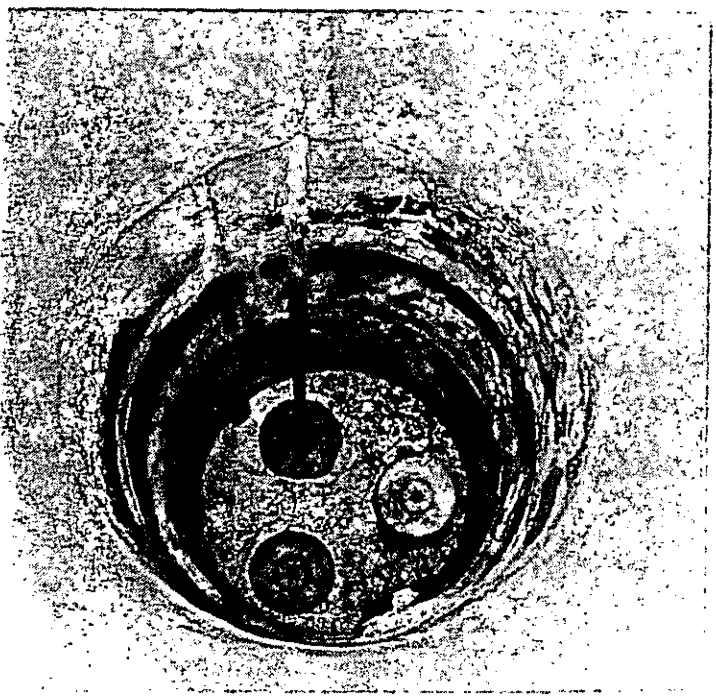
Masonry pad (BIADP,Bangladesh)

Photo Plate 4.4 Water Control Structures

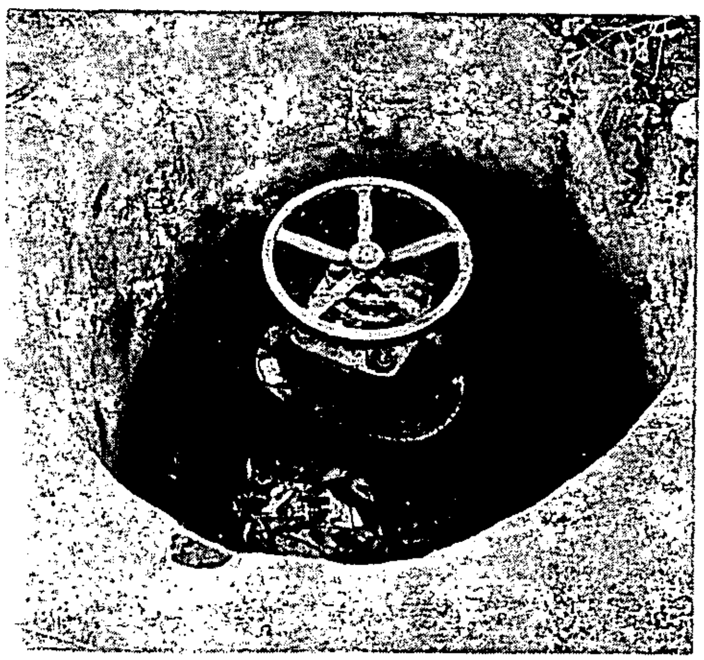


Harris float valve stand (Gadigaltar, India)

Pipeline inlet from open channel with slide gate (Gadigaltar, India)

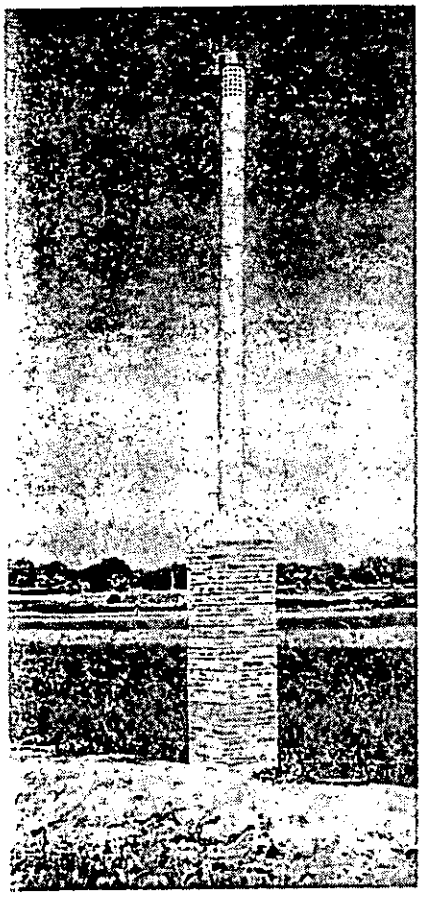


Alfalfa valves on inlets to pipe branches (TADP, Bangladesh)

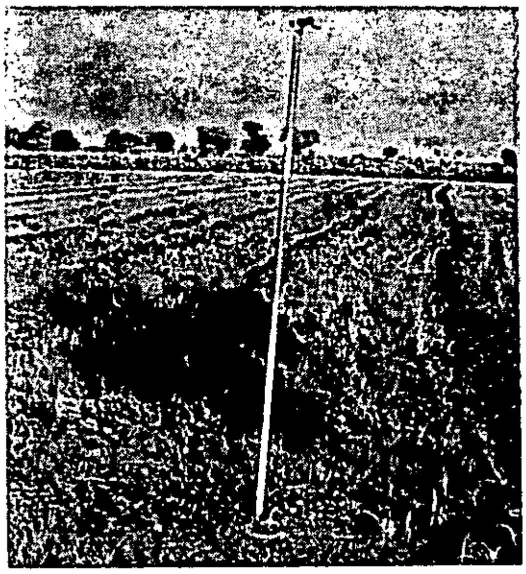


In-line gate valve (LIS, India)

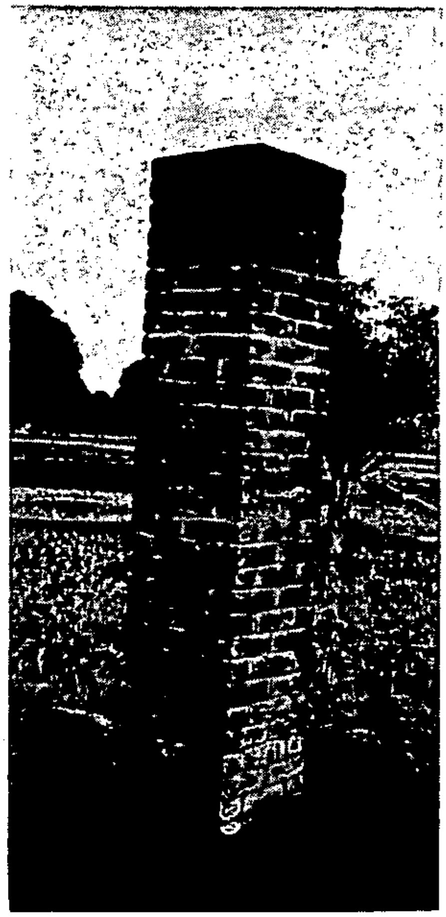
Photo Plate 4.5 Air Vent Structures



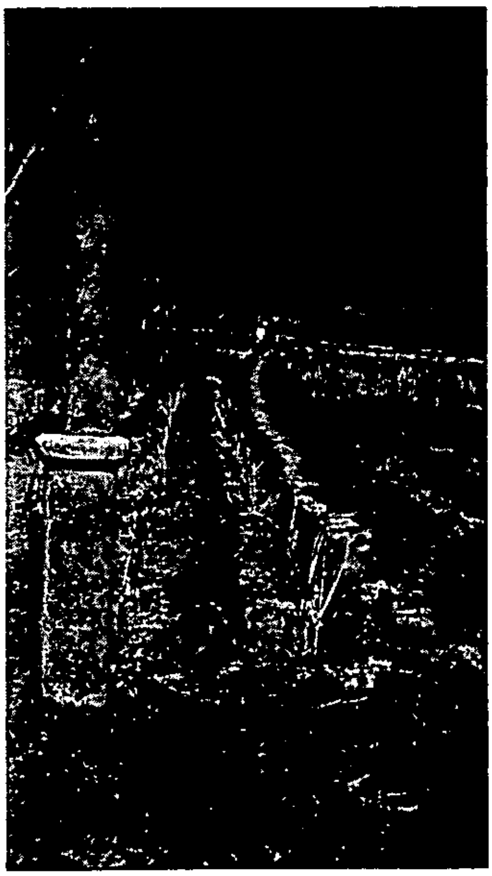
IDTP (Uttar Pradesh, India)



LIS (Madhya Pradesh, India)



BIADP Project
(Bangladesh)

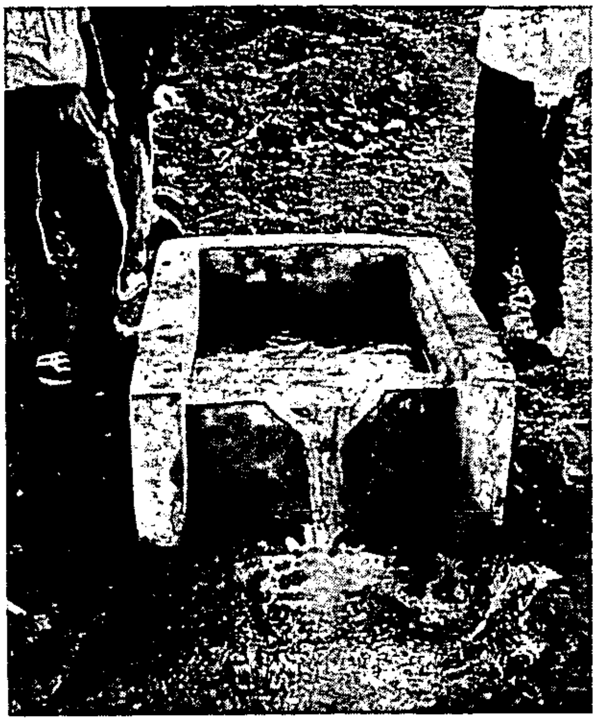


TADP (Bangladesh)

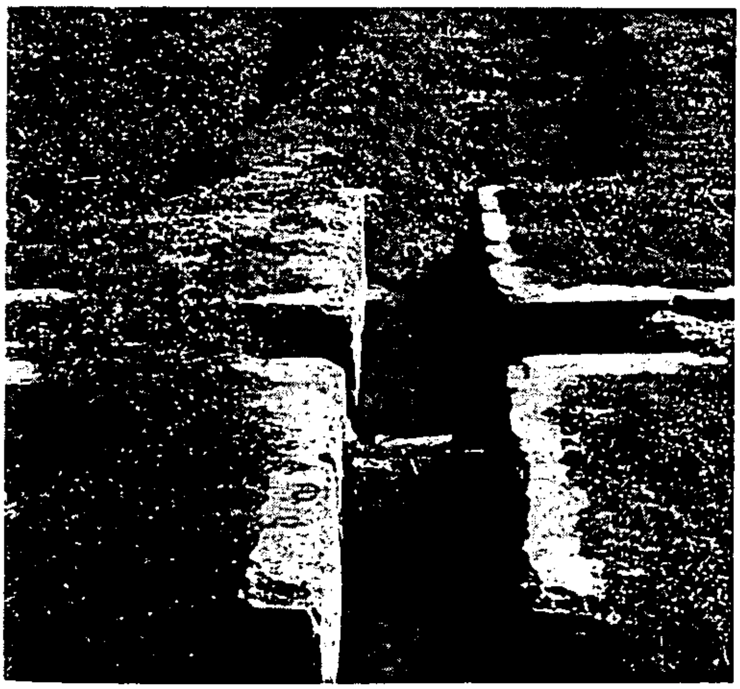
Photo Plate 4.6 Outlet Distribution Structures 2.

(Simple masonry or concrete box)

Sukhothai Project (Thailand)

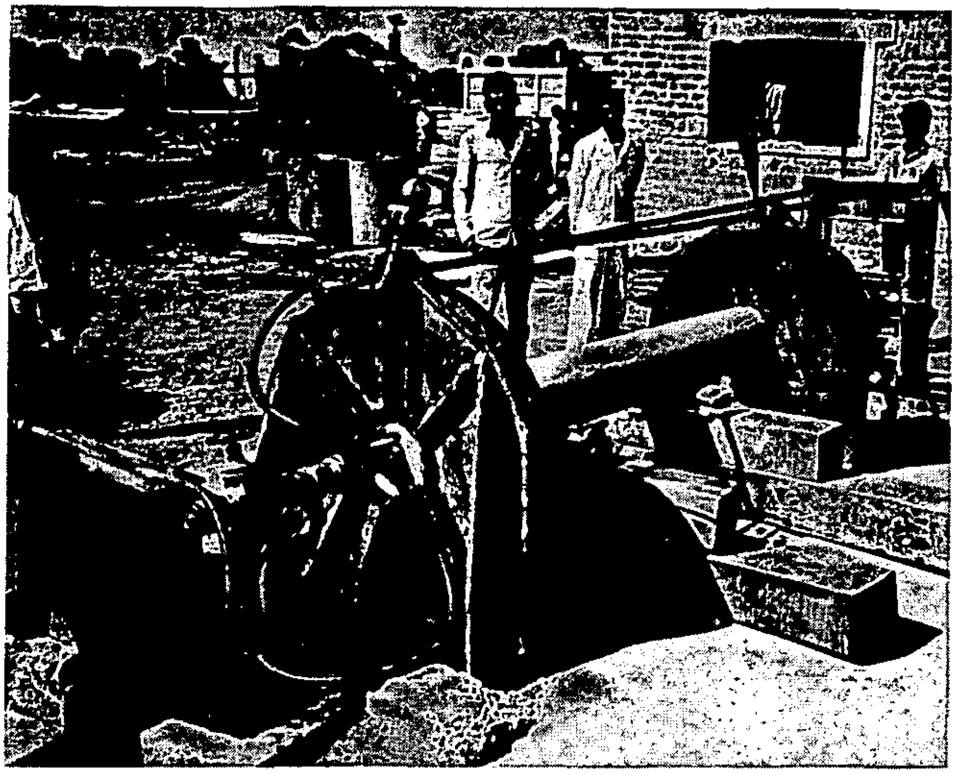


Gadigaltar (Madhya Pradesh, India)

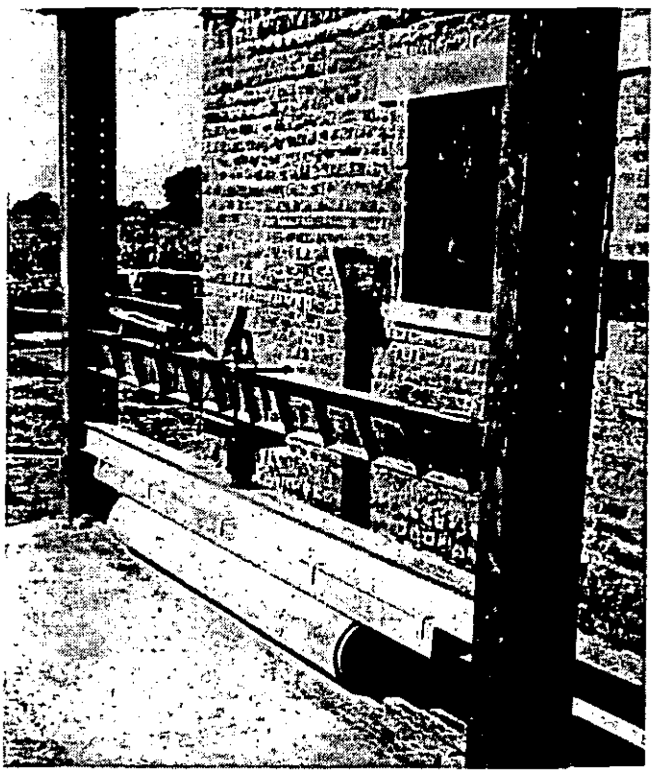


RDA (Bogra, Bangladesh)

Photo Plate 4.7 Concrete Pipe Testing Equipment

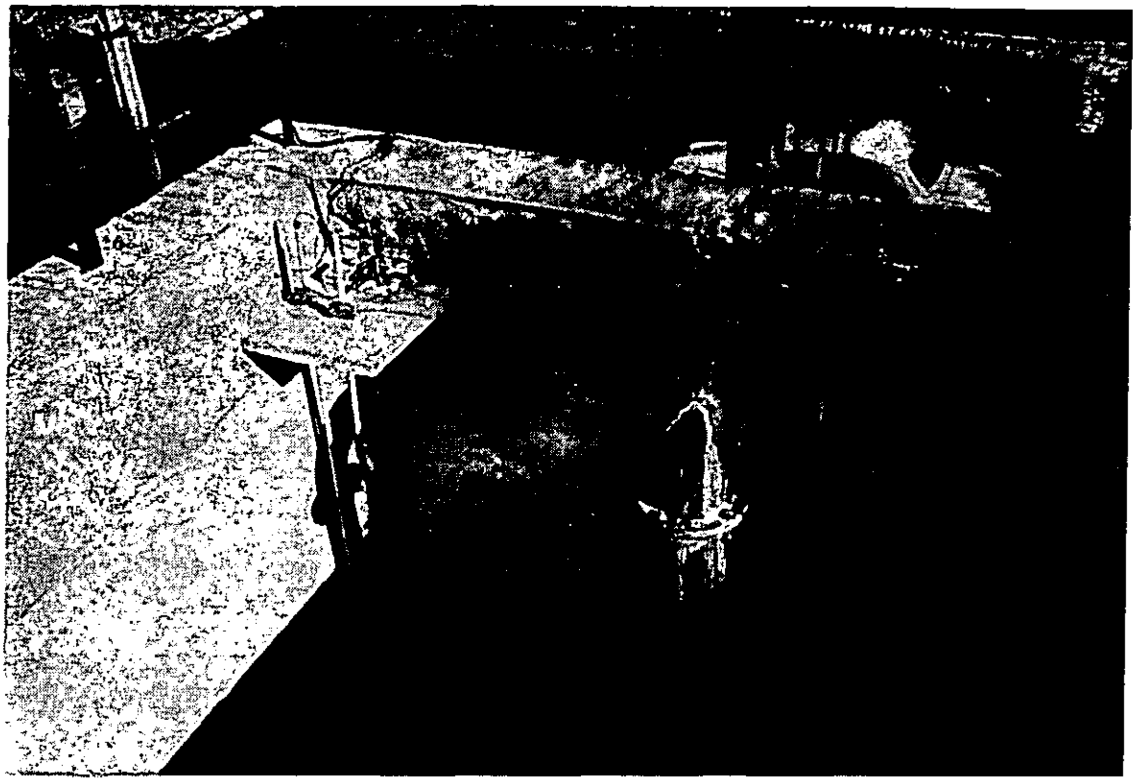


Hydrostatic pressure test equipment (Gadigaltar, India)

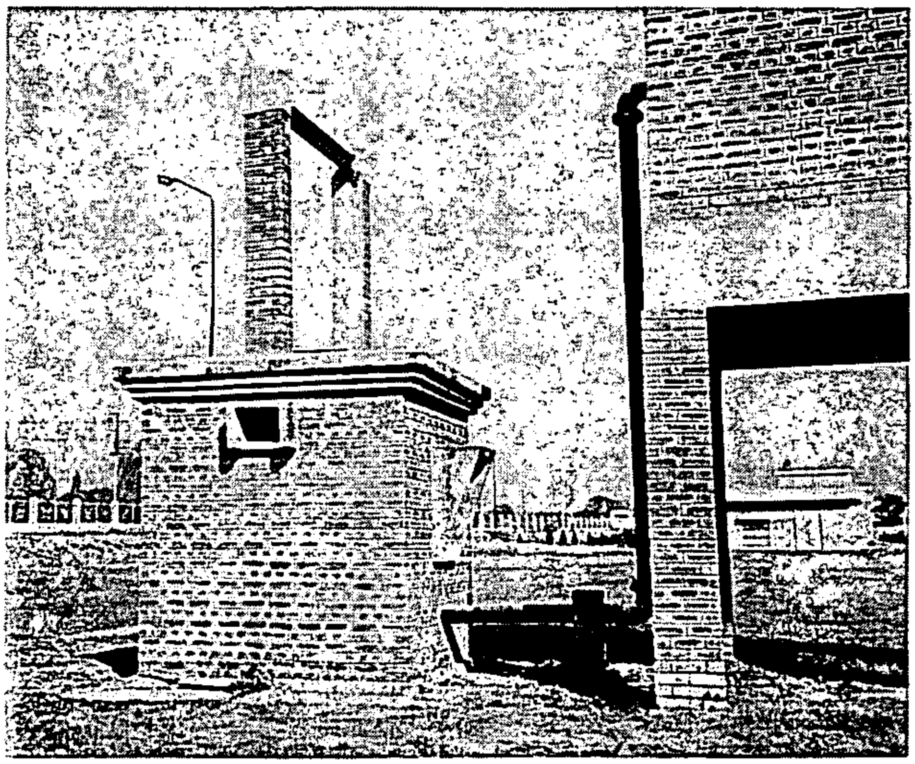


Three edge bearing test rig. (Gadigaltar, India)

Photo Plate 4.8 Elevated Tank (IDTP, India)

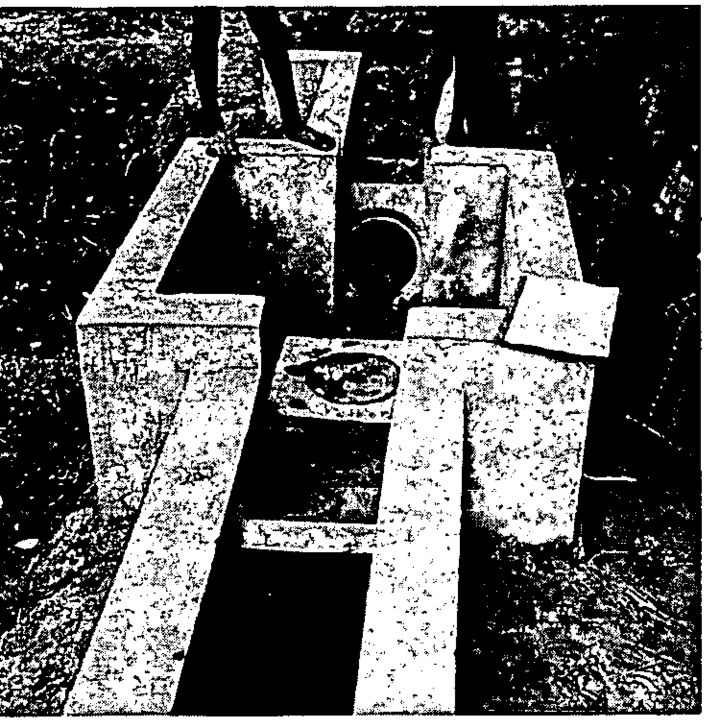


Inside of tank with discharge pipe and probe controls



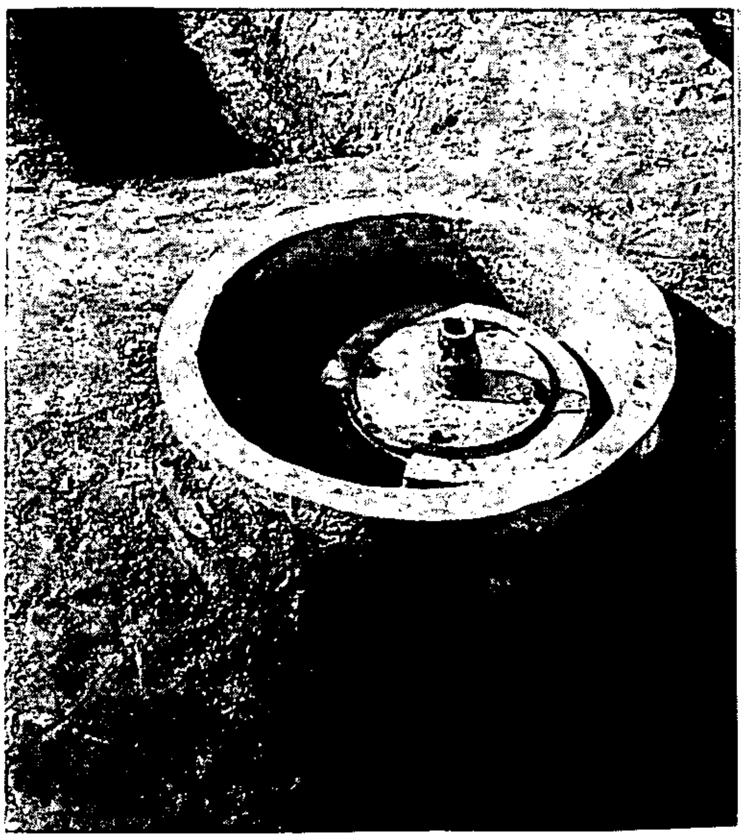
Pumphouse and discharge pipe

Photo Plate 4.9 Outlet Distribution Structures and Channels



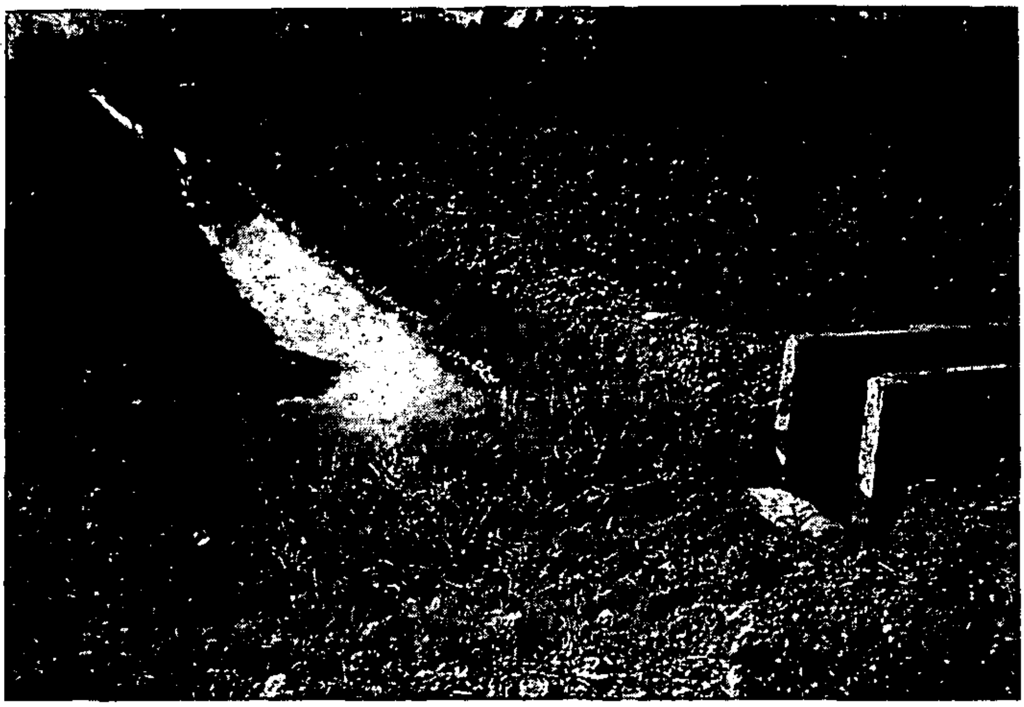
IDA DTW II Project (Bangladesh)

IDTP (Uttar Pradesh, India)

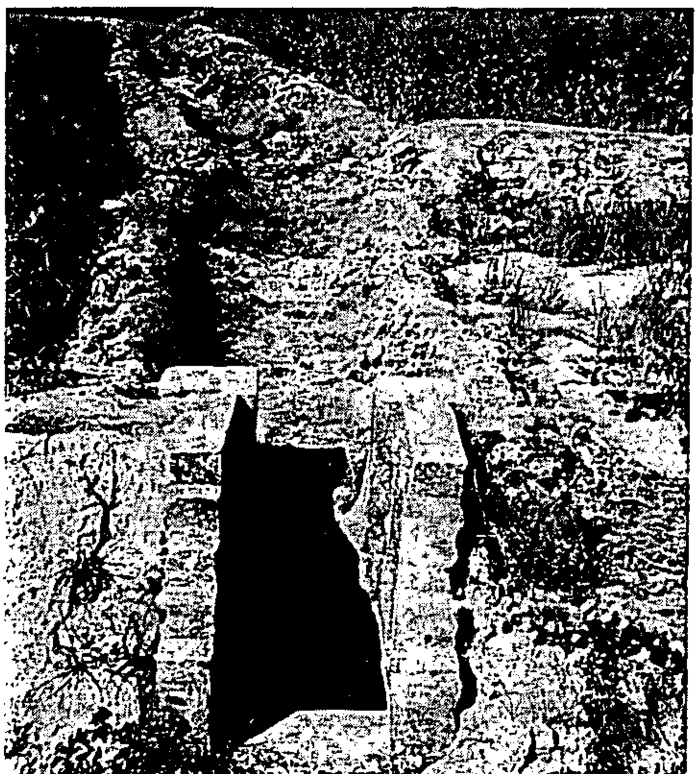


IDTP new design (Uttar Pradesh, India)

Photo Plate 4.10 Field Distribution Structures and Channels



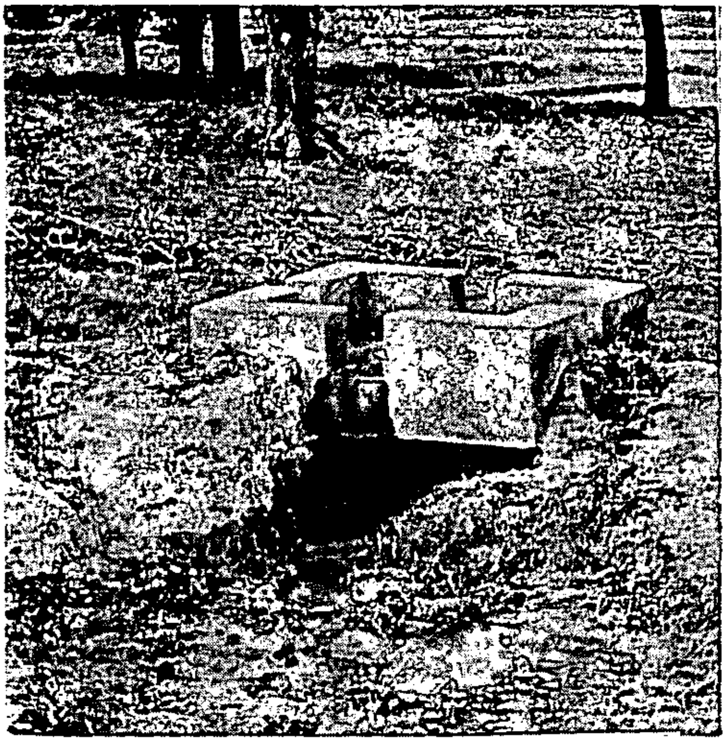
Sukhothai Groundwater Project (Thailand)
Field distribution channel



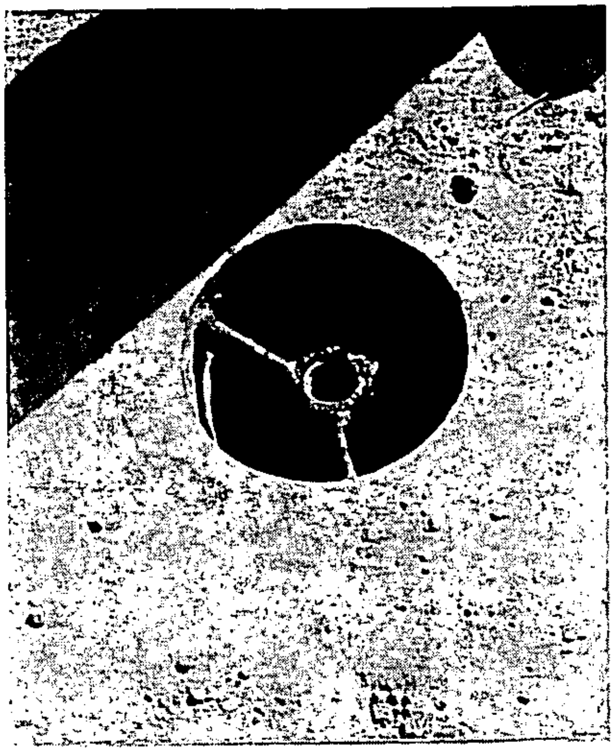
Field channel drop structure
(IDTP, India)

TADP (Bangladesh)
Field channel alongside previous raised distribution channel

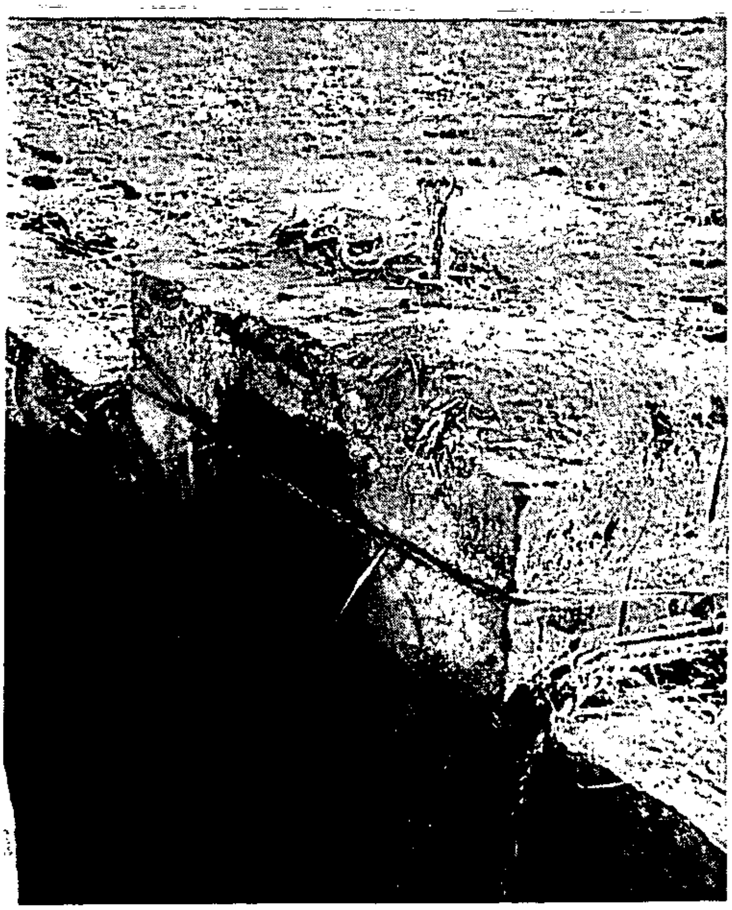
Photo Plate 4.11 Outlet Damage on Buried Pipe Systems



Poor construction and siting of outlet structure (BIADP, Bangladesh)



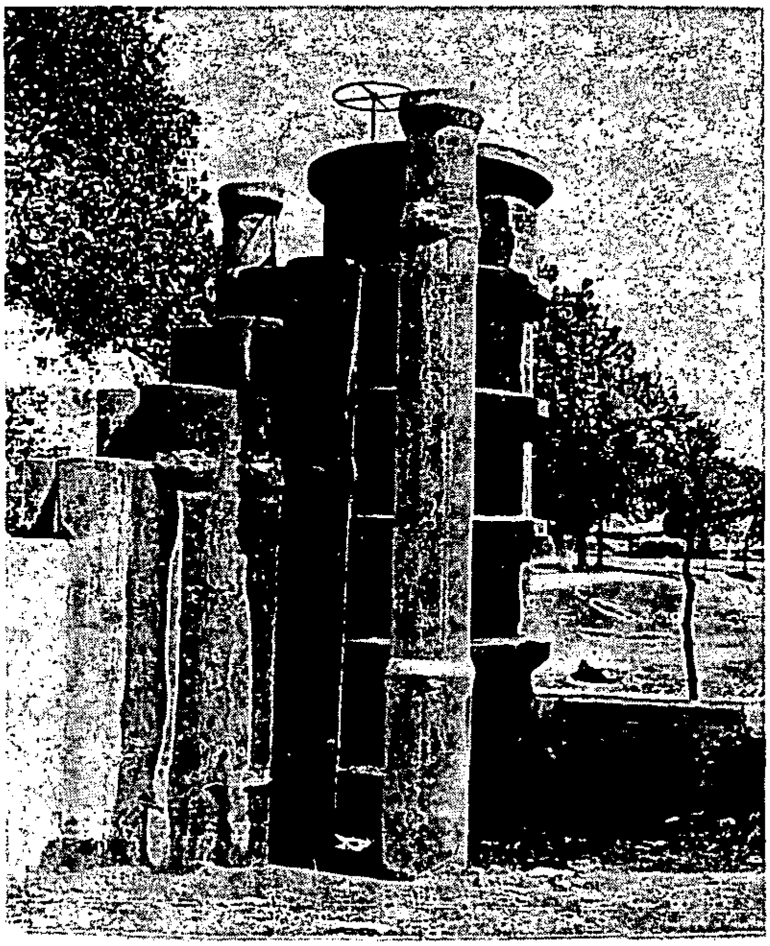
Valve body and stem removed (RDA, Bangladesh)



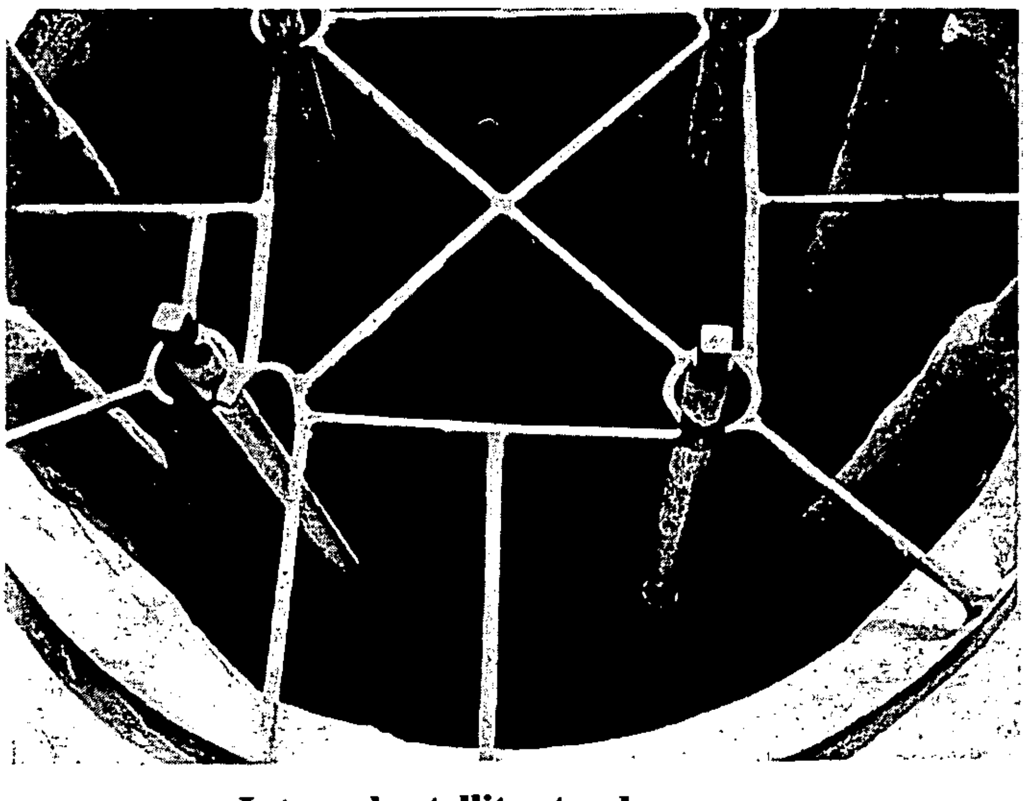
Leaking valve due to stripped spindle (IDTP, India)

Leaking valve due to stripped spindle (TADP, Bangladesh)

Photo Plate 4.12 Pressure Towers with Top Water Level Control



External satellite stands



Internal satellite stands

CHAPTER 5. Recommendations on Selection of Buried Pipe Distribution Systems

5.1 Introduction

The recommendations on selection, and design and construction of buried pipe systems and their components, detailed in chapter 5 and 6 respectively, draw on experience gained from the review of published and unpublished literature, observations of existing buried pipe systems and detailed communication with irrigation practitioners. While many of the recommendations are qualitative, relevant quantitative data have been included where relevant, particularly on transit efficiency.

The recommendations aim to provide irrigation practitioners with a short-cut to understanding gained through many years of field experience.

The selection process has been clarified, into the five steps set out below:

i) Establish the suitability of a buried pipe system over other types of distribution system.

Buried pipe systems will not be the most appropriate choice in all situations. Recommendations on the suitability of a buried pipe system are given, based on information regarding the area to be irrigated, the nature of the water source, and social and environmental factors. Issues influencing suitability such as soil texture, topography of the command area and water availability, are discussed in section 5.2 and summarised in flow chart 5.1.

ii) Select the type of buried pipe system best suited to the topography and water source available.

Pipe system selection is based on the hydraulic operation of the system (refer to flow chart 5.2) and the source of the driving head for the system (see flow chart 5.3). Reference should be made to the definitions of pipe systems already outlined in section 3.3. For each situation there may be more than one alternative and then choice should take into account other factors such as cost and management flexibility.

iii) Select the method of regulating inflow discharge to the pipe system.

Regulation refers here to the matching of inflow discharge with outlet discharge.

Regulation methods available depend on the hydraulic operation of the pipe system and whether the supply is from gravity or pump. These have been discussed in detail in section 3.5.

iv) Select the operating and control system to be used.

The selection of the type of control structure at the inlet and head of the pipe system, coupled with the method of regulation, comprises the operating and control system. Key decision points relate to the ratio of desired outlet discharge to inflow discharge, and where flow is to be divided, the method and position in the pipe system where this is to be achieved. In all cases there will be more than one possible choice of operating and control system, and reference should be made to section 3.6 for further detail. A summary of the issues important in selecting the operating and control system for both pumped and gravity supply systems is given in flow charts 5.4 and 5.5 respectively.

v) Select the pipe layout and pipe material to be used.

An initial selection of pipe layout and pipe material is made on the basis of technical feasibility and total cost, as the pipe comprises the largest proportion of the system cost. Where cost of different pipe materials is comparable, other considerations such as ease of construction become important. During later design, final selection will be made of the pipe sizes and jointing methods to be used. Alternative pipe materials and methods of pipe manufacture are discussed in detail in section 2.7, while section 2.8 considers branching and loop layouts.

Issues relevant to the selection of the pipe material and pipeline layout are summarised in flow charts 5.6 and 5.7 respectively.

5.2 Suitability of Different Types of Distribution System

5.2.1 Alternative Distribution Systems

For water distribution within the tertiary unit of an irrigation scheme the various distribution system alternatives available include:

-earth channel (preferably from compacted earth)
-various in-situ and prefabricated concrete canal linings
-brick lined canals
-low cost membrane lining, including plastic, asbestos and rubber materials

-low pressure pipe systems of concrete, uPVC or asbestos cement.
-mixed systems with differing proportions of any of the above.

If buried pipe systems are to be compared with open channel systems then all systems must include water control structures. While field measurements of transit efficiency, often show the performance of open channel systems to be inferior to that of pipe systems (refer to section 2.3), it is only in particular circumstances that pipe systems are clearly preferable to open channel systems.

The distribution systems considered here are assumed to comprise extensive networks with from 1000 to 2000 m of channel or pipe. For very short networks (small command areas) earth channel networks will frequently still be the most economical choice. Privately developed shallow tubewells surveyed in the Terai area of Nepal, irrigate on average 1.9 ha, although this could be extended to cover 3.4 ha where the earth channels were substantially improved (GDC 1987).

5.2.2 Distribution and Transit Efficiencies

One of the often quoted advantages of pipe distribution systems is their lower seepage losses when compared to surface channel alternatives. However few documented measurements of distribution and transit efficiencies for existing buried pipe systems have been identified, and the figures quoted in this section are largely based on fieldwork completed in Bangladesh (Rashid et al 1992) and data collected during the study tour of northern India and Thailand (van Bentum and Smout 1991a), partially summarised in chapter 4 of this thesis.

The overall distribution efficiency of buried pipe irrigation systems is defined as comprising both the transit efficiency of the pipe system and the distribution efficiency of the field channels. While measurable improvements in transit efficiency are possible, improvements to the distribution efficiency of the field channels are more difficult to achieve.

Transit Efficiency

The transit efficiency of the pipe system is defined as the ratio of the water discharged from the outlet valve or valves to that which is entering the pipe system. The efficiency achieved depends on the pipe material and jointing system used, the seepage losses per unit length and the total length of the continuous pipe system attached to the particular outlet. Seepage losses can occur from any or all of the pipe body, the pipe joints, and the structures associated with the pipeline, for example outlets. Seepage from asbestos cement and plastic pipe systems is only really likely from joints and pipe system structures, provided the pipe material is not damaged after manufacture.

Measured seepage losses (Rashid et al 1992) from different parts of the pipe system, reported in section 2.6, demonstrate considerable seepage loss reductions with the use of buried pipe systems.

Table 5.1 gives estimates of pipe system transit efficiency based on field data for concrete pipe systems in Bangladesh (Rashid et al 1992) and a range of other pipe systems visited throughout south Asia. In the absence of field measurements of seepage losses for uPVC pipe systems, transit estimates are inferred from visual verification of the very low frequency of pipe leakage (IDTP 1989), observations of leaking outlet valves, and experience with uPVC pipe materials in other applications.

Transit efficiencies presented below assume high construction standards for the pipe systems using pipe manufactured by machine spun methods (for nonreinforced concrete) using quality raw materials.

Table 5.1 Typical Pipeline Transit Efficiencies

	Good	Average
Nonreinforced conc.	90%	80-85%
Rigid uPVC	95%	90%

Source: Rashid et al (1992) and field observation of south Asian systems.

Field Channel Distribution Efficiency

To obtain an estimate of the total system efficiency the field channel distribution efficiency must also be included and this will depend on the chosen method of field distribution as well as the outlet to field distance.

The measurements of earth channel losses in Bangladesh (Rashid et al 1992 and MMI 1990b) illustrate the sensitivity of the field channel distribution efficiency to the distance from outlet to field. The advantages of using buried pipe can be effectively cancelled by long travel lengths of tertiary earth channel, and hence it is recommended that distances from outlets to fields never exceed 200m and are preferably around 100m. Because of the large variation in the performance of field channels, actual field measurements should always be taken to establish estimates of distribution efficiency.

5.2.3 Social and Environmental Factors

While it is difficult to quantify the impact of buried pipe distribution systems on specific social environmental problems associated with irrigation, qualitative benefits can be expected when choosing a buried pipe system ahead of alternative open channel systems. A more detailed discussion of benefits accruing to buried pipe systems was given in section 2.6.1. Ways in which buried pipe systems mitigate some of the negative features of irrigation, can be summarised as follows:

-inefficient use of resources of land, water and energy: *A buried pipe distribution system directly reduces the problem of loss of land resources and through its lower transit losses, it also saves resources (water and possibly energy used in pumping and the resources used in construction)*

-damage to land (particularly through waterlogging and salinity): *reduced because less water is lost from a pipe system*

-damage to water resources (for example by drainage water degrading the quality of groundwater or surface water resources): *quantities of drainage water are reduced because of the greater transit efficiency*

-displacement of previous land users: *less of a problem because the land take is reduced, and pipe systems are better able to accommodate existing patterns of land ownership*

-damage caused during construction: *construction is completed more quickly with less disruption*

-spread of aquatic weeds and associated pests (eg rodents) and disease vectors: *suitable habitats in the irrigation system are eliminated by pipe systems; drains are drier and therefore less suitable habitats, because of improved transit efficiencies*

-increase in human illness (particularly schistosomiasis, malaria): *by elimination of vector habitats, pipe systems can assist with the control of these diseases*

Buried pipe systems can enhance the use of the irrigation system as a source for domestic water. MMI (1990b) acknowledges that replacement of an open channel system with a buried pipe system, can improve the availability of quality water at locations far from the deep tubewells, although at intermediate positions water becomes less accessible when discharge from the pump immediately enters the pipe system.

5.2.4 Specific Situations Suited to Pipe Distribution Systems

In order to compare open channel systems fairly, comparisons should be made between earth channel systems with adequate water control structures. In the absence of such structures, considerable management inefficiency is likely to result. The higher transit efficiencies already outlined become important where water is in limited supply and/or expensive to obtain, as observed in plateau areas of central India (pumped lift irrigation schemes observed in Maharashtra, India).

Situations in which open earth channels are likely to have high seepage losses, include coarse soil textures, and undulating command areas where sections of raised earth channel become essential, in order to transfer irrigation water across localised gully features and depressions to elevated areas of the command. Flow chart 5.1 summarises the main criteria used in selecting pipe systems ahead of open channel alternatives, while flow charts 5.2 and 5.3 detail selection of the type of pipe systems suited to each situation.

The conclusions set out below have been reached as a result of observation of existing pipe systems, study of the literature, experience with buried pipe system design and communication with irrigation practitioners.

i) Coarse Textured Soils

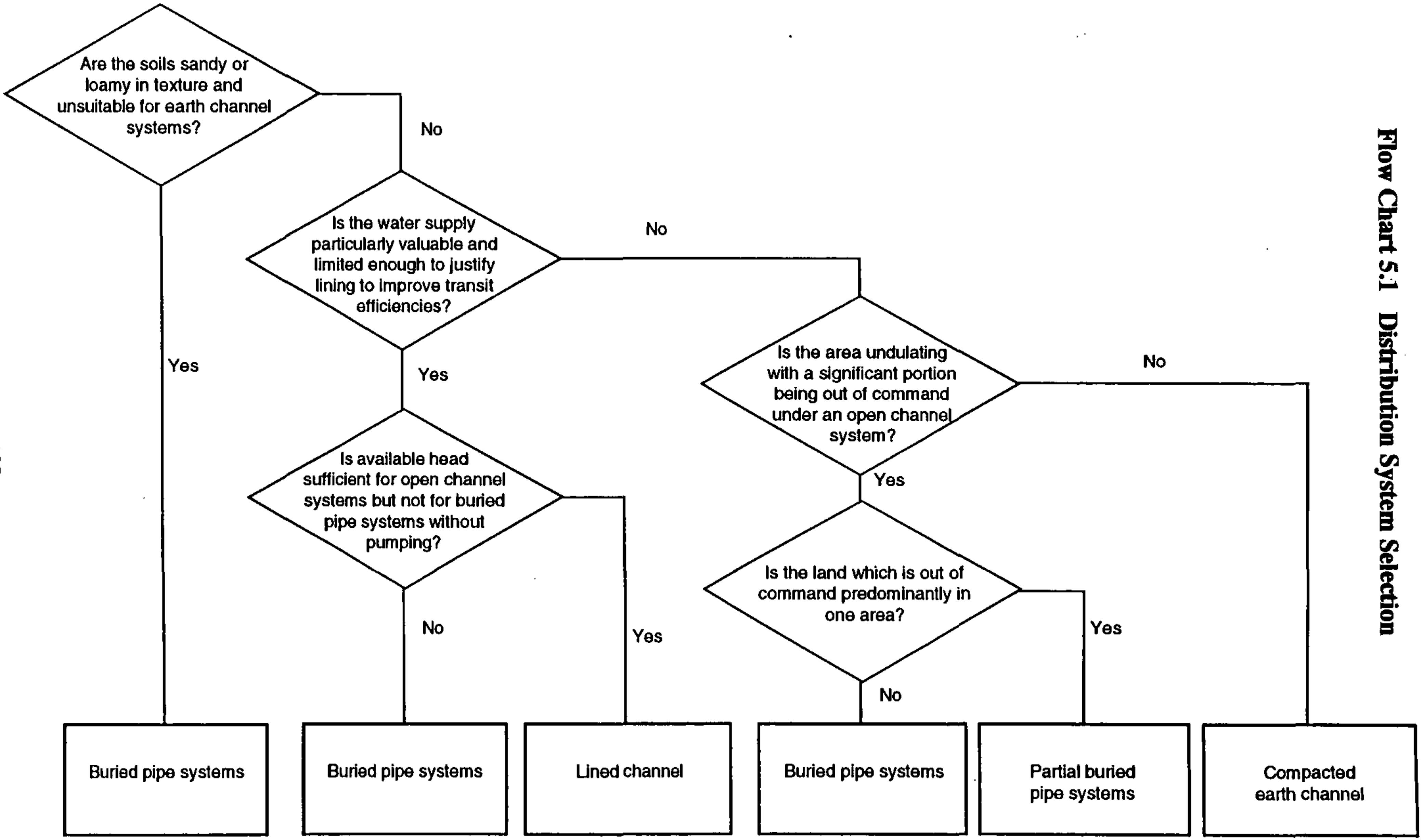
Earth channel systems built in sandy and coarse textured soils with poor cohesion, will have potentially high seepage losses, require frequent and heavy maintenance, and will often have a very limited life. Such soils also appear to be subject to a higher level of animal burrowing activity, and root penetration. Goldsmith and Makin (1989) recognised the waterlogging problems caused by leaking surface channels which can not only reduce the command area but also depress crop yields in neighbouring fields.

Canals built with coarse textured soils will often require flatter embankment batter slopes so taking up more land for the channel network, than finer textured materials. MMI (1990b) recognised the benefits of replacing lined and unlined channels on raised embankments, by installing short sections of buried pipe to replace the leaking raised channel sections.

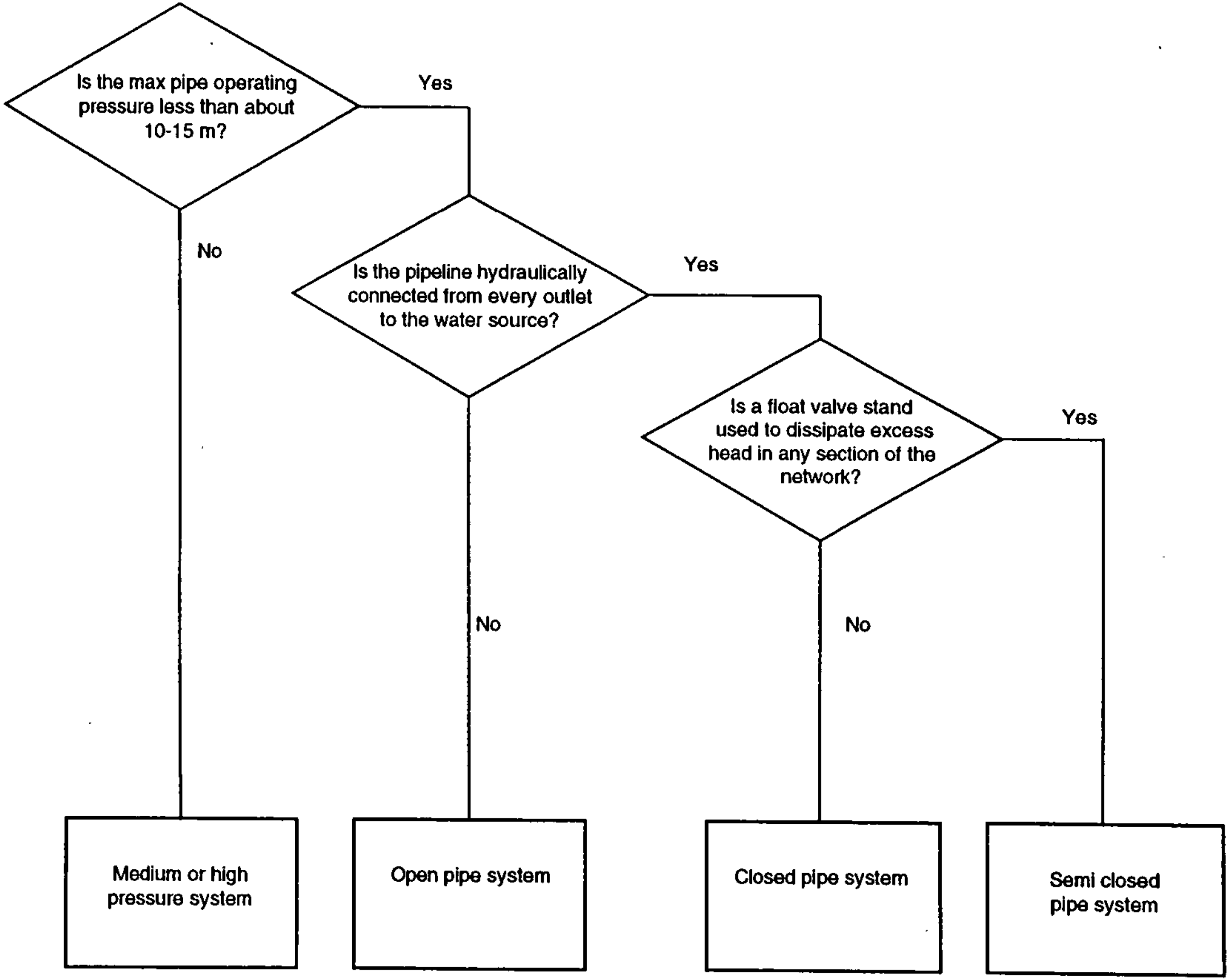
ii) Valuable and Limited Water Source

Buried pipe systems are particularly attractive where water is both valuable in terms of the crops which can be grown, and limited as evidenced by limited reservoir storage or restrictive controls on water abstraction from river or groundwater sources.

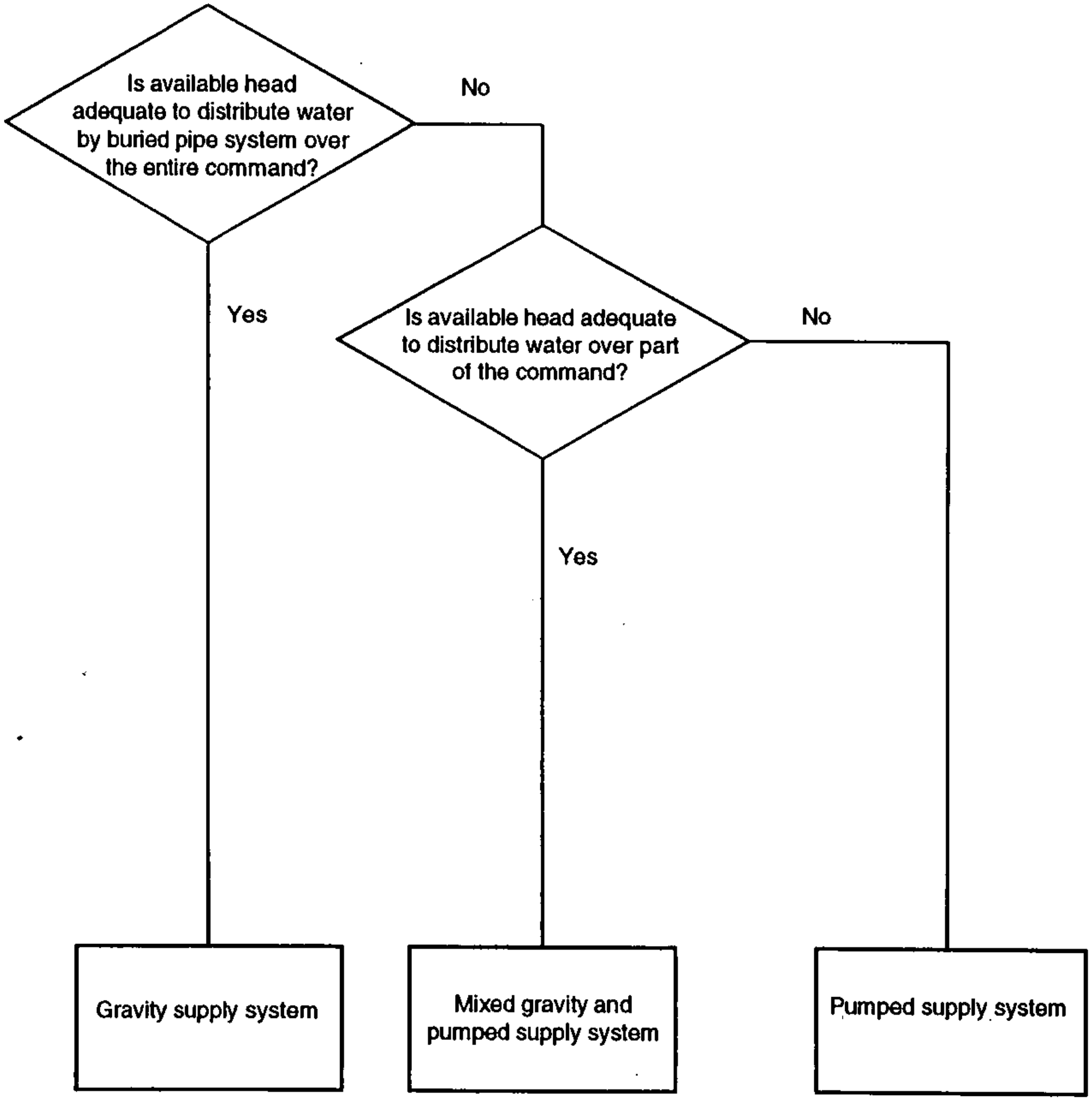
Flow Chart 5.1 Distribution System Selection



Flow Chart 5.2 Pipe Systems Selection According to Hydraulic Operation



Flow Chart 5.3 Pipe System Selection According to Origin of Pressure



Such situations include:

-water harvesting reservoirs where supplemental irrigation of rainfed crops can provide dramatic yield responses, and water demand far outstrips supply. (Schemes in northern India utilising pipe systems for this reason are described by Seckler, 1986)

-in regions of poorly yielding and/or poor quality groundwater where abstraction from limited surface water sources during the dry season is strictly controlled. (Observed on pump lift irrigation systems visited in Maharashtra, India)

-where dry season irrigation of short duration high value crops can provide significant cash income. (Gisselquist, 1989, describes these advantages for pipe systems in Tangail, Bangladesh).

In addition to the better distribution efficiencies possible with buried pipe systems, they can provide a more flexible supply, by making redirection of flow within the pipe system to different outlets at short notice, feasible, because of the lower transit time of water in a pipe system compared with an open channel system. Such changes in rate and duration of irrigation, are considered both desirable by Merriam (1987a), and practical by Campbell (1984) when using a buried pipe system for irrigation in intensive high value cropping systems.

The better distribution efficiencies are particularly valuable, in the case of deep groundwater abstraction and high pump lift schemes with their high pumping costs. The limited water supply (both river and fractured groundwater) and high cost of pumping are cited by local irrigation practitioners as reasons for the extensive use of buried pipe systems on central Indian pump lift irrigation schemes (Schemes observed in Maharashtra and Madhya Pradesh, India).

iii) Command Area Topography

While areas of new irrigation development will still allow rational canal layouts to be constructed, improvement of existing irrigation systems and intensive existing settlement and land ownership patterns place constraints on open channel improvements. Command area constraints which are partly resolved by the use of buried pipe systems are discussed below.

Firstly pipe systems allow irrigation of land which may be out of command, under an existing canal distribution system, because of physical obstacles or cross-drainage channels. A pipe system allows driving head to be retained while crossing intermediate areas of lower elevation.

Where areas of high or undulating land are confined to one section of the command, systems involving partial buried pipe networks and open channel systems (which are of lower capital cost than full pipe systems) are seen as attractive solutions. Systems of this type have been constructed in Bangladesh (MMI 1990a) and India (MMP, 1989a), and have received ready acceptance by irrigators.

Pipe systems can also mitigate the delays and costs associated with obtaining land required for an equivalent open channel distribution system. Where land intensities are extremely high, for example in Uttar Pradesh (Kolavalli and Shah, 1989) and Kerala (Campbell 1986), then resistance to new land acquisition can delay implementation.

iv) Origin of Pressure.

Buried pipe systems can be readily adopted in sloping command areas where gravity head is sufficient to overcome pipe friction losses. With slopes in excess of 1%, open channel systems will require frequent drop structures to dissipate excess head. Buried pipe systems can be installed with fewer simpler pressure reducing structures particularly where a semi-closed pipeline system is practical.

Similarly the change to a buried pipe system is attractive where the water source requires pumping (for example with a deep tubewell) and the additional head required to overcome friction losses in the buried pipe system can be attained by the existing pump installation without significantly reducing discharge.

Less attractive are irrigation schemes with existing distribution systems which would require a pumped supply for a buried pipe system, where a gravity open channel system had previously been adequate.

5.3 Selection of the Method of Regulation

5.3.1 Introduction

In this section recommendations are confined to the selection of the method of regulating inflow discharge to buried pipe systems. Definitions and detailed discussion have already been presented in section 3.5.

5.3.2 Open Pipe Systems

In all cases the inflow discharge to open pipe systems must be regulated manually, using either slide gates or valves, if operational spillage at the overflow stands is to be avoided.

Automatic operation can only be achieved by converting the systems to semi-closed with the installation at modest cost of float valves, provided the pipeline can withstand the higher operating pressures.

5.3.3 Gravity Supply Semi-Closed and Closed Pipe Systems

Gravity supply semi-closed and closed pipe systems will be self-regulating provided sufficient water and head is available, and pressure control structures are provided. Outlet discharge will increase up to the limit of the pipe system's capacity.

5.3.4 Pumped Supply Semi-Closed and Closed Pipe Systems

Recommended regulation methods differ for both diesel and electric motor driven pumps.

Diesel Motor Driven Pumps

Because diesel engines should not be stopped and started frequently, regulation is best achieved manually by altering the pump speed and hence discharge to more closely match the irrigation demand.

Electric Motor Driven Pumps

Regulation of electric motor driven pumps will mainly comprise automatic or manual switching of the pump off and on, to achieve a desired water level in a reservoir or tank. Because of the high breakdown rates of automated control systems (Kolavalli and Shah, 1989), backup manual regulation should always be provided.

In both diesel and electric motor driven pump systems, although operation of several outlet valves simultaneously on the pipeline is possible to balance demand discharge and inflow discharge, it cannot be recommended. In the absence of a low pressure flow regulator, flows will fluctuate widely in response to varying outlet pressures.

A little used method of regulating inflow discharge, described by EWUP Fort Collins (1983), is the selection of one or more pumps from a set, to match a widely varying demand. This regulation method is best suited to large irrigation schemes, and can be automated using a flowmeter which senses the demand discharge and switches on suitable pumps accordingly (Labye et al 1988).

5.4 Selection of Operating and Control System

5.4.1 Introduction

As already detailed in section 3.6, the operating and control system combines the method of regulating inflow to the pipe system with the type of control structure at the head of the pipe system. For each of the alternative system choices, the type of buried pipe system best suited to the layout is recommended.

5.4.2 Gravity Supply Systems

Open Pipe Systems with In-line Valve Control

In all open pipe systems the inflow discharge and combined outlet discharge need to be balanced. In all open systems some form of in-line gate or valve control is required to set the inflow discharge. Open pipe systems best suited to this type of operation and control are those supplied by well regulated canals, and constant water level reservoirs, although conversion to semi-closed systems would allow more flexible irrigation scheduling (Merriam 1987a).

Semi Closed and Closed Pipe Systems

In all semi-closed and closed pipe systems, provided the inlet to the pipe system is closed to the atmosphere or extends above the top inlet water level, then the systems will be self-regulating.

In two alternative situations, described below, additional gate structures may be provided at the inlet to the pipe system.

Manual Gate Backup

Firstly a manually operating gate may be installed to allow for shutting of the supply, and to allow the demand discharge to be throttled to below the peak flow capacity of the pipeline.

Automatic Water Level Control

Secondly where the variation in controlling water level at the head of the pipe system is sufficient to result in variations in the pipeline delivery flow rate, a gate or device to maintain a near constant inlet water level to the pipeline may be installed.

Provided water is available, inflow to the pipeline will automatically balance the outlet discharge upto the capacity of the pipe system. Screens and air vents or valves should be provided at the inlet. Selection of the operating and control system most appropriate for gravity supply systems is described in flow chart 5.4.

5.4.3 Pumped Supply Systems

Five alternative operating and control systems are distinguished namely:

-pump connected directly to the pipe network

-pump connected via a head riser pipe to the pipe network
-pressure tower with distribution by bottom valve control
-pressure tower with top water division
-elevated tank supplying separate pipe networks via individual stand pipes

Selection of the most appropriate operating and control system is summarised in flow chart 5.5.

i) Pump connected directly to the pipe network

In all cases manual regulation is used together with air release and pressure relief valves. The sealed nature of the pipe system allows higher flow velocities to be accepted, with the possibility of reducing pipe diameter and a reduction in the pipe cost.

Command areas which slope uphill from the water source are best served by this arrangement, as pressure can be transmitted up to the limit of the low pressure pipe material used.

ii) Pump connected via a head riser pipe to the pipe network

In a similar way to the direct coupled system, this arrangement is suited to systems where the full inflow discharge can be comfortably handled by one irrigator at a time. The presence of a head riser pipe allows low pressure pipe materials to be used without special pressure protection.

iii) Pressure tower with distribution by bottom valve control

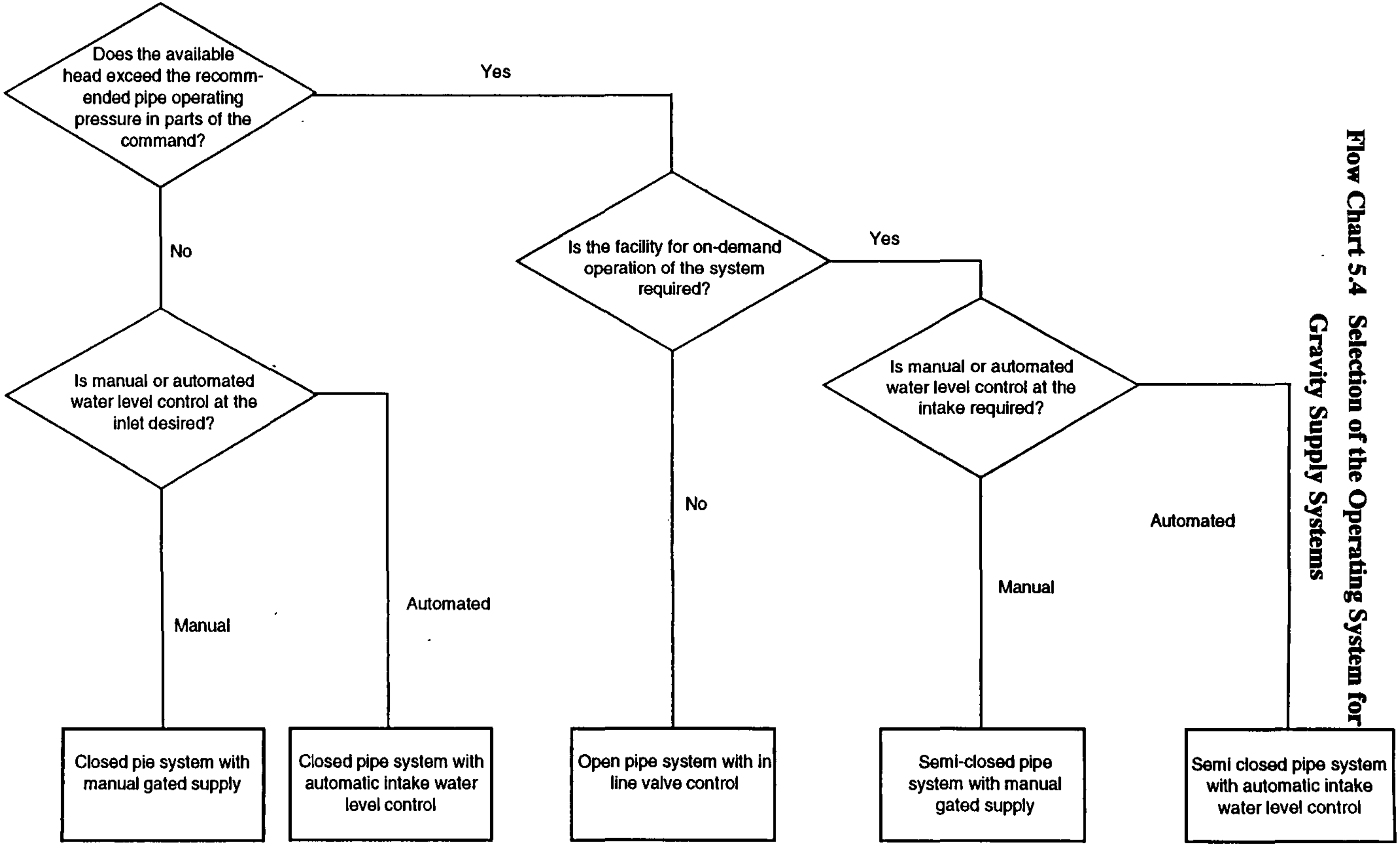
Pipe systems where the water supply is at the centre of the command area, and where the full inflow discharge can be handled by one irrigator at a time, are best suited to this type of operation and control. Where concrete pipe is used, individual pipelines can be closed to reduce the seepage losses during operation of outlets on other pipelines.

The pressure tower is not designed to provide sufficient storage for automatic control of electric pump operation. Although operation of several outlets simultaneously is widely practised, it cannot be recommended because of the variability of outlet discharge under varying operating pressures.

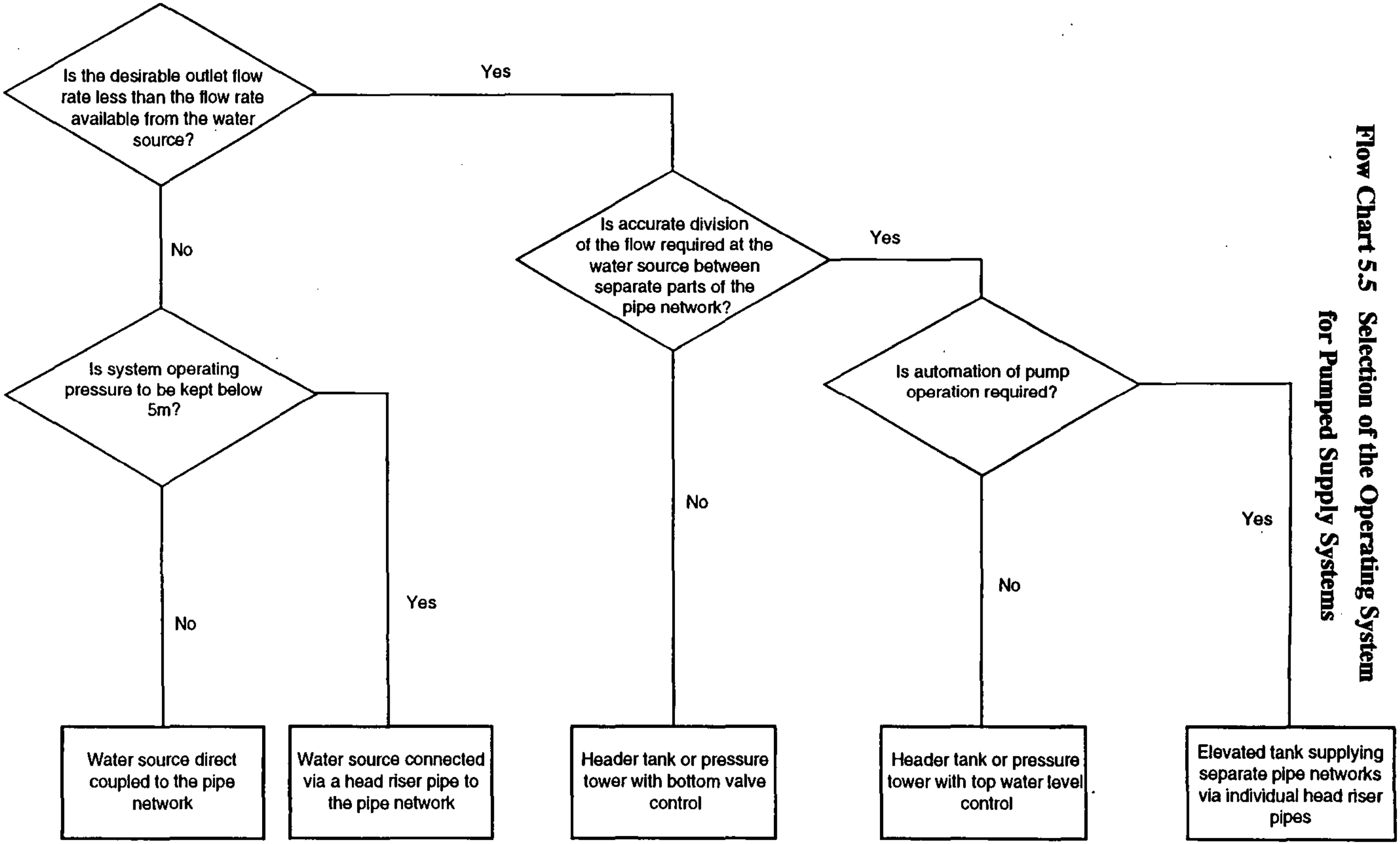
iv) Pressure tower with top water division

Pipe systems with inflow discharges which are greater than one farmer can comfortably use, can be operated using a pressure tower with top water level division to one or more disconnected pipe networks. The pipelines are linked to the pressure tower either by open

Flow Chart 5.4 Selection of the Operating System for Gravity Supply Systems



Flow Chart 5.5 Selection of the Operating System for Pumped Supply Systems



stand pipes or chambers integral to the pressure tower.

As water must rise to the top of the pressure tower before passing to the individual pipe networks, no storage is available, and hence automated regulation of pump inflow is not possible. In all cases manual regulation is recommended, although successful operation will require coordination of demand on all the individual pipe networks.

In-line valves on the pipe networks, or alfalfa valves at the inlets to the pipelines, or stop logs on the weirs are all used to control the division of flow to different pipe networks.

v) Elevated tank supplying separate pipe networks via individual riser pipes

The elevated tank is a modification of the pressure tower, and provides the storage volume required above the maximum driving head to enable automation of electric pump supply. This system is again suited to situations where inflow discharge needs to be split between a number of irrigators.

The system is suited to loop layouts where the reduction in flow, through flow division at the head of the pipe system allows for a reduction in pipe diameter. While automation using probe controls is possible manual backup should be provided.

5.5 Selection of the Pipe Layout

The recommendations on pipe layout selection are based on an analysis of idealised layouts, summarised in table 5.2 and the field experience of irrigation practitioners in south Asia.

Issues important in the selection between a loop or branching layout include the type of pipe material chosen, the required outlet density and nature of the command area, and some of these issues are summarised in flow chart 5.6.

While all closed pipe systems can utilise loop pipelines, open or semi-closed systems can only include loops, as part of a closed pipe section, ie. where both ends of the loop close on a single section of pipe.

i) Branch.

Pipelines using pipe materials which are prone to frequent leakage, should use branching layouts because parts of the system can be easily isolated when not in use with little

Table 5.2 Summary of Pipe Length and Area Data for Idealised Layouts

Layout No	Position DTW	Shape	FCL = 50m Pipe Length	Area ha	L/A	FCL = 100 m Pipe Length	Area (ha)	L/A	FCL = 150 m Pipe Length	Area (ha)	L/A
1.	Centre	Circular	1160	12.6	92	2320	50.2	46.2	3480	113	30.8
2.	Centre	Circular	1060	12.6	84	2120	50.2	42.2	3180	113	28.1
3.	Rim	Circular	1405	12.6	111.5	2810	50.2	56	4215	113	37.3
4.	Rim	Circular	1235	12.6	98	2470	50.2	49.2	3705	113	32.8
5.	Centre	Circular	3075	28.2	109	6150	113	54.4	9225	254	36.3
6.	Centre	Circular	2585	28.2	91.7	5170	113	45.7	7755	254	30.5
7.	Centre	Square	1700	16	106	3400	64	53.1	5100	144	35.4
8.	Centre	Square	1100	9	122	2200	36	61.1	3300	81	40.7
9.	Rim	Square	1000	9	111	2000	36	55.5	3000	81	37
10.	Rim	Square	1700	16	106	3400	64	53.1	5100	144	35.4
11.	Centre	Rectangular	900	8	112.5	1800	32	56.3	2700	72	37.5
12.	Centre	Rectangular	700	8	87.5	1400	32	43.8	2100	72	29.2
13.	Centre	Rectangular	2250	18	125	4500	72	62.5	6750	162	41.6
14.	Centre	Rectangular	1850	18	103	3700	72	51.4	5550	162	34.2
15.	Rim	Rectangular	950	8	119	1900	32	59.4	2850	72	39.6
16.	Rim	Rectangular	800	8	100	1600	32	50	2400	72	33.3
17.	Rim	Rectangular	1950	18	108.3	3900	72	54.2	5850	162	36.1
18.	Rim	Rectangular	1750	18	97.2	3500	72	48.6	5250	162	32.4

disruption to the operation of the system, and a significant saving in water lost. Maintenance and leakage repair is then facilitated by the ability to isolate particular parts of the system.

Because it does not appear possible to build pipe systems, from nonreinforced concrete pipe, which do not leak, concrete pipe systems are best built with branching layouts. The advantage with loop layouts, of pipe size reduction, as explained below, is of only marginal benefit with concrete pipe systems. Because the cost saving in providing smaller diameter concrete pipes is generally insufficient to cover the cost of the extra length of pipe required to close the loop, branching layouts are nearly always chosen.

The analysis of standard pipe layouts, indicates that for the same command area, typically a branching pipe system will require less pipe than a loop system, to achieve a similar density of outlets and maximum field channel distance (refer to section 6.3.2).

When designing layouts, experience suggests it is easier, with a branching layout, to achieve an even density of outlets with acceptable distances from outlet to field plots particularly where the command area is fragmented or irregular in shape (MMP 1989a).

ii) Loop.

Because loop systems split the flow between the two arms of the loop, a pipe diameter reduction is possible with corresponding lowering of system cost.

Because sections of a loop pipeline cannot be easily isolated without reducing the system capacity or complicating system operation, it is preferable that the rate of leakage from the pipe is low. Where the loop remains full of water, flow will occur from the open outlet almost immediately on valve opening and the water supply being actuated. Unplasticised PVC and asbestos cement pipe systems if well built have very low seepage losses and have both been used for loop layouts (MMP 1989c, Cunningham 1984, Plusje 1981 and WAPDA 1989).

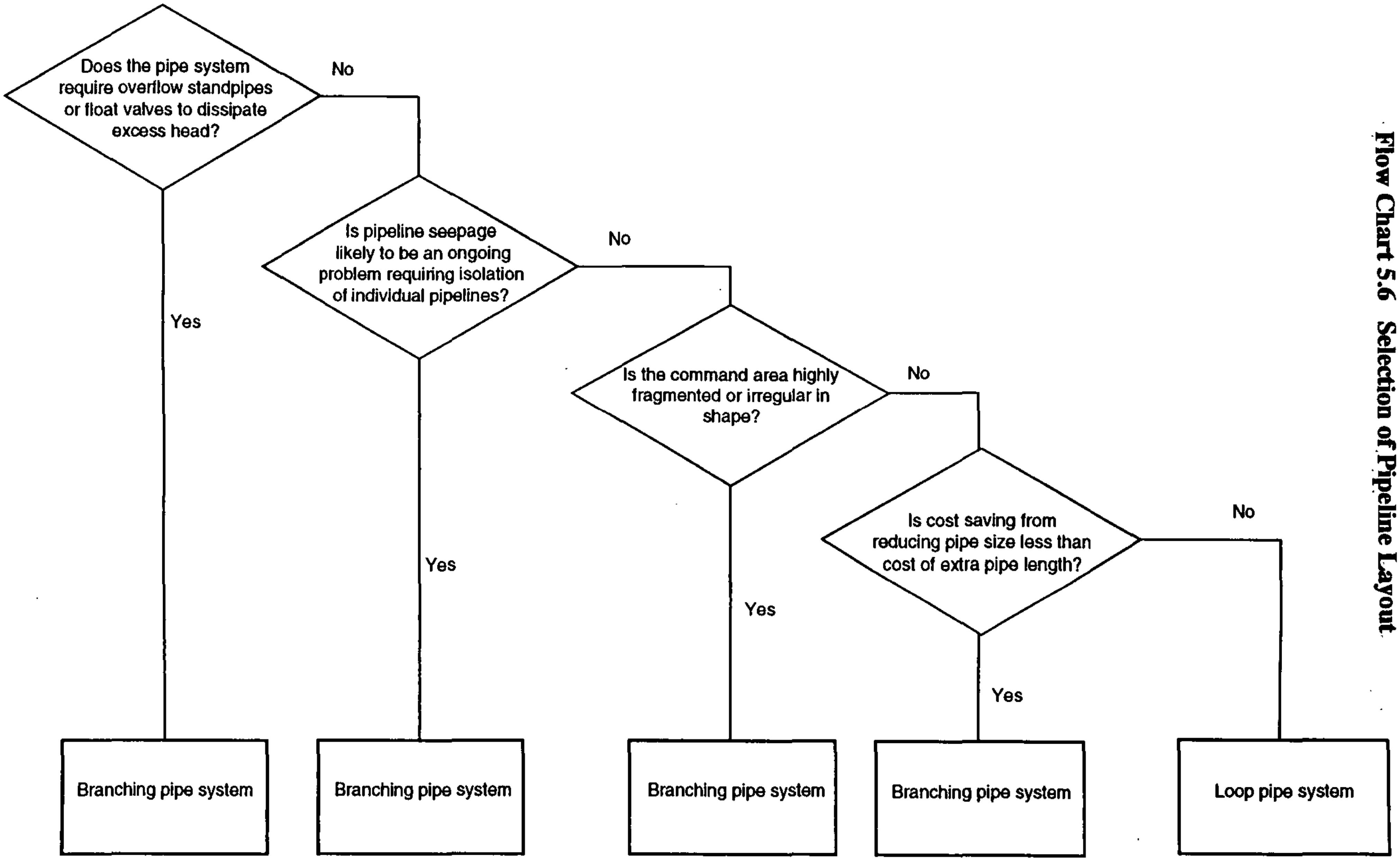
5.6 Pipe Material Selection

5.6.1 Introduction

Pipe materials which have been used for low pressure pipe distribution systems include:

-nonreinforced concrete pipe; used in USA (Pimley and Fischer 1990), Sri Lanka (Merriam 1985), China (Dept. Sci. Tech. China, 1990), India (Gisselquist 1986), Bangladesh (MMP 1989a) and southern France (Galand 1990). (see photo plate 2.1)

Flow Chart 5.6 Selection of Pipeline Layout



-cast-in-place concrete pipe; used in China (Dept. Sci. Tech. China, 1990) and USA (ACI 1980).

-nonpressure class reinforced concrete pipe; used in central India (observed in Maharashtra).

-nonpressure class asbestos cement pipe; used in Bangladesh (Plusje 1981), Pakistan (WAPDA 1989) and Egypt (EWUP Fort Collins 1983).

-rigid uPVC pipe in pressure classes from 2.5 to 5 bar (25 to 50 m head); used in Uttar Pradesh, India (Cunningham 1984); Maharashtra and Madhya Pradesh, India (observed, van Bentum); east Java, Indonesia (Republic of Indonesia, 1990); Thailand (HHP/HTS 1988); southern Nepal (GDC 1987): southern France (Galand 1990) and southern Spain. (see photo plate 2.1)

-thin walled corrugated smooth bore spirally wound uPVC pipe; used in central India (Jain, Ribloc 1991), eastern China (Dept. Sci. Tech. China 1990), Australia and southern Spain (Ribloc Australia, 1991). (see photo plate 2.1)

-thin walled buried polythene hose; used in western China (Chengzhi 1988).

Apart from the differences in transit efficiency between different pipe materials already described, important issues influencing selection of the pipe material, which are discussed in more detail below, and summarised in flow chart 5.7 include:

i) Material suitability under the prevailing physical conditions. This includes pipe flexibility under soil settlement and movement, and resistance to aggressive soil conditions.

ii) For situations where seepage losses are to be minimised, for example where a loop layout is to be used, then uPVC pipe is often chosen despite its generally higher cost.

iii) The installed cost of the final pipeline. To compare the pipe materials on an equivalent basis any cost comparison needs to consider the total cost of construction including transportation, installation, material and maintenance costs.

iv) The ease of pipeline construction. Where pipe materials have adequate physical properties and comparable installed cost, consideration needs to be given to the ease with which the particular pipe system can be successfully built to a satisfactory standard given the resources available.

5.6.2 Physical Suitability

i) Pipe Flexibility.

General

Where pipelines are built on earth subgrade, and backfilled by hand with in-situ material, some settlement of the pipeline and backfill material must be expected.

Koluvek (1970) highlights problems in soils, which are subject to cycles of movement due to changes in temperature and moisture, as this can lead to the disruption of joints, and on occasion pipes, in rigid pipe materials like non-reinforced concrete pipe. This would apply particularly to organic soils and those with a high proportion of expansive clay, such as montmorillonite.

Even in non-organic soils, work by Rashid et al (1992), provided evidence that significant numbers of leaks continued to occur after initial construction and testing, and it is possible that soil settlement contributed to the pattern of continuing pipeline leakage.

Another though infrequent occurrence is the problem of frost heave with shallow pipe embedment depths where very cold temperatures occur. Bealey (1987) mentions this as a problem for the durability of concrete pipe, though the relative importance of frost heave in irrigated areas is not known.

Although leak repair, for non-reinforced concrete pipelines, can be relatively inexpensive (Gisselquist, 1989), it is inconvenient and must be considered a disadvantage where it continues to be required. While uPVC pipe materials are certainly more flexible, current manufacturer's recommendations (Jain 1989, HPPA 1989) regarding application and installation, are very conservative and do not as yet cover low pressure applications.

Recommended strategies to help overcome these problem soil situations are discussed below and include:

-the selection of a more flexible pipe material such as uPVC plastic or high density polyethylene in problem areas.
-ensuring pipe is bedded below any problem soil horizons.
-provide backfill material, such as a graded gravel which protects the pipe from these soil movements.

-provide for the early diagnosis and timely repair of pipeline leaks as they occur.

Flexible Plastic Pipe Materials

Flexible pipe materials by allowing a controlled amount of deformation enable a considerable proportion of the total external pipe load to be transferred to the surrounding soil (WRC 1986). Plastic pipes are able to adjust to changes in soil loading with time as they redistribute stresses to the adjacent soil. The degree of load transfer depends significantly on the nature and compaction of the backfill and surrounding soil (WRC 1986).

Design for flexible plastic pipes in irrigation applications is based largely on the calculation of deformations or deflections of the pipe under soil and live loads and containing these within permitted limits (Järvenkylä 1988, Gumbel 1982, and WRC 1986). Although there is considerable agreement on the method of calculating deflection under load, there is also considerable divergence regarding the deflection limits allowable (Järvenkylä 1988, and WRC 1986). There is no evidence to suggest that the higher long term deformation limits accepted in other European countries results in a higher incidence of pipe failure (Walton and Elzink 1988). To the contrary Walton and Elzink (1988) suggest that current UK specifications include a very high factor of safety. UK uPVC pipe manufacturers specify that vertical deflection should not exceed 6% in the long term (50 years), though as in practice most of the deformation occurs within the first 2 years, this can be used as the point in time at which to assess actual field measured deflection (WRC 1986). Actual pipe deflection for pipelines installed for periods ranging from 14 to 20 years, have been verified as being within allowable deflection limits (Walton and Elzink 1988).

If design were modified to allow much greater in-situ deflection, then specifications for the installation and backfilling of thin walled uPVC pipe materials, could be relaxed considerably, with a possible reduction in the system cost. However in the absence of agreement, to quote conservative design standards, for both short and long term deflections (Jain 1991, and HPPA 1989).

ii) Pipe Corrosion

Bealey (1987) concludes that aggressive soil conditions severe enough to result in durability problems for concrete pipe are quite rare. He considers that it is really only of concern for concrete pipe materials, as plastic pipes are generally suitable for all irrigation water qualities normally encountered. Bealey (1987) notes that only particular waste waters when used for irrigation could present corrosion problems for concrete pipe used in irrigation.

Aggressive acidic soil or groundwater conditions seldom occur naturally and even then acid in contact with concrete pipe is neutralised and generally results in a neutral zone around the pipe (Bealey 1987). Continued attack from acidic groundwater flow is only likely in some landfill sites and mining situations, when it may also present a problem for thin walled plastic pipe materials (Jain 1991 and Bealey 1987).

The American Society of Agricultural Engineers (1989) highlights the problem of high sulphate soils in corroding concrete pipe. High sulphate salt concentrations are typical in some of the gypsum rich soils of the dry western states of the USA and some parts of the Middle East.

Recommendations from ASAE S261.7 (1989), suggest that only where water soluble sulphate levels are less than 0.1% should standard concrete pipe be used. In situations where water soluble sulphate levels are between 0.2% and 1%, the use of special sulphate resistant cement, is suggested. For higher sulphate concentration soils, there appears little alternative to the use of an alternative pipe material to concrete (ASAE S261.7 1989). The criteria and solutions recommended are summarised in flow chart 5.8.

5.6.3 Loop Layout or Requirement for Low Seepage Losses

Where because of the size of the command area and the arrangement of the outlets, a loop layout is chosen, then concrete pipe with its persistent leakage problem, must be considered unsuitable. Reasons for advocating the use of branching pipe layouts for concrete pipe have been discussed in section 5.5.

Loop systems which have been built, have used either uPVC pipe (Cunningham 1986, MMP 1989a and IDTP 1989) or asbestos cement pipe (WAPDA 1989, and Plusje 1981). Experience in India and Bangladesh suggests that uPVC pipe systems with very low seepage can be successfully built.

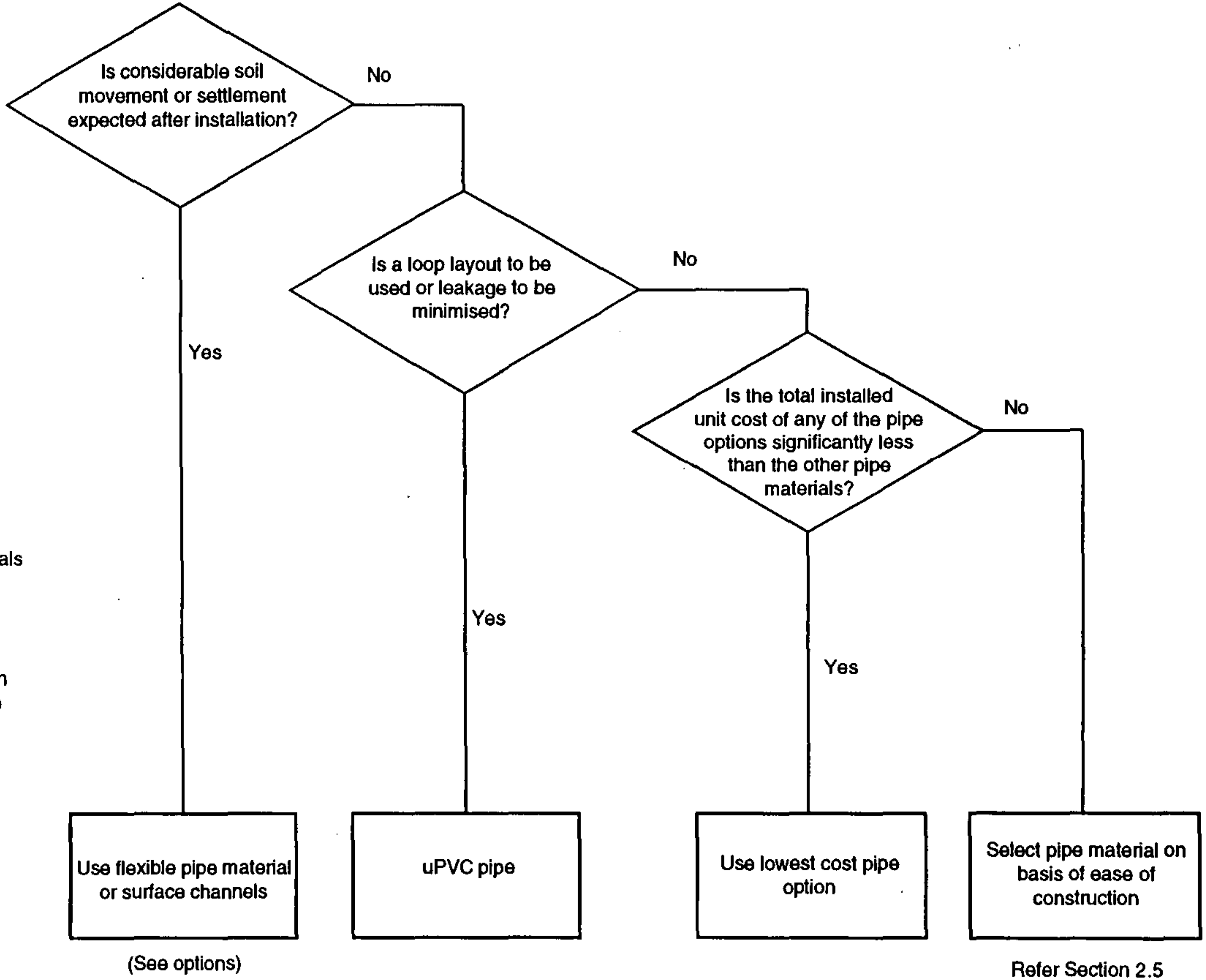
5.6.4 Installed Cost of Pipeline

When considering the cost of alternative pipe materials it is important to consider all factors which contribute to the cost of a unit length of installed pipe.

A full comparison should include:

-pipe material cost
-pipe manufacturing cost
-transportation cost including breakage
-installation cost

Flow Chart 5.7 Pipe Material Selection



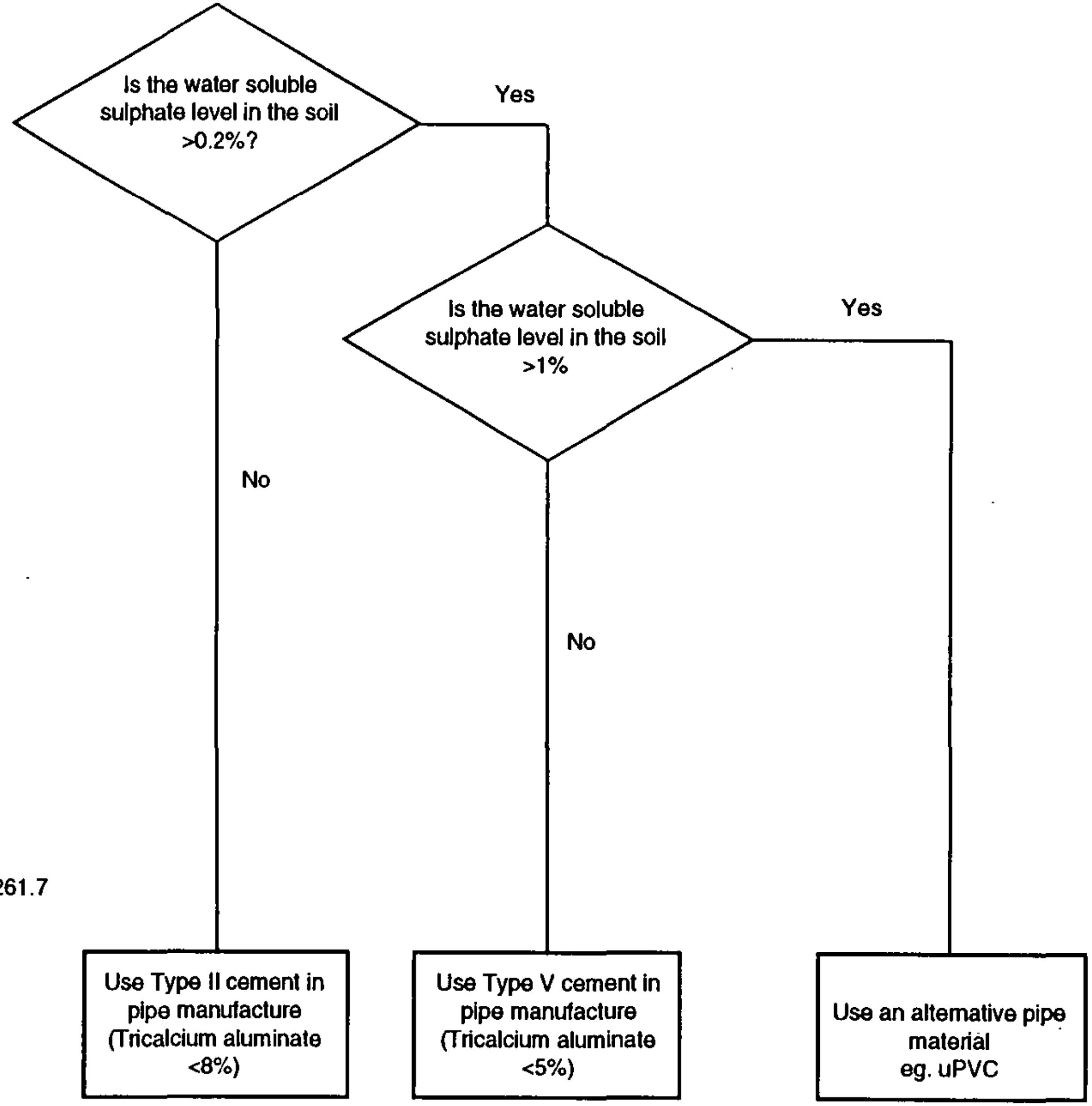
Options:

- polythene pipe
- uPVC pipe materials
- surface channels

Note:

For concrete pipe in sulphate soils - see Appendix B

Flow Chart 5.8 Selection of Concrete Pipe in Sulphate Soils



Source:
ASAE Standard S261.7
Sept 1989

-pipe life where it can be estimated with some confidence
-implications of different distribution efficiencies
-differences in recurrent maintenance costs
-implications of the proportion of imported and local material content

Although the optimum choice of pipe material will depend on local availability and be very area specific, a number of general recommendations can be made. The findings described below apply to pipe systems in south Asia and are based on cost information collected and presented in chapter 7.

1. In all situations studied, uPVC pipe systems are considerably more expensive than nonreinforced concrete pipe, where both are available, over pipe diameters ranging from 150 to 300 mm (MMP 1989a and Gisselquist, 1986), even where the lower roughness of uPVC pipe is taken into account.

2. More recent thin walled uPVC pipe materials, appear competitive with nonreinforced concrete pipe in sizes larger than 300 mm, where transportation is a significant portion of the cost (Jain 1989).

3. Nonreinforced concrete pipes will be competitive in price where local manufacture keeps transportation distances small, and an adequate quality of construction and jointing can be achieved.

5.6.5 Ease of Construction

Consideration must be given to the ease with which a pipe system of adequate quality can be built. Using observations and information from local irrigation practitioners on the buried pipe systems evaluated in south Asia, the ranking, illustrated below, of the low pressure pipe materials, was developed based on an assessment of the ease of installation.

This takes into account the amount of supervision and quality control required to achieve a system with acceptable performance. Only pipe materials identified as being in use for low pressure irrigation are included.

Easiest

-rigid uPVC spigot socket cement-jointed pipe
-thin walled uPVC pipe materials
-asbestos cement pipe
-nonreinforced concrete pipe with tongue and groove joint

-nonreinforced concrete pipe with plane ends

-cast-in-place nonreinforced concrete pipe

Most difficult

Where the cost and likely performance of various pipe material options is similar, then easier installation can lead to savings in the cost of supervision, reduced disruption to existing agricultural operations, and savings in the cost of repairing poor quality work at a later date.

5.7 Selection of the Mode of Operation

Four different modes of operation available on most buried pipe systems are described in detail in section 3.7. Though the final choice of the mode of operation will be that of the irrigators, it will depend on the degree of cooperation and the pattern of irrigation demand at different times of the year. Experience from existing pipe systems suggests that each mode of operation is suited best to particular situations.

Mode A. One irrigator takes the full inflow discharge at one outlet.

For any pipe system where the full inflow discharge can be handled efficiently by the irrigator, this mode of operation should be used. Typically small buried pipe systems where the pump is directly connected or connected via a head riser pipe, should be operated in this way.

All the remaining modes of operation relate to systems where the inflow discharge is greater than the optimum field discharge.

Mode B. The full inflow discharge is delivered to one outlet, where it is shared between two or more farmers by means of an outlet distribution structure.

This mode of operation while acceptable because of the equity of supply provided, requires that the outlet incorporate a flow division structure to facilitate flow division. Experience in Bangladesh suggests that problems can be encountered where cooperation among the irrigators is weak, and during low demand periods when it is difficult to coordinate requirements for two irrigators at one outlet to both take water simultaneously. This often results in irrigation by one irrigator with consequent overtopping of earthen field channels and high field distribution losses.

Mode C. In this case the inflow discharge is divided at the water source between two or more separate pipe networks.

This method is by far the most preferable and reduces the degree of cooperation necessary to the coordination of irrigation water use by at least one farmer on each of the pipe networks operated. In situations where four pipe networks are supplied from the same source, water can be delivered to two or three networks without sacrificing the principle of equity. Flow division at the head of the pipe system does not guarantee equity, as differences in leakage rates over varying pipeline lengths can substantially reduce the outlet discharge (MMI 1990b).

Mode D. The inflow discharge is shared between several outlets on the same pipe network.

Although all pipe systems can be operated in this way, this mode of operation cannot be recommended because of the uncertainty regarding the resulting outlet discharges, with variable outlet operating pressures.

5.8 Selection of System Components

5.8.1 Introduction

All buried pipe systems require a number of basic structures or components for the control and operation of the system, though these are generally fewer in number than for equivalent open channel systems.

Structures which are more elaborate than necessary increase the cost of the system and require more maintenance. In many cases a little modification is all that is necessary for a structure to assume several additional functions. Such modifications may include ensuring a minimum dimension is adhered to, as for example in the case of open stand pipes in water hammer protection, or that an outlet distribution structure incorporates a v-notch or broad crested weir for measurement of outlet discharge.

The selection of buried pipe system structures is necessarily based on an understanding of their function. The structures required will be partly determined by the selections already made for regulating inflow discharge and for the operation and control of the system.

While in section 3.4 definitions for each of the component structures were provided, the following section distinguishes between essential and additional functions performed by each structure. References are also given to figures illustrating standard designs used on buried pipe systems in current operation.

Recommendations on specific aspects of design and construction of pipe system components are detailed by van Bentum and Smout (1992).

5.8.2 Pumpstand and Header Tank

It is usually of a diameter sufficient to provide some limited buffer storage, significant reduction in water velocity and allow for fitting of valves on the inlets to the pipes. Structures can be divided into two groups, firstly those where water level is forced to rise above the pump discharge pipe and secondly those where the pump or water source discharges freely to atmosphere.

Structures in the first group include pressure towers, and head riser pipes, with low head pumpstands and elevated tanks included in the second.

i) Pressure Tower

Essential

-connect the water source to the buried pipe network
-provide the driving head for flow through the pipe network
-where there is more than one line distribute the flow to different sections of the pipe system
-act as an air vent and surge riser for water hammer control

Additional

-provide for flow measurement for the entire or individual parts of the scheme
-provide for accurate flow division between two or more distinct parts of the command
-allow for automation of pump operation using probes or float switches
-function as a sand trap
-provide some limited buffer storage to assist in inflow regulation
-allow for the fitting of valves on the inlets to the pipelines

A design for a typical pressure tower connection as built in Bangladesh, with two pipelines and an outlet at the pumphouse is illustrated in figure 5.1.

ii) Head Riser Pipe

Essential

-connect the water source to the buried pipe network

-provide the gravity head to drive the flow through the pipe network
-act to relieve pressure so that the rated pipe operating pressure is not exceeded

Additional
-provide for some limited buffer storage

iii) Low Head Pumpstand

Essential
-connect the water source to the buried pipe network
-where there is more than one pipeline, distributes the flow to different sections of the pipe system
-act as an air vent and surge riser for sudden valve closure on nearby outlets

Additional
-function as a sand trap
-provide for some limited buffer storage
-allow for the fitting of valves on the inlet to the individual pipelines

A typical low head pumpstand is illustrated in cross-section in figure 5.2.

iv) Elevated Tank

Essential
-connect the water source to the buried pipe network
-provide the driving head for flow through the pipe network
-where there is more than one line distribute the flow to different sections of the pipe system

Additional
-provide for flow measurement for the entire or individual parts of the scheme
-provide for accurate flow division between two or more distinct parts of the command
-allow for automation of pump operation using probes or float switches
-function as a sand trap

5.8.3 Stand Pipe Structures

i) Overflow Stand.

Essential
-dissipate excess head in open pipe systems by allowing water to fall over an internal baffle

Additional

-prevent pipelines which are higher in elevation than the pump discharge, from emptying completely during periods when they are not operating

-provide for the controlled release of trapped air

-serve to reflect pressure waves during water hammer events

-function as a sand trap

A typical overflow stand pipe is illustrated in figure 5.3.

ii) Float Valve Stand.

Essential

-to provide a housing for the float valve which dissipates excess head in a semi-closed pipe system

-to absorb flow momentum during changes in outlet flows on the pipeline

-to prevent operational spillage when supply exceeds demand and allow demand to be sensed at the inlet to the pipe system

Additional

-provide for the controlled release of trapped air

-serve to reflect pressure waves during water hammer events

-enable automatic control of the water supply to the pipe system

A typical float valve stand is illustrated in cross-section in figure 5.4.

iii) Gate Stand.

Essential

-to house gates to control the flow of water at a branch in the pipe network

Additional

-to provide for the controlled release of trapped air

-serve to reflect pressure waves during water hammer events

A cross-section of a typical gate stand is illustrated in figure 5.5.

(iv) Surge Riser

Essential

-acts as an open stand for the reflection of pressure waves developed during water hammer events

Additional

-allow for the controlled release of air which becomes trapped in the system without the loss of excessive amounts of water

The design of a typical surge riser as built in Bangladesh is illustrated in figure 5.6.

5.8.4 Air Vents or Valves

i) Open Vents

Essential

-allow for the controlled release of air which becomes trapped in the system without the loss of excessive amounts of water

Additional

-acts as an open stand for the reflection of pressure waves developed during water hammer events

A typical air vent design as installed on low pressure systems in the U.S.A. is illustrated in figure 5.7.

ii) Air Valve

Essential

-allow for the controlled release of air which becomes trapped in the system without the loss of excessive amounts of water where the use of an open vent is not practical.

5.8.5 Riser

Essential

-convey water from the buried pipeline to the outlet valve at the surface where it can be released if required.

A riser pipe and alfalfa valve as built in Bangladesh are illustrated in figure 5.8.

5.8.6 Outlet Valve

Essential

-deliver water from the buried pipe system at an adequate head for the field distribution system to be used

Additional

-allow the fitting of a portable hydrant for distribution of water by smooth or gated surface pipe

-allow the use of a flexible rubber hose for infield irrigation distribution

Various alternative designs of outlet valves are illustrated in figures 5.9 and 5.10.

5.8.7 Hydrant

Essential

-allow for the connection of the outlet to surface pipe or hose for in-field distribution

Two alternative designs of hydrants are detailed in figure 5.10.

5.8.8 Outlet Distribution Structure

Essential

-allow the flow to be directed and distributed to one or more farmer's field channels

-protect the surrounding area from scouring due to high flow velocities and uncontrolled discharge

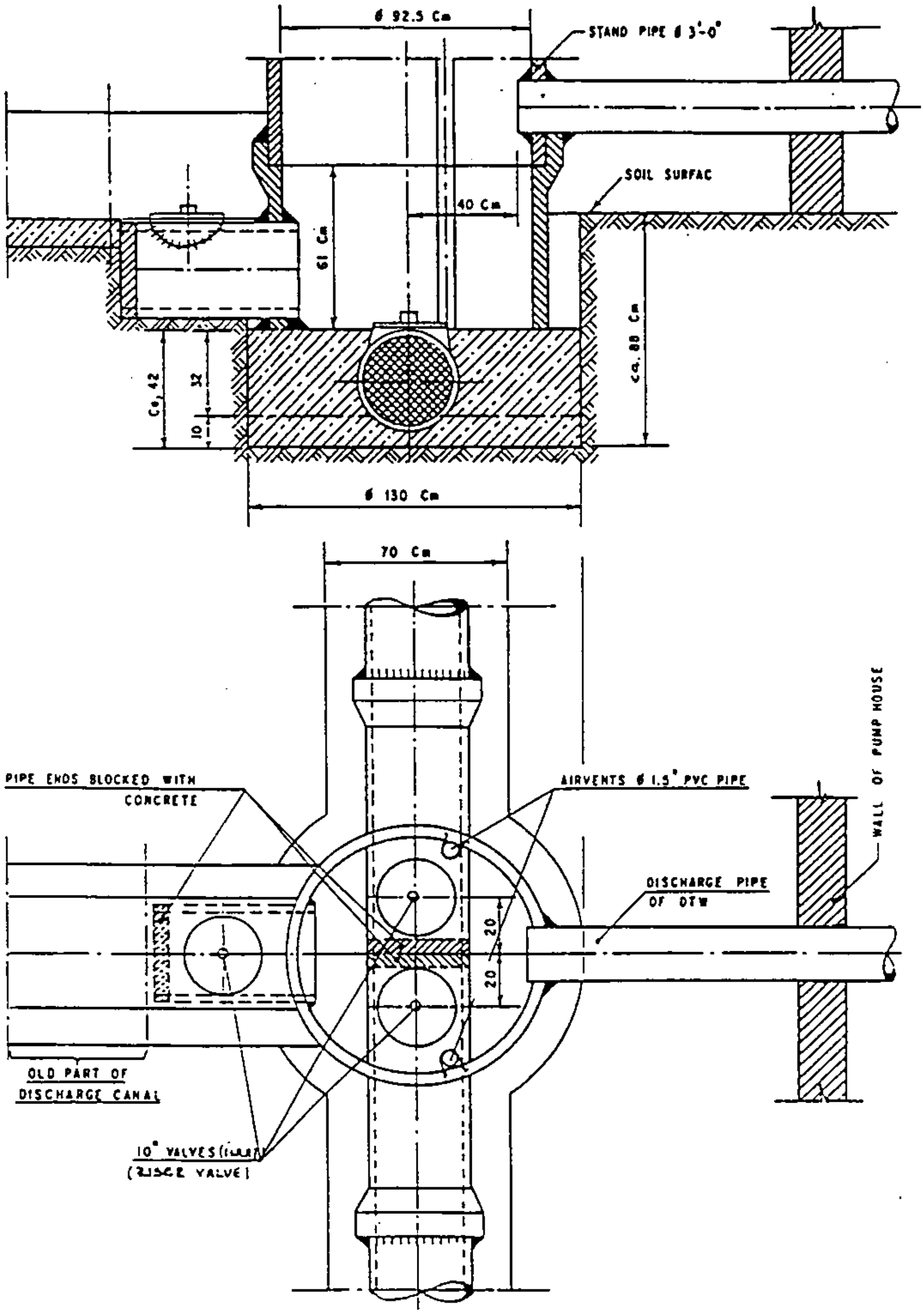
Additional

-discourage physical tampering with the outlet, valve and riser

-provide for accurate flow division between one or more in-field channels

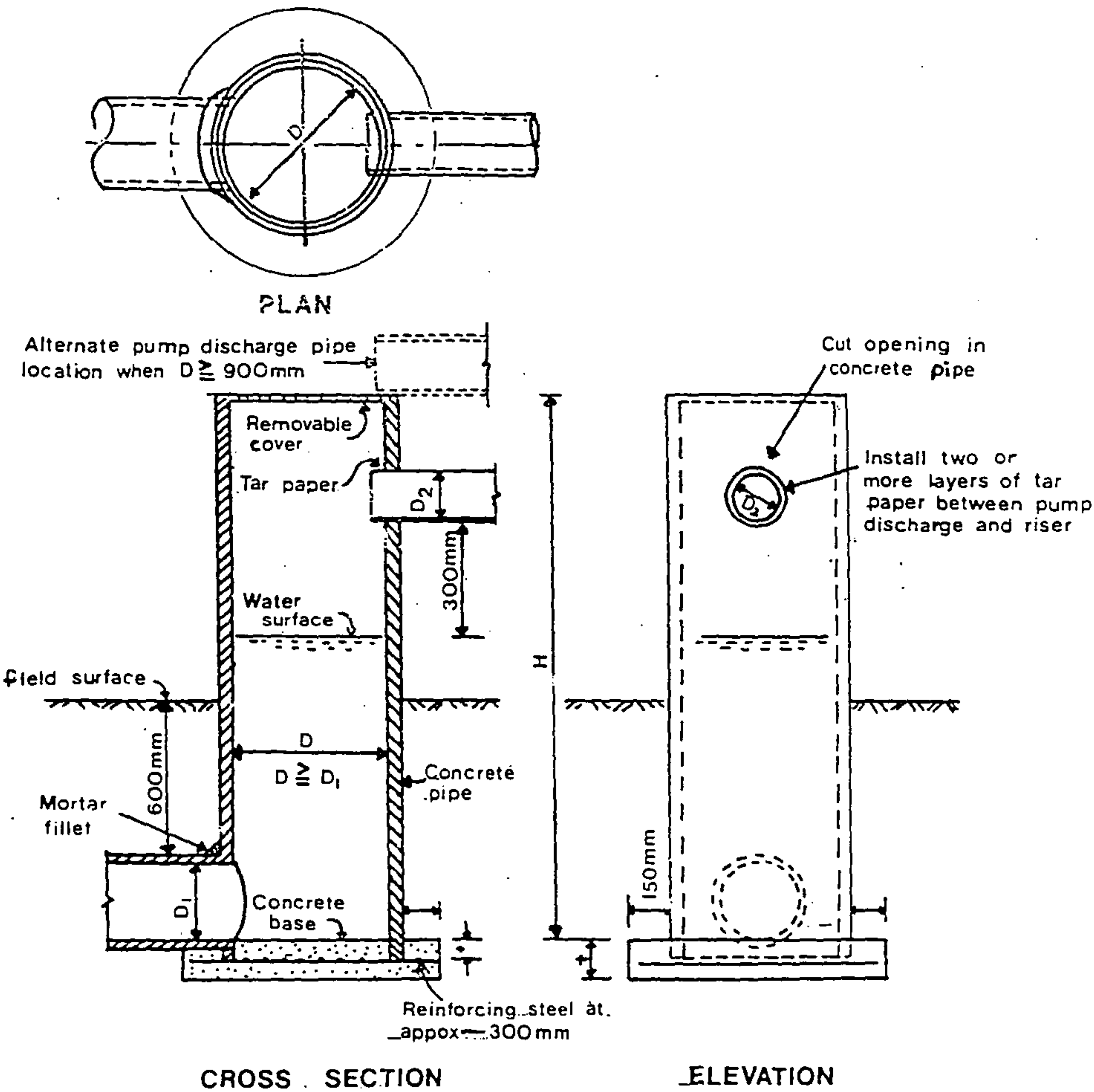
-provide for the measurement of the outlet flow

Figure 5.1 Bangladesh Pressure Tower Connection



Source: Georgi (1989) TADP

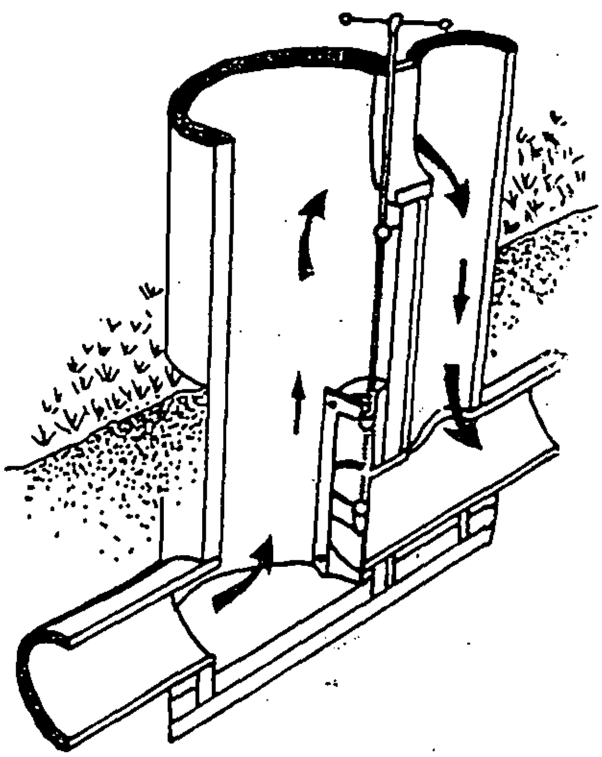
Figure 5.2 Low Head Pumpstand



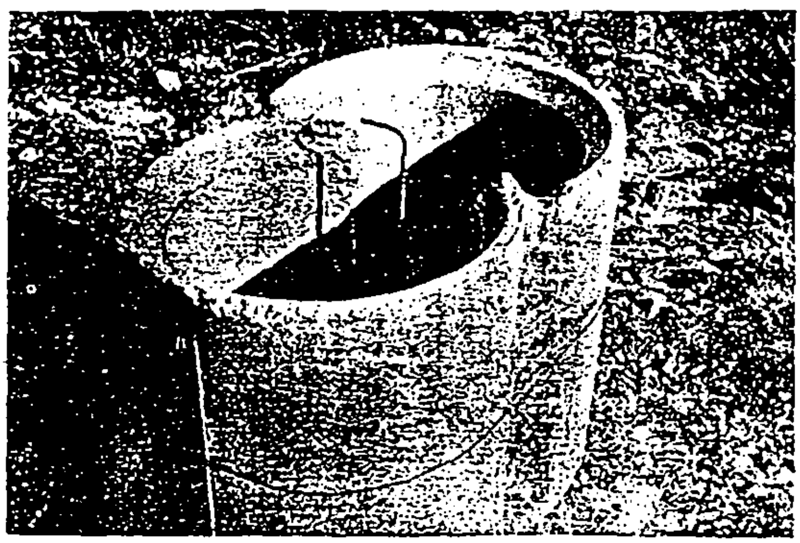
Source US SCS (1967)

Figure 5.3 Overflow Stand Pipe

Source: US SCS (1967)

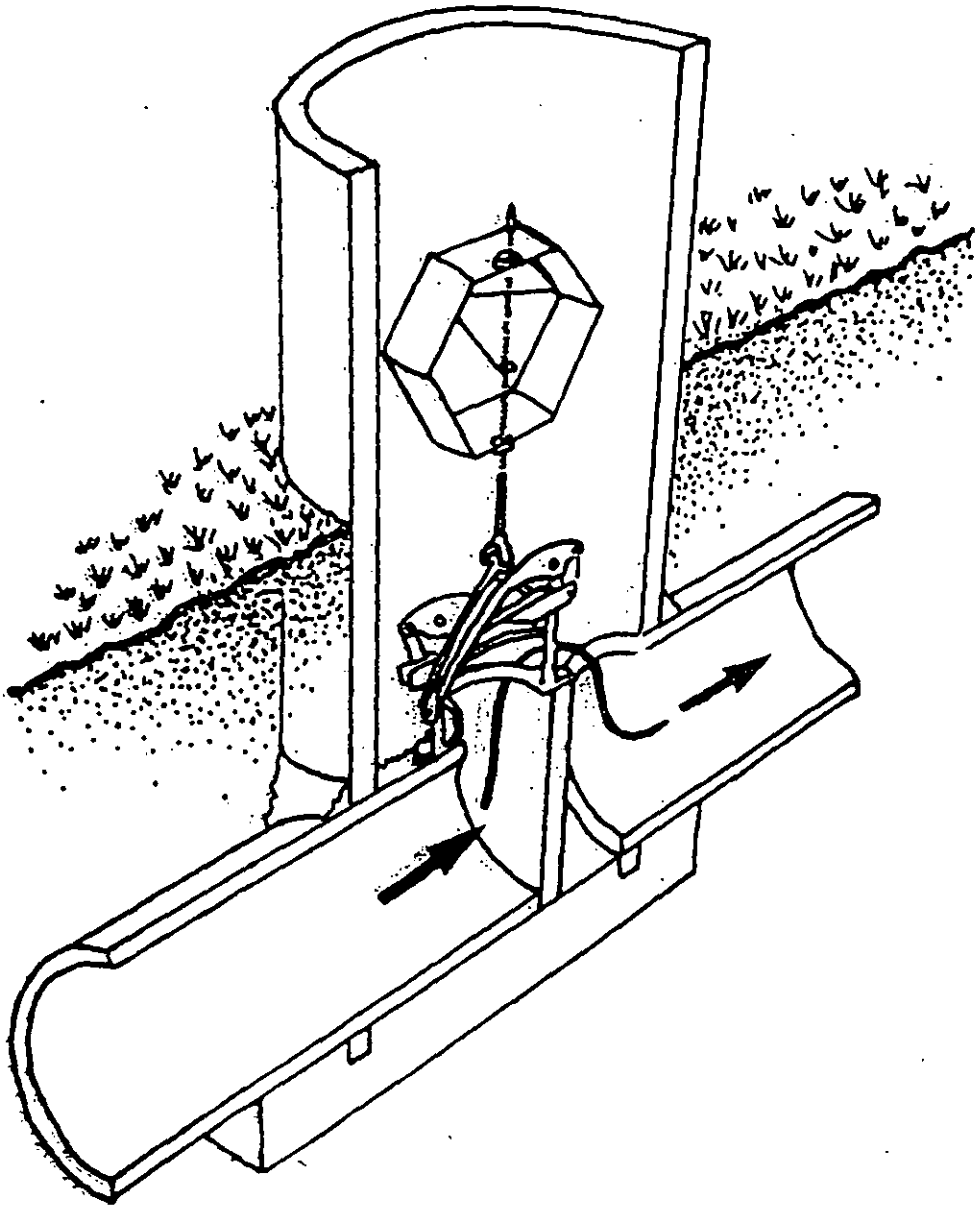


Section of an Overflow Stand



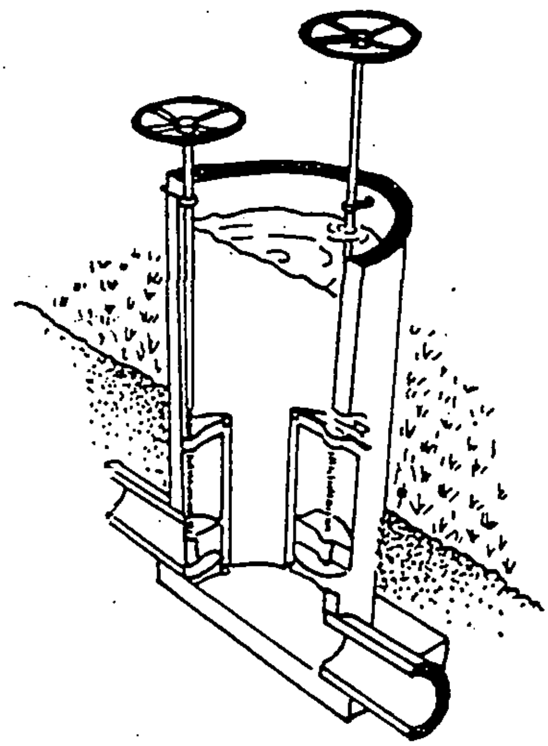
View of a Concrete Overflow Stand

Figure 5.4 Float Valve and Stand



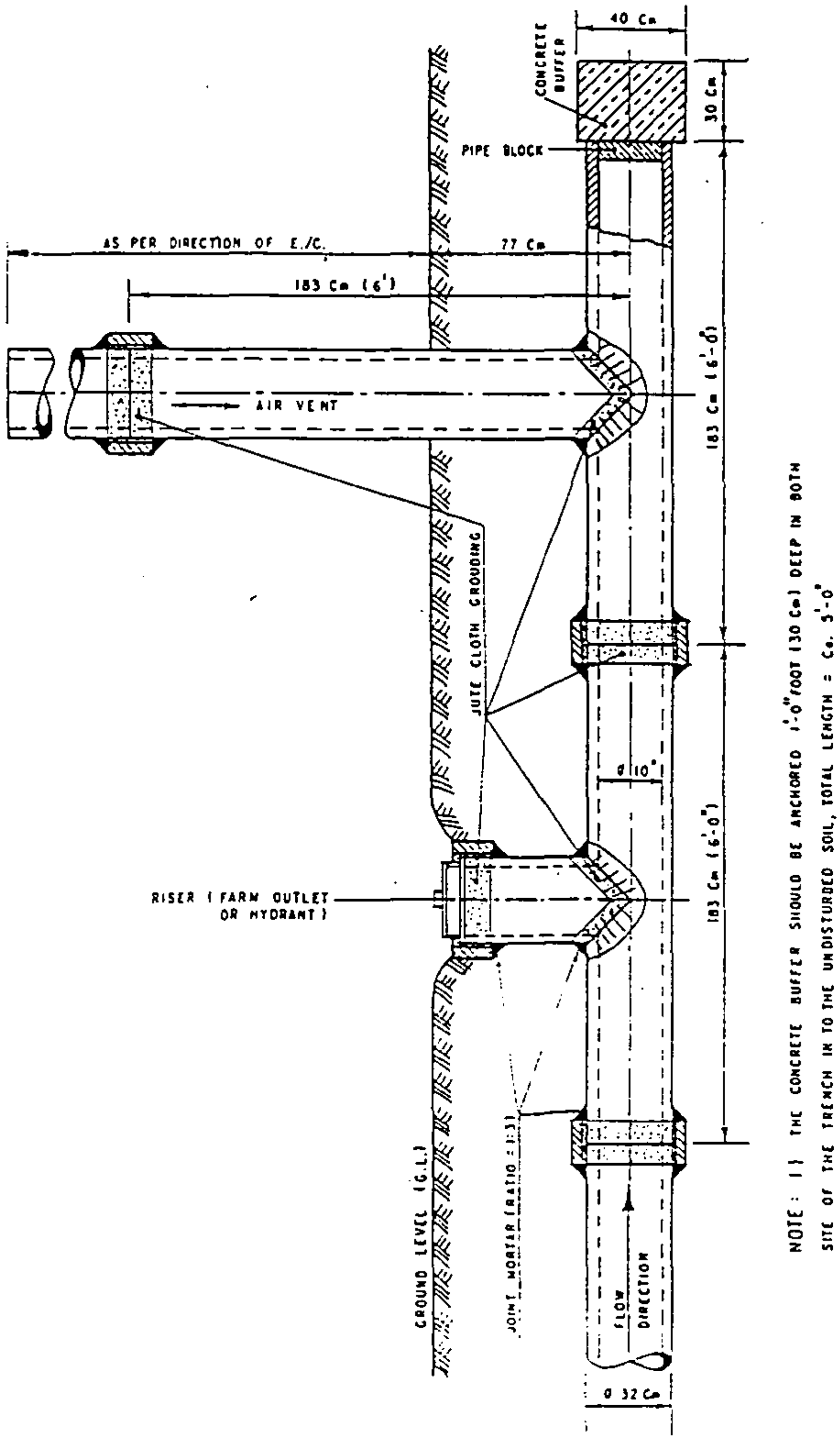
Source: US SCS (1967)

Figure 5.5 Gate Stand



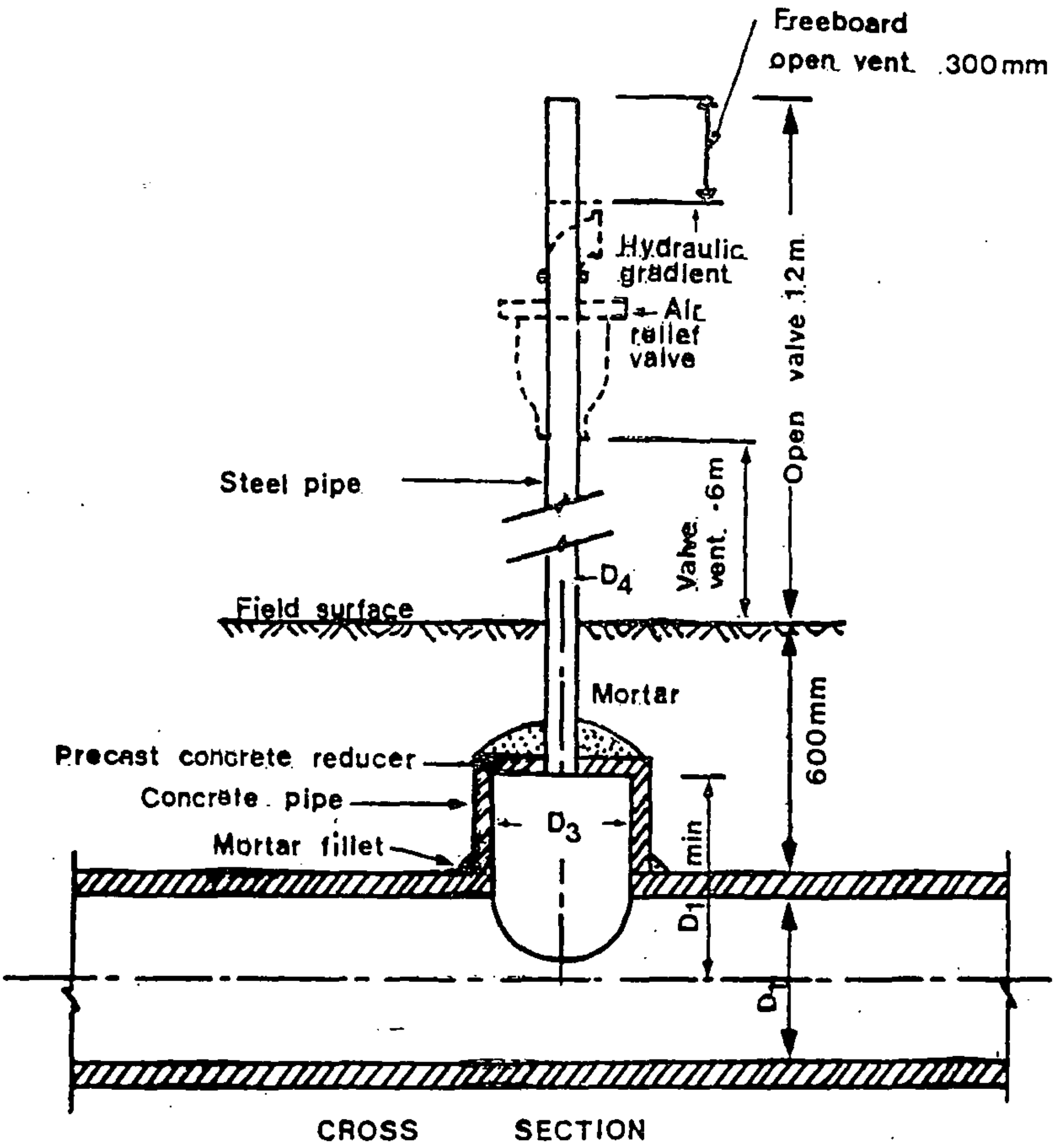
Source: US SCS (1967)

Figure 5.6 Air Vent/Surge Riser (Bangladesh Model)



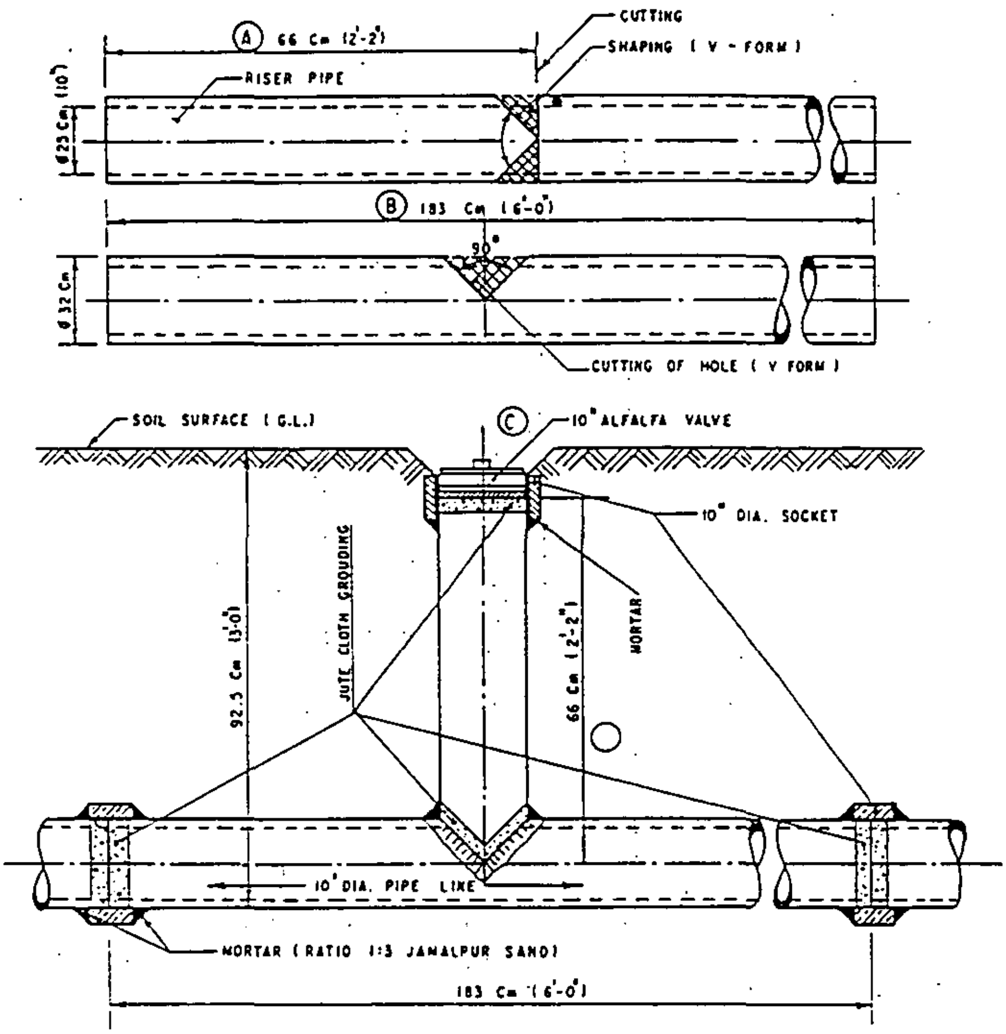
Source: Georgi (1989)

Figure 5.7 Air Vent (Small Diameter)



Source: US SCS (1967)

Figure 5.8 Riser Pipe and Alfalfa Valve

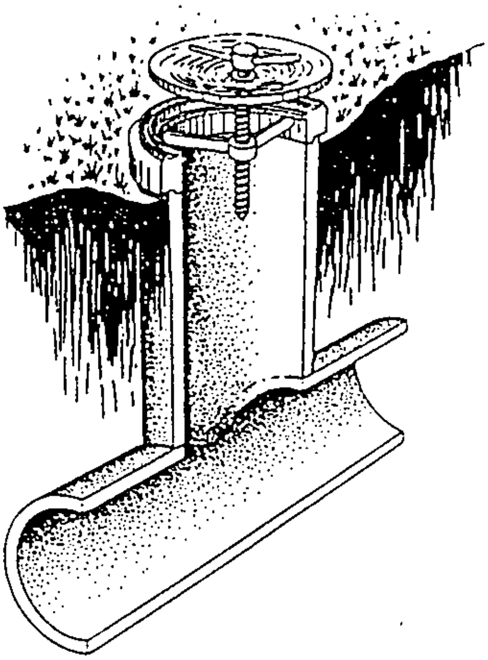


NOTE : 1) THE SEAT OF THE LID OF ALFALFA VALVE HAS TO BE MINIMUM 1/4" ABOVE SOCKET
2) TOP OF LID (ALFALFA VALVE) Ca, 3" BELOW GROUND LEVEL (G.L.)
3) LENGTH OF PIPES RELATED TO SPANNED PIPES

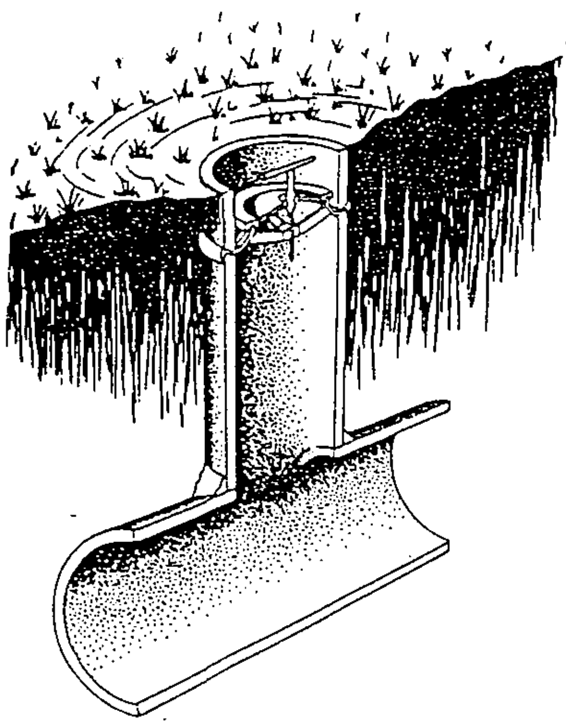
SYSTEM \ MEASUREMENT	A (Cm)	B (Cm)	C (In)
8"	72 Cm	100-110	6"
9"	68 Cm	- " -	8"
12"	60 Cm	- " -	10"

Source: TADP, Georgi (1989)

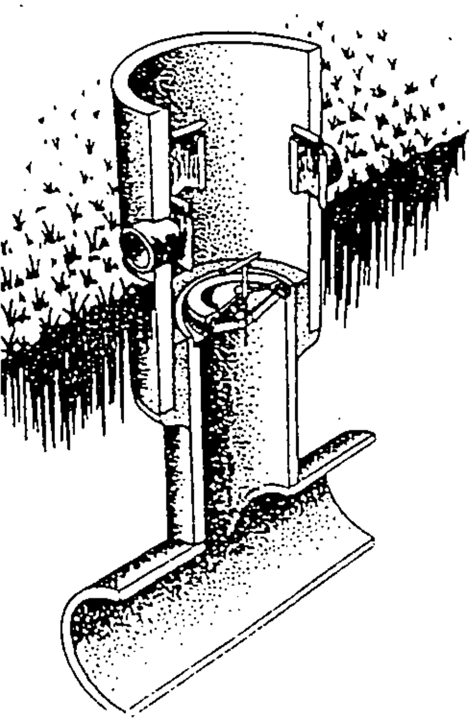
Figure 5.9 Alternative Outlet Designs 1.



i) Alfalfa Valve Outlet



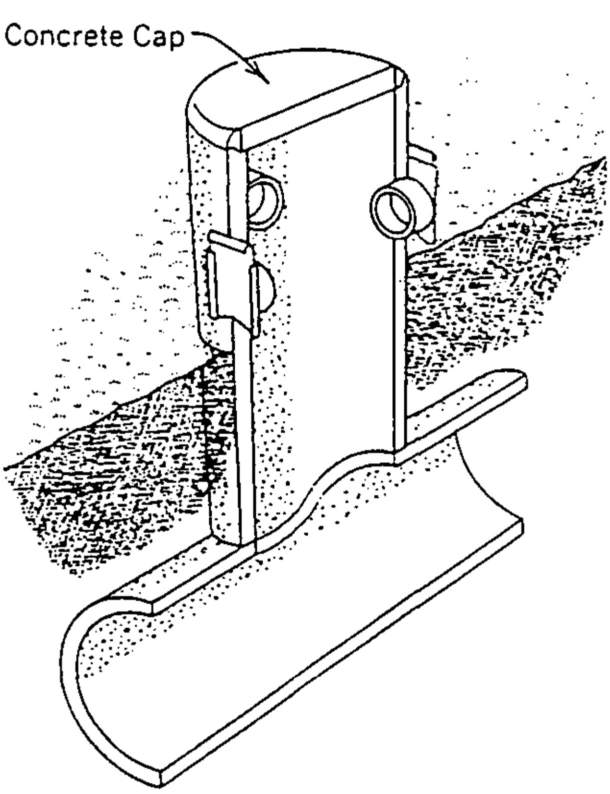
ii) Orchard Valve Outlet



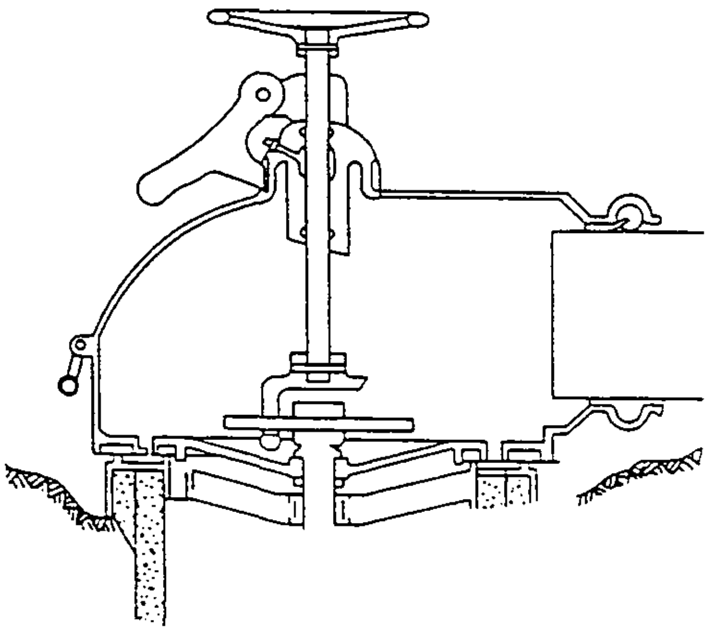
iii) Orchard Valve with Open Pot Outlet

Source: Baudequin et al (1990)

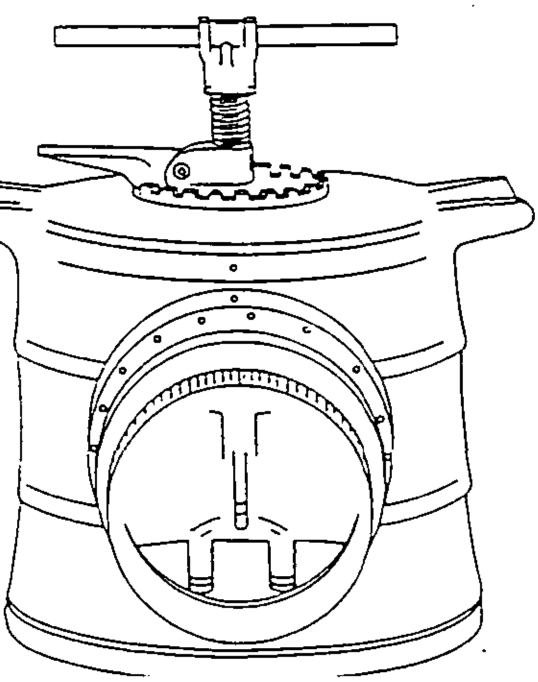
Figure 5.10 Alternative Outlet Designs 2.



i) Capped Risers or Pot Outlet



Cast Aluminium Portable Hydrant



iii) Sheet Metal Portable Hydrant

Source: Larry James (1988)

CHAPTER 6. Recommendations on System Design and Construction

6.1 Introduction

This chapter gives recommendations regarding system design and construction arising from the field evaluation of existing buried pipe systems and the experience reported by engineers and technicians in both published and unpublished material.

The chapter documents proposed design procedures and methods developed for buried pipe systems as a result of the research work. While elements of the methods outlined are described by engineers with experience of buried pipe system design, in no publication has the whole process been detailed sufficiently for practitioners unfamiliar with the technology. As illustrated in the summary flow charts, particular steps in the process are by nature iterative, and so appear on several occasions. Elements of pipeline design which are routine for higher pressure pipe system design, such as pipe friction estimation and pipe size selection are included for completeness.

Attention is only given to aspects of design which are specific to low pressure buried pipe systems. For further detail on system or component design and construction, in addition to that contained here, reference should be made to the forthcoming publication by van Bentum and Smout (1992).

The design of low pressure pipe systems is similar to design of other pipe systems, although important elements such as hydraulic and structure design will vary for each type of low pressure pipe system. A worked example of a design for a closed pipe system distributing water from a deep tubewell supply is detailed in van Bentum and Smout (1992).

Pipe system design, as summarised in flow chart 6.1, can be described by the following five steps:

1. General scheme feasibility and pre-design survey

Feasibility studies covering technical as well as social and economic aspects of the proposed scheme are an essential part of the planning and feasibility study for any irrigation scheme. For details of recommended procedures in the planning of irrigation schemes reference should be made to standard irrigation texts.

As already discussed in section 2.6, buried pipe systems can help to reduce the social problems raised by irrigation development, through resolution of disagreements over distribution system alignments.

2. Preparation of preliminary pipeline layout.

A preliminary layout is the first stage in obtaining beneficiary agreement on the pipe layout, outlet positions and the operation and control system to be used. Layout preparation aims to minimise the pipe length, while trying to achieve the optimum outlet density. Pipeline layout design has been summarised into four steps detailed below, which are discussed in more detail in section 6.3 and summarised in flow chart 6.2.

-establish the target irrigable command area
-set the maximum length of the field channels
-establish outlet intensity
-select the simplest pipe alignment which satisfies design requirements

3. Finalise system selection and obtain beneficiary agreement.

The preliminary layout may need to be amended on several occasions before it can be agreed, and the operating and control system and mode of operation finalised with the beneficiaries.

4. Hydraulic design of the pipeline.

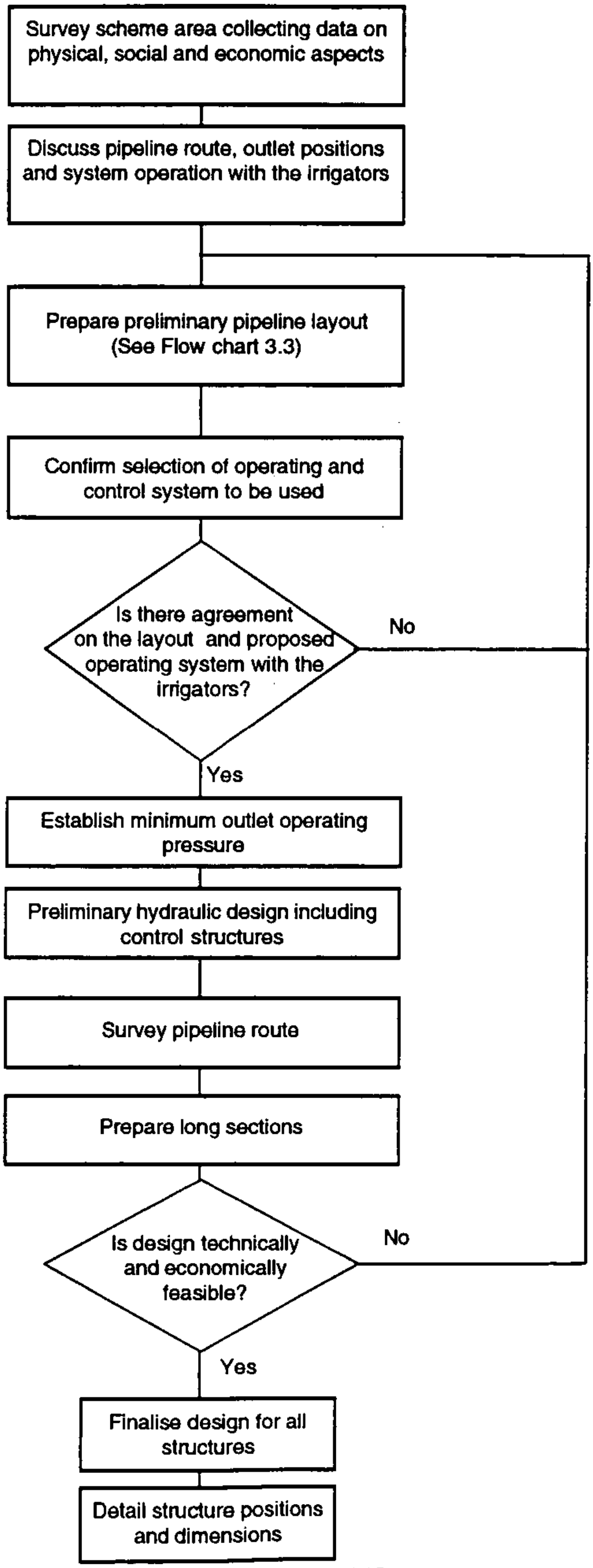
As with all pipe design, pipes must be sized and designed to deliver the design flow within the allowable friction loss. With pipe distribution systems this is set by the difference between the head available at the inlet to the pipe system and the operating pressure required at the critical outlet.

Specific hydraulic design methods for open, closed and semi-closed systems are detailed in section 6.4 and summarised in flow charts 6.3, 6.4 and 6.5.

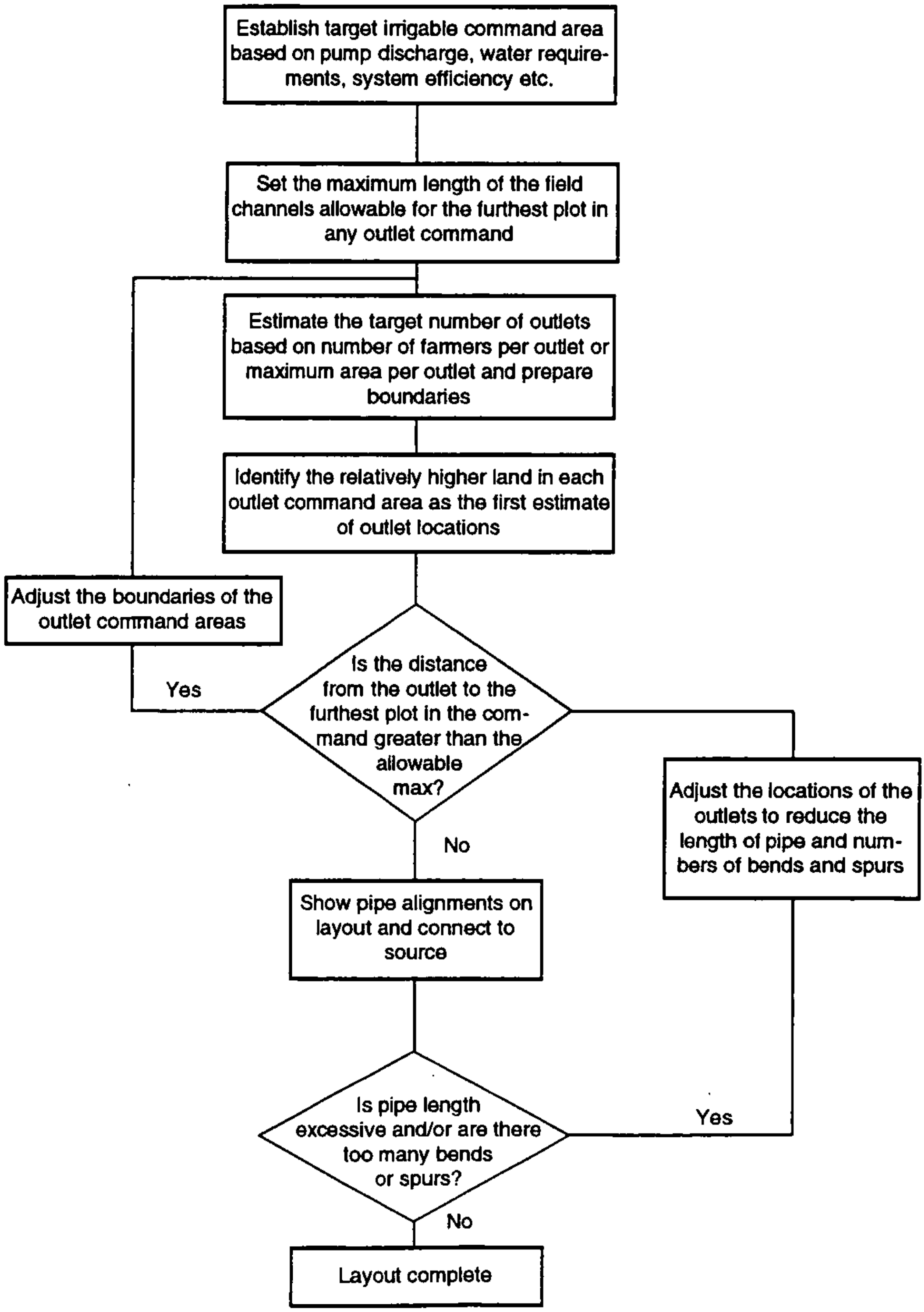
5. Selection and design of remaining component structures

With the pipeline network and alignment fixed, long sections for the pipe routes can be

Flow Chart 6.1 Design of Buried Pipe System



Flow Chart 6.2 Preparation of a Preliminary Pipeline Layout



prepared and requirements for air release and water hammer protection structures established and their positions and any specific dimensions detailed. Specific recommendations on structure design are outlined in section 6.5.

6.2 Surveying and Data Collection Requirements

Design data which should already have been decided will include the inflow discharge available from the water source, the method of in-field distribution and irrigation application to be used as well as optimum outlet and field level discharges.

Survey Information

Surveying requirements for buried pipe systems will be similar to those of open channel systems and will include:

-Land elevation as displayed by contour or relevant spot heights.

-Boundaries for administrative areas, villages, individual land holdings and where practical individual plots.

-Areas which will not be irrigated, such as homestead compounds, ponds, low lying areas or forested land.

-The position of any existing utilities within the command area.

-Any relevant community infrastructure.

Surveying should be completed with the collaboration of the beneficiaries, both to encourage early participation and dialogue and to enable accurate field checking of maps and databases which are prepared.

While ground level contours will be valuable for the purposes of design, in most cases spot levels for one or two positions (high points) in each plot or field will be sufficient for system design, along with details of the existing layouts of field distribution systems in the vicinity of any proposed outlets.

6.3 Preparation of a Pipeline Layout

6.3.1 Establish the Target Irrigable Command Area

i) Introduction

As with any irrigation scheme the design command area (A) can be initially calculated from the following equation:

$$A = \frac{Q}{q_d}$$

where A = design command area (ha)
Q = design inflow discharge to pipe system (l/s)

q_d = design irrigation duty (l/s/ha)

$$= \frac{I_f \times 10000}{t \times 3600} \times \frac{100}{E_d}$$

where I_f = field irrigation requirements (mm/d)
E_d = distribution efficiency (%)
t = duration of inflow per day (hours)

The size of the command area will therefore depend on:

-the design water duty and inflow discharge available from the water source
-the proposed cropping pattern and related crop water requirements
-the transit efficiency of the pipe system
-topographical features
-social and economic factors

ii) Available Discharge and Water Duty

Setting the design irrigation duty requires a decision about the peak water requirement which can be satisfied and hence the range and pattern of crops which can be grown. The design capacity of the pipe system must be at least sufficient for the peak water requirements envisaged, and possibly a little greater. It appears more difficult to change a design decision taken to limit the capacity of a pipe system, than for a open channel system.

Merriam (1987c) considers that because one of the major advantages of pipe systems is their ability to provide a flexible water supply, any design decision taken to limit the system capacity, will not only be expensive to reverse, but may reduce the economic and financial returns to more intensive cropping systems.

Without buffer storage on pumped supply pipe systems, the pump capacity and duration of pump operation per day will set the peak water duty which can be satisfied for a particular command area. While irrigation durations of more than 12 hours are feasible, to provide for temporary peaks in water demand, these should not be for more than several weeks as extended night irrigation is often not only inefficient but also highly unpopular.

iii) Cropping Pattern and Crop Water Requirements

The design water duty reflects a choice of cropping pattern and corresponding water requirements profile. Field experience suggests buried pipe systems allow irrigators to manage more complex cropping patterns, and cope more successfully with periods of water shortage, than on open channel systems by allowing more precise flow division and rapid switching of flow from one part of the command area to another, with a minimum of wastage (Rashid et al 1992).

Pipe systems may also help to reduce average water duties by providing the flexibility to enable farmers to switch to more diversified cropping patterns (Campbell 1980, Gisselquist 1989), away from higher water consuming crops such as rice.

iv) Transit Efficiency of the Pipe System and Field Distribution Efficiency

The replacement of open channels with buried pipe distribution systems in an existing irrigation scheme, can be used to mitigate supply shortfalls or alternatively to increase the command area, as a result of the savings in water due to reduced transit losses. Estimates of transit efficiency for typical buried pipe systems are given in Table 5.1.

The field distribution efficiency will depend on the length of earth channels, their condition and their capacity in relation to the outlet discharge.

Outlet discharge should not exceed the capacity of the field distribution system, as overtopping of the field channel or earth bunding around the outlet can lead to waterlogging of adjacent fields, leading to soil deterioration (salinisation) and crop yield losses. Goldsmith and Makin (1989) acknowledged the development of soil salinity, with waterlogging in areas of saline groundwater during field studies in surface irrigation schemes in northern India.

v) Topographical Features

Limitations to the command area of a buried pipe system include:

-the extent of the rise in elevation between the pump discharge and the level of the highest field to be irrigated.

-the depth to invert of a gully or drainage feature

-a permanent body of water

Where elevations or gully crossings result in the pressure rating of a pipe being exceeded short sections of higher pressure rated pipe can be used.

Where command areas are sloping uphill, or are large in area, closed pumped supply systems may be the only option, as large elevation differences preclude the use of low pressure pipe materials. For pumped systems using pressure towers, such structures become both expensive and difficult to build successfully using local materials where their height exceeds 4 to 5 m. In all cases care must be taken to ensure that the maximum design working pressure of the pipe material is not exceeded. Recommended maximum pipe pressures and above ground heights for header structures are detailed in tables 3.1 and 6.1 respectively.

Where a pipe system is being installed on an existing pumped supply system the additional head required to overcome pipe friction losses should not result in a significant decline in pump discharge.

vi) Social and Economic Factors

Even more important than technical considerations, are social and economic factors which influence the selection of the command area. The importance of community participation in all irrigation schemes is generally acknowledged, but often ignored by design engineers through the early stages of irrigation scheme planning. Van Bentum and Smout (1992) highlight social issues which are particularly important on buried pipe systems.

A number of recommendations are made (van Bentum and Smout 1992) regarding social and economic factors to be considered during initial design including:

1. Avoid excessively large command areas both at scheme and outlet level.

These may create social tensions particularly where water supply does not match farmer expectation (Refer to case study 4.6). Large scheme development will stretch local organisational structures beyond their capacity, particularly where structures are only weakly developed. Smaller pipe systems with fewer participating farmers are likely to have fewer organisational problems, and where the delivery stream is sized conveniently for the irrigator, design and operation is considerably simplified. Although capital costs per hectare will usually be higher for these smaller command areas (refer to section 7), it is suggested that costs per hectare actually irrigated, may prove to be lower because of the higher irrigation intensities achieved (Kolavalli and Shah 1989).

2. Try not to cut across existing community boundaries, both in relation to administrative bodies and structures involved in community organisation and decision making.

3. Proceed only when there is strong evidence of community commitment.

4. Involve irrigators at every possible stage of scheme selection and design.

6.3.2 Set the Maximum Length for the Field Channels

For any given command area there is an optimum layout which in most situations is defined as the layout with the shortest pipe length. Based on an analysis of standard command areas using idealised pipeline layouts the results of which are summarised in table 5.2, the following conclusion can be drawn.

The total length of pipe in any layout, appears to be inversely proportional to the maximum distance from any outlet to the furthest field commanded by that outlet. This distance, defined as the maximum field channel distance (maximum FCL), while approximated as the length of a straight field channel will typically be a less than direct route.

Alternatively it can be said, that as the maximum field channel length (maximum FCL) increases then pipeline length per ha decreases. This usually reflects a decrease in the number of outlets, and hence increase in the outlet command area, so that a shorter pipe network is required to link fewer outlets.

The objective of design for a distribution system, is to achieve a high system efficiency at a modest cost. In section 1.3, distribution system efficiency is defined as the product of both transit and field channel efficiency. Field channel efficiency in turn is influenced by the position and intensity of the outlets in the pipe scheme, because they set the average distance from outlet to field plot.

Other factors influencing the maximum length of field channel include the choice of type of in-field distribution system, the soil type, and the quality of construction particularly of earthen field channels.

i) Type of In-field Distribution System

The choice of the distribution system used will depend on the crop grown, plot size and irrigation method used. Where large plots and good land grading allow graded furrows and borders to be used, distribution channels or surface pipelines need only be short, compared to the more extensive channel networks required to supply highly fragmented basin irrigated plots.

Where surface pipes, gated pipes or hoses are used, the distance between outlet and plot will be limited by the cost of the pipe or hose material rather than the field distribution efficiency. This cost is reduced where a number of irrigators can share the use of the surface equipment.

Earthen channels though the least efficient of the distribution alternatives will generally have the lowest capital cost. They should only be used over short lengths (less than 100m) except where there are low permeability soils and where there is good cooperation among beneficiaries and a willingness to carry out timely and adequate maintenance.

ii) Soil Type

Field experience suggests that earth channels constructed from poorly cohesive and coarse textured soils tend to have poorer field distribution efficiencies. Even for fine textured silt loams in Bangladesh, measurements of earthen field channel distribution efficiencies (Rashid et al, 1990a and 1990b; MMI, 1990b), indicate transit losses averaging ten times those measured on concrete buried pipe systems (Rashid et al 1992).

Any gains from an improvement in transit efficiency by the use of buried pipes, can be lost with excessively long earthen field channels. Based on the Bangladesh data, even with low infiltration rate soils field channel lengths should not exceed 200 m, and with highly porous field channels, maximum lengths ideally should not exceed 100 m.

iii) Construction Quality of the Distribution System (Earthen Channels)

Field observations in Bangladesh appear to indicate that the crops and cropping pattern undertaken, strongly influence the quality of the earthen field channels. Where widespread basin irrigation of rice is carried out, field channels are commonly rebuilt on an annual basis with very limited compaction (Rashid et al 1992). Where a wider range of crops is grown throughout the year, the field channels tend to be a more permanent feature (as observed in Uttar Pradesh, India).

Early assessment of the likely performance of the in-field distribution system at the design stage will help in establishing a realistic field channel length.

6.3.3 Establish Required Outlet Intensity

Factors influencing outlet number and command area include:

-the acceptable field channel length within the outlet command
-the number of land holders and the extent of land fragmentation
-the proportion of non-irrigable land proximate to the outlet

Acceptable Field Channel Length Within the Outlet Command

As the allowable maximum length of the field channel rises, so the size of each outlet command area increases. Based on systems constructed in Bangladesh with maximum field channel distances of 200m, outlet command areas are in the range of 2 to 4 ha and they fall to below 2 ha only in situations where the maximum FCL approaches 100 m.

Outlet command areas of uPVC pipe systems which have been constructed in India (Cunningham 1986 and refer to case study 4.6), are larger than comparable nonreinforced concrete pipe systems in Bangladesh (MMP 1989e and refer to case study 4.7) and this is reflected in long maximum field channel lengths often in excess of 250 metres. It is likely that the benefits of the higher transit efficiency of the uPVC pipe system is negated by the much longer lengths of field distribution channel.

Number of Land Holders

Situations where the number of land holders in the vicinity of an outlet are large, common in highly fragmented holdings (IDTP 1988 and refer to case study 4.6), will justify smaller outlet commands than would be suggested for technical reasons. Land consolidation can help to increase plot size and reduce the complexity of the irrigation system, so simplifying water allocation between small holders, however progress is often very slow (IDTP 1988).

6.3.4 Determining the Optimum Pipeline Layout

Almost all command areas where pipe systems might be used can be described in terms of a regular shape approximating a square, rectangle or circle. Optimising pipe layouts, within these command areas, will involve achieving a desired outlet distribution and density with a minimum length of pipe. This can be denoted by the index "pipe length per hectare of command area".

Based on an analysis of standard layouts, it would appear that differences in pipe length per hectare are influenced more strongly by outlet intensity, while only small differences, in pipe length per hectare, result from variations in the shape of the command. The conclusions, are discussed below, and summary data from the analysis is given in Table 5.2.

1. Positioning the water source on the edge of the command area, increases the length of

the pipe system for the same field channel length.

For circular or irregular shaped commands, given the same field channel length, a water source at the perimeter increases the pipe length by up to 20 % compared with a more central position. For more rectangular shaped commands total pipe length appears to depend more on other factors. Central positions for the water supply are unlikely to be practical on gravity supply systems.

Other factors which may influence the position of the water source in relation to the command area include:

-proximity to power supply for electric motor driven pump supplies. It may be cheaper to bring the pump to the power source rather than the reverse, even when the implications on the cost of the distribution system are considered.

-proximity to village settlement for ease of supervision, and prevention of vandalism.

-location of high land to facilitate gravity supply or lowering the height of an elevated tank.

2. The greater the proportion of the gross command area which is not irrigable, the more extensive is the pipe network required to achieve a desired net command area.

In such cases, particularly if the irrigable land is fragmented, it may not be economically sensible to invest in a single tertiary distribution system for the whole area. A better alternative would be to provide smaller systems in separate parts of the command area, with higher proportions of irrigable land. An example of this would be the use of a number of smaller capacity tubewells, as an alternative to one large deep tubewell.

3. As the target command area increases, so the length of pipe required per irrigated hectare, to achieve the same outlet density also increases.

Larger command areas however, allow the cost of the water source and control structures to be spread, resulting in lower costs per unit area (refer to chapter 7). The cost decrease normally outweighs any increase due to the extra length of pipe per hectare up to command areas of 100 ha. This advantage is apparent with pipeline systems associated with deep tubewells or where the provision of the water source is costly. For lower cost gravity intakes, smaller command areas requiring shorter pipelines may well be more economical.

6.4 Hydraulic Design

6.4.1 General

While hydraulic design for medium and high pressure systems is well documented, specific procedures for low pressure systems are absent from most publications.

Hydraulic design must be completed for each individual pipeline, so that for open and semi-closed pipe systems each pipeline section between pressure reducing structures must be considered separately. However it is likely that, where ground slope and operating pressures are similar, then pipe design for different pipe sections will be equivalent. Similarly for closed pipe systems separate branches or loop pipelines originating from the same water source are designed separately.

Koluvek (1970) gives the following general recommendations for the design of all low pressure pipe systems and calculation of the hydraulic gradient:

1. The hydraulic gradient should not drop below the pipe elevation at any point where water is flowing

2. Design should be based on operation of the critical outlet, which is usually the outlet most distant and/or highest in elevation relative to the water source.

3. For branching pipe systems design should begin downstream on each branch, and for sections above junctions with stand pipes, design should be based on the highest gradient required.

6.4.2 Discussion of Maximum and Minimum Design Velocities

i) Maximum Velocities

The choice of design velocity is a compromise between higher velocities aimed at reducing required pipe diameters and therefore pipe cost, and the higher cost of water hammer protection associated with higher operating velocities. Additional energy costs are usually relatively small compared to the cost of providing water hammer protection at higher velocities.

Recommended maximum velocities for flow in low pressure pipelines are in the range of 1.3 to 1.5 m/s (ASAE S261.7). These apply to mortar jointed nonreinforced concrete pipe, low pressure asbestos-cement, and thin walled uPVC materials. Typically flow velocities for buried pipe systems built in India (IDTP 1988) and Bangladesh (MMP 1989a) will be in the range 0.6 to 1 m/s.

In the case of open and semi-closed pipe systems where slopes are in excess of those required to overcome pipe friction losses, pipe size is selected to ensure that recommended flow velocities are not exceeded. Head in excess of the pipe friction loss at design flow, is then dissipated in the respective overflow and float valve stands.

ii) Minimum Pipeline Velocities

Recommended minimum velocities are similar for most pipe distribution systems and based on the need to ensure that any sediment or debris entering the pipe system is flushed during normal operation. Finer material settling during periods of low flow should be adequately scoured when normal flow regimes resume.

Standard texts (Withers and Vipond, 1988) indicate scouring velocities for non-cohesive materials in the range of 0.3 m/s for silts and 0.5 m/s for fine sands, which are likely to be the most troublesome materials entering low pressure buried pipelines.

Labye et al (1988) give more specific recommendations which allow for lower minimum velocities in pipes of smaller diameter, for example 0.2 m/s for 200 mm diameter pipe.

iii) Pipeline Slopes

Though low pressure pipelines can be used over land slopes ranging from 0 to 10 %, they will frequently be impractical in very steeply rising or falling command areas. This will be because of the operating pressure limitation imposed by the low pressure pipe materials and the high cost of providing frequent pressure reducing structures.

Short sections of quite steep pipelines can be installed provided adequate provision is made for any axial thrust forces, and for the venting or air which may accumulate.

Closed pipe systems on very flat topography should be laid at positive slopes to avoid surge problems resulting from trapped air being suddenly released. Pipeline slopes should be such as to encourage air movement to nearby vents and open stand structures (Twort et al 1985). Where problems recur, additional air vents or large orifice air valves should be provided.

6.4.3 Hydraulic Design of Open and Semi-Closed Pipe Systems

Design for open and semi-closed pipe systems can be considered in two steps, firstly the determination of the height and spacing of the pressure control structures, which will depend on the allowable maximum design pressure of the pipe material and secondly the selection of the appropriate pipe size, so that at design flow the maximum velocity is not exceeded.

Step 1. The spacing between stands is given from the equation

$$M = E + D + s_g L$$

where M is the maximum safe pressure for the pipe

E is the minimum energy head required at the stand

s_g is the ground slope

L is the stand spacing

For open pipe systems the maximum stand height must also not be exceeded. Detail on the design and construction of open stands and float valve stands is given in section 6.5.2.

Step 2. Pipeline selection

The diameter of the pipeline between two structures can be selected from standard friction loss tables and charts (Hydraulic Research 1990a and 1990b). The head which is not dissipated in friction at design flow is lost in the overflow stand or float valve stand.

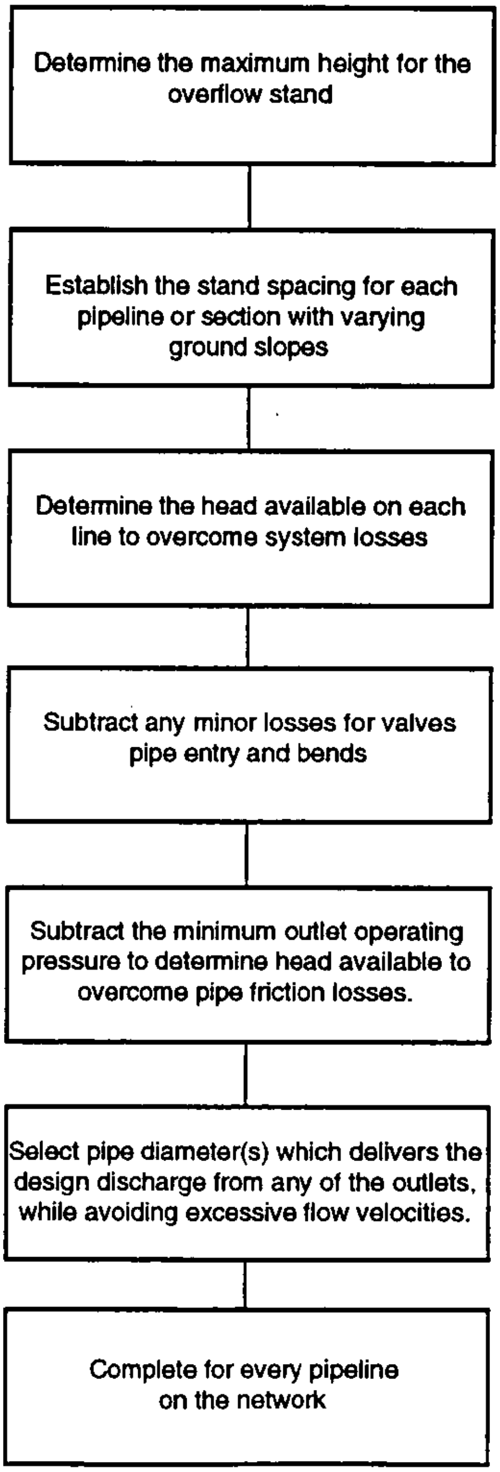
Further detail of the design of overflow stands for open pipe systems and float valves for semi-closed pipe systems is given by van Bentum and Smout (1992) and Merriam (1987b). Summaries of the hydraulic design procedures for open systems and for semi-closed systems are presented in flow charts 6.3 and 6.4 respectively.

6.4.4 Hydraulic Design of Closed Pipe Systems

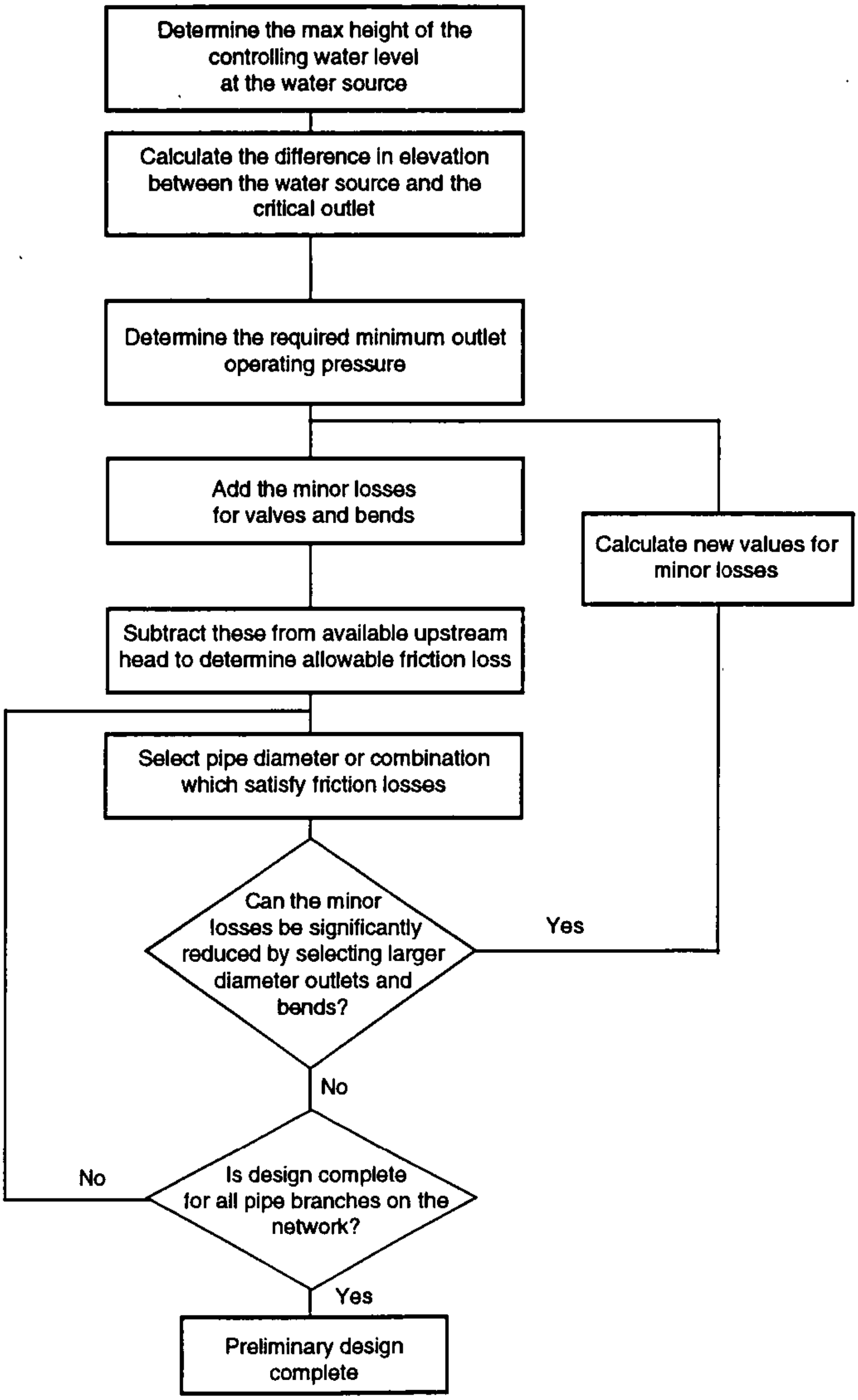
The hydraulic design of closed pipe systems relies on identifying the critical path for each distinct pipe network, which will involve analysing the head losses for the design flow to a number of outlets (usually on or near the perimeter of the network). Minor losses and the minimum operating pressure at the critical outlet are subtracted from the available upstream head to determine the head available for pipe friction losses. The design is then completed for all the remaining parts of the network.

Each step in the hydraulic design is discussed in more detail in the sections which follow and summarised in flow chart 6.5.

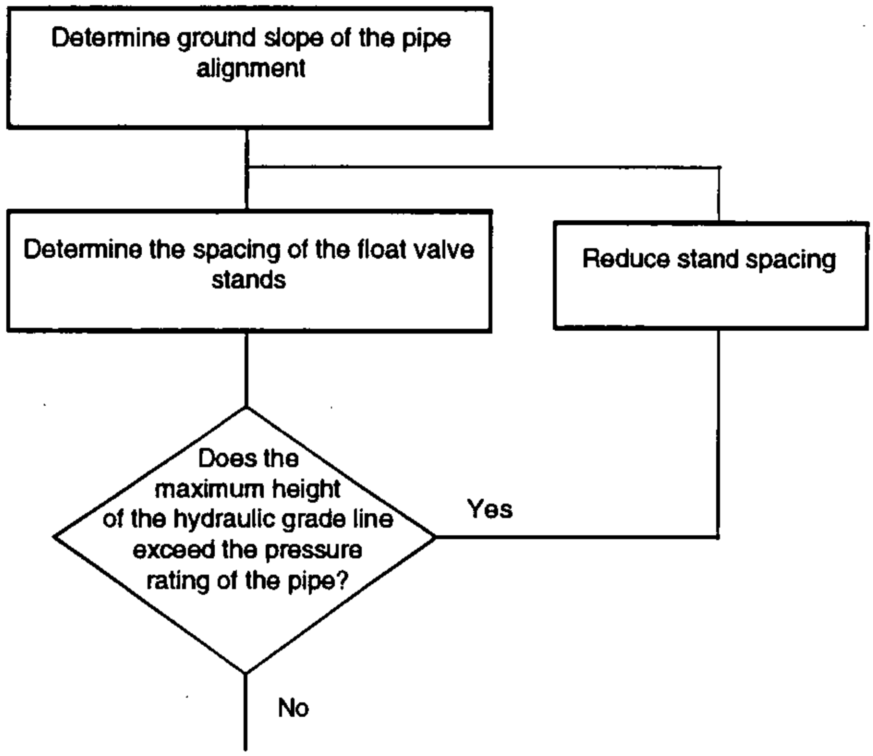
Flow Chart 6.3 Hydraulic Design of Open Pipe Systems



Flow Chart 6.4 Hydraulic Design of Closed Pipe Systems



Flow Chart 6.5 Hydraulic Design of Semi-Closed Pipe Systems



Steps

1. Select the pipe(s) with regard to max velocity of flow
2. Calculate the head to be dissipated at the float valve for the design flow rate
3. Select size and type of float valve, so that friction loss at design is less than head to be dissipated
4. Calculate the flow rate possible through the wide open valve
5. Determine the float setting for the design flow
6. Calculate the max water level in the float stand
7. Calculate the float submergence required to close
8. Determine stand height and maximum upstream pressure

i) Available Upstream Head

The driving head available will be determined by the maximum height of the controlling water level at the water source.

For pumped supply systems this will be set by the maximum practical height of the control tank or pressure tower, the pressure rating of the pipe and the head/discharge characteristic for the pump. The maximum height of the pressure tower will depend on the materials and method of construction used provided it is less than the pipe pressure rating.

On gravity supply systems available upstream head will be the lowest expected operating water level. For pressure tower systems the limitation is often the increase in pumping costs and the height of the tower is kept to that required to provide the outlet operating pressure at the critical outlet, allowing for friction losses of typically 2 to 3 m, in the pipe network.

Recommendations of practical height limits for pumpstands and header tanks are given in Table 6.1, for some designs which have been widely built, and are based on field construction experience in Bangladesh, India and the USA.

Table 6.1 Practical Above Ground Heights of Inlet Structures

Type of Tank	Practical Height Limit (m agl)
Elevated Tank with column support	5-6
Nonreinforced concrete pipe rings	3-4
Reinforced brick pressure tower	4-5
Steel Riser Pipe	8-10

(m agl) = metres above ground level

Source: Field evaluation of pipe systems in south Asia.

ii) Outlet Design Water Level

Sufficient head must be available at each outlet to allow irrigation of the furthest part of each outlet command by whatever in-field method of distribution is used. The critical field will be the highest and/or furthest field from the outlet. Outlets should be sited on or very near the highest point in the outlet command to avoid having to build raised earth channels on embankments.

The design outlet water level is calculated from the following components:

Head loss through the outlet

+

Head loss through the outlet distribution structure

+

Head loss in field distribution system to critical field

+

Head loss from the distribution system to the field

+

Depth of water ponded in the field

+

Ground level of the critical field

A. Head loss through the outlet

Head losses through the outlet are normally restricted to less than 0.3 m, and if high heads are to be dissipated the valve can be partially closed. Typically alfalfa valve head losses will be in the range 1.5 to 2.2 times the velocity head through the riser (Labye et al 1988).

Head losses through standard alfalfa valve outlets are detailed by Booher (1984) and reproduced by van Bentum and Smout (1992). These head losses are based on precisely manufactured valves, and where local fabrication is involved allowance should be made for higher friction losses.

B. Head loss through the distribution structure

An outlet distribution structure will normally be required where open field channels are used to distribute water to more than one irrigator. Friction losses through the structure will be associated with:

-the geometry of the structure
-division of flow
-flow across a weir and stilling basin

Total head losses for an outlet distribution structure at design flow will normally be less than 0.2 m and should not exceed 0.3 m.

C. Head loss in the field distribution system to the critical field

The head loss will depend both on the type of field distribution system used and the length of that system to the critical field. Although earth channels are most commonly used, alternatives include surface pipe, gated pipe and surface hoses. Pipe and hoses will require higher outlet operating pressures compared to earth channels and their higher capital cost will limit their range from an outlet.

Recommendations regarding establishing the maximum field channel distance from outlet to field have already been discussed in section 6.3.2.

James (1988) and Labye et al (1988), describe typical operating pressures required at the outlet for different field distribution systems as follows:

Earthen Channel	0.2 m
Gated Pipe	0.2-2 m
Surface Pipe	0.5-2 m
Layflat Hose	1-1.5 m

D. Head loss from the distribution system to the field

The magnitude of this head loss though small will depend on the way water is transferred from the distribution system to the field. In pipe and hose systems it is included in the operating head for the system, needed to overcome exit losses from one or more orifices. The magnitude of this head loss will in all cases be less than 0.1 m.

E. Maximum depth of water ponded on field during irrigation

This will depend on the crop grown, soil type and irrigation interval but is unlikely to exceed 0.15 m.

F. Relative difference in ground level between outlet and critical field

The outlet should where possible be higher in elevation than the critical field to avoid embanked earth channels. Where the outlet is lower than any of the fields, surface pipe or hose can be used to transfer outlet pressure as an alternative to building a raised earth channel. Conversely outlets which are too much higher than the surrounding fields require that drop structures or scour protection be provided. Photo plate 4.11 illustrates the damage that can occur where outlet valve protection is not provided.

iii) Minor Losses

In general unless poor selection of fittings and structure sizes has been made, or pipe assemblies are particularly short, system head losses due to bends and valves comprise only 5 to 10 % of total pipe friction losses and are frequently referred to as minor. Unnecessary bends and fittings should however be avoided as not only do they add to the friction losses but they are also more likely to be positions at which leakage occurs.

Friction losses are calculated as the product of a friction loss coefficient for the fitting or structure and the velocity head under normal pipe operation (Labye et al 1988).

For the situations encountered on buried pipe systems the following friction loss coefficients are considered typical:

Table 6.2 Summary of Typical Friction Loss Coefficients

90 bend	0.2 to 0.3
45 bend	0.1 to 0.15
22.5 bend	0.05 to 0.1
90 tee in-line	0.1
90 tee side outlet	1.3 to 1.8
Pipe into stand	1
Pipe out of gate stand	0.5 to 0.8
Alfalfa valve outlet	1.5 to 2.2
Alfalfa inlet	4 to 6

Source: MMP (1989a) and Labye et al (1988)

6.4.5 Optimisation of Pipe Size

In complex pipeline systems, because pipe costs are directly proportional to pipe diameter and pumping costs are inversely proportional to pipe diameter, pipe selection is often carried out using an optimisation process.

Because the cost of the pipe material represents from 60 to 90 % of the cost of the pipe system, designers try to select the minimum capital cost combination of pipes which delivers the required flow.

On the simple pipeline networks considered here, selection by trial and error will not usually be onerous, particularly as standardisation of pipe sizes and materials can reduce design and construction costs. Savings can be considerable where a large number of similar schemes are planned, outweighing the benefits of precise selection from a wide range of pipe size options.

In practice for the simple pipe network considered, minimising the capital cost of any pipe section will usually involve not more than two different sized pipes and probably 90 % of the different sections will comprise only a single pipe diameter (Labye et al 1988).

Before selecting the pipe sizes both the available head and the design flow capacity of the pipeline need to be established for the whole and individual parts of the pipe network.

Loop or Branching Systems

On loop pipe systems the general practice is to select one pipe size for the entire loop, although on occasion two sizes of pipe may be required to provide the required balance between head loss and capital cost.

On branching systems pipe size will tend to decrease away from the water source. The critical branch and outlet will determine the selection of pipes from the range available, given the head available to overcome friction losses. While optimisation of pipe selection would suggest smaller diameter pipe be installed on short non-critical pipe branches, in general pipe lengths of less than 50 m are not fitted with a second smaller diameter pipe, in order to simplify construction.

Using larger pipe than required for some of the network may allow a slight reduction in the operating cost in some circumstances where a pumped source is involved, and also allow for some future expansion.

v) Pipe Friction Estimates

With information on the peak flow rates to be conveyed in different parts of the system, pipe friction estimates can be made. Increasing flow velocity to reduce pipe diameter will not usually be a viable alternative for low pressure pipes given the low maximum pressures allowed.

Of all the estimates used for pipe friction losses, values calculated using Colebrook-White, which combines the theory of turbulent flow with experimental data for flow in commercial pipes, appears the most reliable and useful of the estimating methods. Not only do field measurements of pipe friction loss in Bangladesh (Rashid et al 1992) confirm the general accuracy of the equation, but there exists a wide range of experience in the selection of representative values of roughness height for the pipe materials in current use (Hydraulics Research 1990a and 1990b).

While equations suitable for hand held calculators have been developed, tables and nomographs prepared by Hydraulics Research (Hydraulic Research, 1990a and 1990b) considerably simplify calculation for the situations likely to occur in buried pipe distribution systems.

Values of roughness height based on field verified measurements are shown in Table 6.3 below. These are conservative and manufacturers will invariably quote more optimistic values, for example k = 0.015 for uPVC pipe. For the small pipe sizes and low flow velocities generally encountered this will make only a small difference to the estimated friction loss. In situations where unknown pipe materials or pipe system designs are to be used, field measurement should be carried out early on in the design process to verify the choice of roughness height.

Table 6.3 Recommended Values of Roughness Height

Condition of Pipe	uPVC	Nonreinforced concrete	Asbestos Cement
good	0.03	0.3	0.015
normal	0.06	0.6	0.03

Source: Hydraulics Research 1990b verified by field calibration.

6.4.6 Surge and Water Hammer Protection in Low Pressure Pipelines

i) Introduction

Although the theory of water hammer is treated fully in many standard texts much of the theory, relates to pipe selection in high pressure situations. Although Campbell (1986) describes water hammer in relation to low pressure systems in some detail, no short summary of methods for design of water hammer protection of low pressure systems is presented.

While specific structures can be installed to control water hammer, most of the emphasis should be given to strategies to limit the size of any pressure rise through overall scheme design and specific operating procedures.

In this section particular attention is given to water hammer and surge protection for closed pipe systems where open stand pipes can be installed to minimise the magnitude of the pressure rise. The procedure is summarised in flow chart 6.6, and detailed fully by van Bentum and Smout (1992).

Before discussing the design and provision of water hammer protection, brief definitions of surge and water hammer are given, as although both can result in damaging pressure rises, they are quite different phenomena.

Surge

Surge is defined as any transient pressure fluctuation occurring in pipeline systems at atmospheric pressure. During surge, water flow is characterised as being unsteady, oscillating from one steady state condition to another.

Surge in low pressure pipelines is usually caused by the sudden and uncontrolled release of entrapped air from the pipeline. The air may have collected during filling or been entrained within the flow at structures such as overflow stand pipes. Merriam (1987a) notes that open pipe systems frequently suffer from surge, because of the air entrained during normal operation, and if large volumes of air are released suddenly, a pressure wave may be generated.

Methods for avoiding surge include:

-the provision of air valves or vents within pipe systems to provide for the controlled release of air.

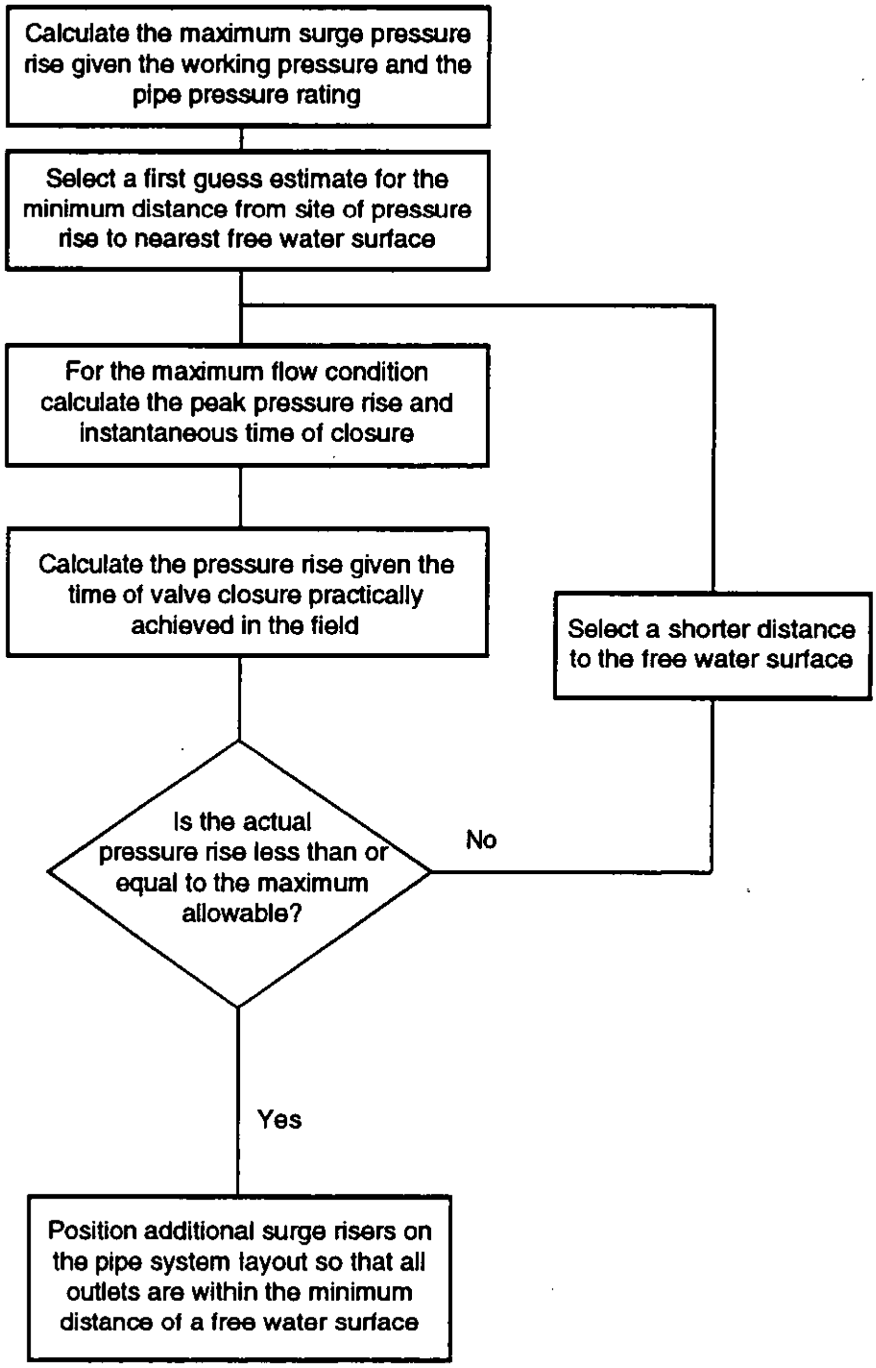
-avoiding severe and unnecessary changes in the vertical pipe alignment to reduce the positions in the pipeline system where air is trapped for later sudden release.

-ensuring that pipe systems remain full of water even when not operating can dramatically reduce the incidence of surge.

Water Hammer

When the kinetic energy of moving water is transformed into pressure energy, a pressure wave is generated that oscillates back and forth in the pipeline. At any point in the pipeline this is registered as a surge in pressure which is known as water hammer. The pressure wave is reflected back on itself when it encounters any free water surface, usually at an open stand structure, and becomes superimposed on itself so resulting in the dampening of the wave (Campbell 1986).

Flow Chart 6.6 Water Hammer Protection for Closed Pipe Systems With Open Vents



Water hammer in buried pipe systems occurs usually as a result of the sudden arrest of flow caused by one of the following:

1. Sudden valve closure
2. Sudden release of air
3. Sudden pump stoppage

The risks for buried pipe systems if surge pressures are not restricted to below certain limits include:

-the rupture of pipe bodies or joints if maximum operating pressures are exceeded

-the development of negative pressure within the pipeline may lead to the creation of pockets of cavitation, leading to possible collapse of the pipe wall with thin walled uPVC pipe materials and/or ingress of pipe seals with more rigid pipe materials.

-pipe failure over time due to cyclic positive and negative pressures causing pipe fatigue (WRC 1989).

The requirement for surge and water hammer protection and the choice of methods of protection available differ for each type of buried pipe system.

ii) Water Hammer Protection in Open and Semi-Closed Pipe Systems

In open and semi-closed systems the spacing of overflow stands and float valve stands generally ensures that water hammer events are quickly dampened in nearby stand structures restricting the size of the pressure rise (Merriam 1987b).

Where pipelines are flat and pressure control structures infrequent reference should be made to the design for water hammer protection on closed systems, as additional open vents or pressure relief valves may be required. In systems where a number of irrigators are taking water at the same time, then changes in flow momentum due to one valve suddenly closing are small and provide few problems.

Methods which help to avoid the entrapment of excessive quantities of air and its subsequent sudden release include:

-provision of undershot gates in overflow stands in open pipe systems (Merriam, 1987a).
-slow and careful filling of the pipe system from empty

iii) Water Hammer Protection in Closed Pipe Systems

In most closed pipe systems, open vent structures can be installed to limit the extent of any pressure rise. Where this is not possible special pressure relief valves would need to be used, or alternatively pipe of a higher pressure rating installed.

Sudden Pump Stoppage

In most pipe systems with a pumped supply, an open stand pipe or tank is provided between the pump and the pipeline, and is adequate for protection of the pipe network from water hammer due to sudden stoppage of the pump. Where the pump is direct coupled to the pipeline then a pressure relief valve is required.

Sudden Release of Air

Water hammer due to a sudden release of air in the pipeline is prevented by the installation of air vents or air release valves at high points or problem areas. As any open stand structure will function as an air vent and reduce the likelihood of sudden air release occurring, the need for additional air venting is usually small.

Sudden Valve Closure

This constitutes the predominant cause of water hammer in closed pipe systems, and minimising the pressure rise which occurs is the main reason for the provision of open vent surge risers. Other methods for reducing the pressure rise are detailed by Campbell (1986) and discussed below, and should be used before resorting to providing surge risers.

iv) Methods for Reducing the Damaging Pressure Rise due to Sudden Valve Closure

Campbell (1986) concludes that the analysis of water hammer is complex and any attempt to predict the conditions arising is necessarily an approximation. However a number of general recommendations can be made. In relation to sudden valve closure, instantaneous closure time is defined as the time taken for the pressure wave developed at closure to travel the round trip distance to the nearest free water surface. Definitions of water hammer and the derivation of the equations can be found in Campbell (1986).

-if the time of valve closure is more than twenty times the instantaneous closure time then surge pressure can be regarded as insignificant

-the surge pressure peaks when the time of valve closure equals the instantaneous closure time

-for any situation in between design decisions to reduce either the pressure rises or their damaging effects need to be taken.

The magnitude of the pressure rise can be controlled in a number of ways including:

-control of the rate of valve closure by the use of valves with finely threaded spindles (Georgi 1989) or valves which require opening with a special spanner (Campbell 1986). Field experience suggests valve closure periods of greater than 20 seconds are not practical. The special spanner attachment proposed by Campbell for Kallada Irrigation scheme is detailed in figure 6.1.

-installation of surge risers, is the main method of limiting the magnitude of the pressure rise and detailed in the following section. In practice any open stand structure of adequate diameter will serve to reflect the pressure wave.

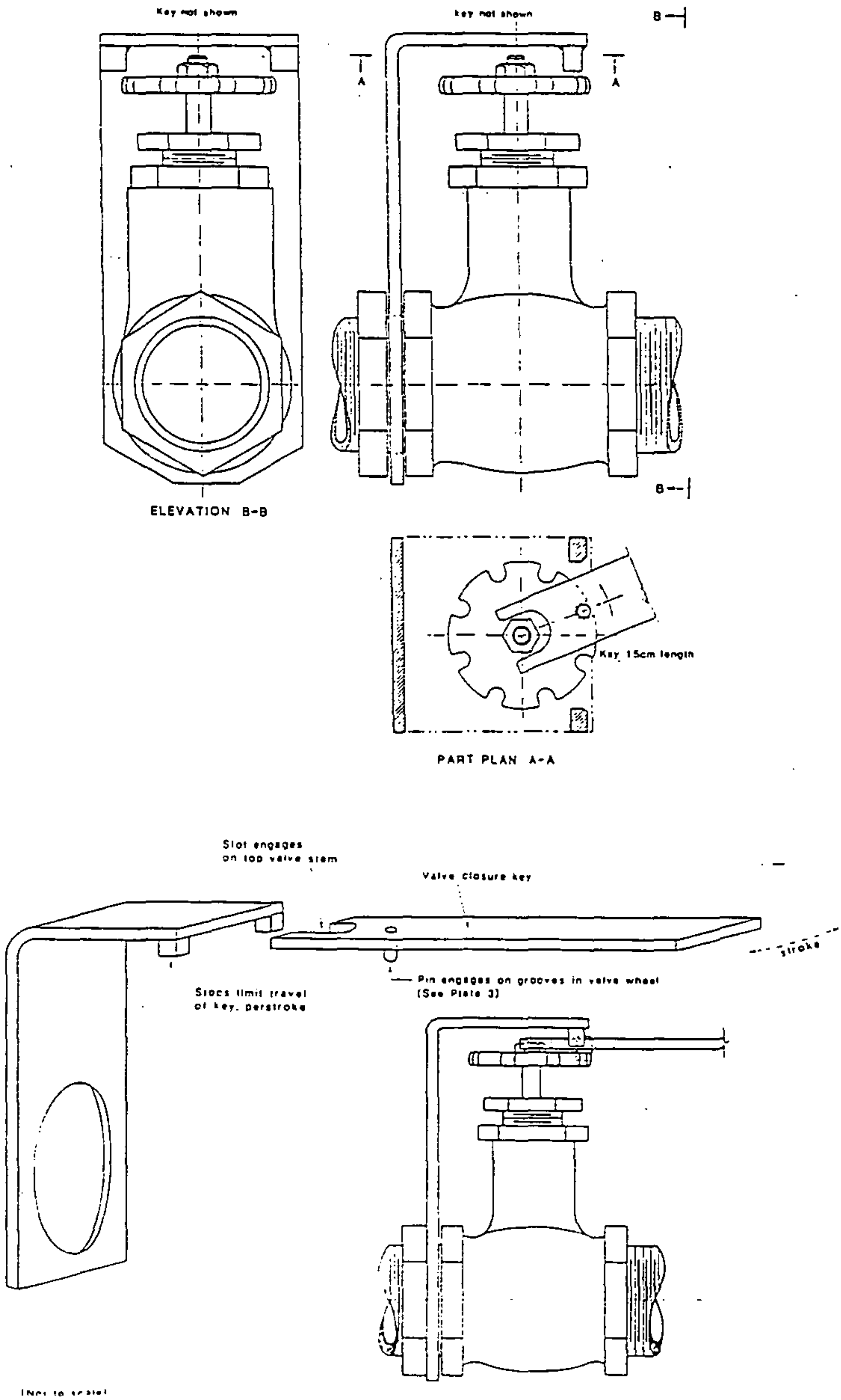
-installation of pressure relief and vacuum relief valves, is normally an application used on pump supplied systems where pump stoppage and power failure are common causes of water hammer. Simple pressure relief valves which can be actuated at relatively low pressures and which respond before damaging pressure rises occur are not however currently available.

-care during pipe installation, involves limiting the number of sharp changes in gradient and ensuring the hydraulic grade line is above the elevation of the pipeline so as to avoid the development of negative pressures during valve closure. The air admitted by vacuum valves during negative pressure events may cause surge problems later if suddenly released.

v) Design Procedure for Water Hammer Protection on Closed Pipe Systems using Open Vents

The usual approach for closed pipe system design to avoid water hammer must be to specify pipe which can withstand the estimated pressure surges, for a realistic speed of valve closure, providing surge risers where required. The design procedure for specifying open vents, based on Campbell (1986), can be summarised in the five steps below, which are illustrated in flow chart 6.6.

Figure 6.1 Attachment to Ensure Slow Valve Opening (Kallada, south India)



Source: Campbell (1986)

Design experience suggests that distances from free water surfaces of 200-300 metres for concrete pipe systems and 500-600 metres for uPVC pipe systems will generally be adequate for minimising damaging pressure rises.

The design method outlined is presented in further detail in van Bentum and Smout (1992).

Step 1. Calculate the maximum allowable surge pressure rise.

This will be defined by the maximum operating pressure at that point and the pressure rating for the pipe. As previously mentioned for uPVC pipe, surge pressure should not exceed 30 % of the pipe pressure rating. For low pressure concrete pipe surge pressure added to operating pressure should not exceed 25 to 35 % of the hydrostatic test pressure.

Step 2. Select a first guess estimate for the maximum distance between the site of pressure rise and any free water surface.

For uPVC pipe systems this would be from 600 to 800 m.
For nonreinforced concrete pipe systems this would be from 300 to 500 m

Step 3. For the maximum flow calculate the peak pressure rise occurring at the instantaneous time of closure.

Peak pressure rise occurs when valve closure or pump stoppage occurs in any time period which is equal to or less than the time it takes for the pressure wave to travel the round trip to a free water surface (called the time of concentration).

Step 4. Calculate the pressure rise for rates of flow reduction which are less than at instantaneous closure.

In order to estimate the pressure rise for longer valve closure times an approximation must be made because the rate of change of velocity is not uniform over the period of closure. The assumption made is that the change in velocity during the round trip time is three times the rate averaged over the whole period of closure.

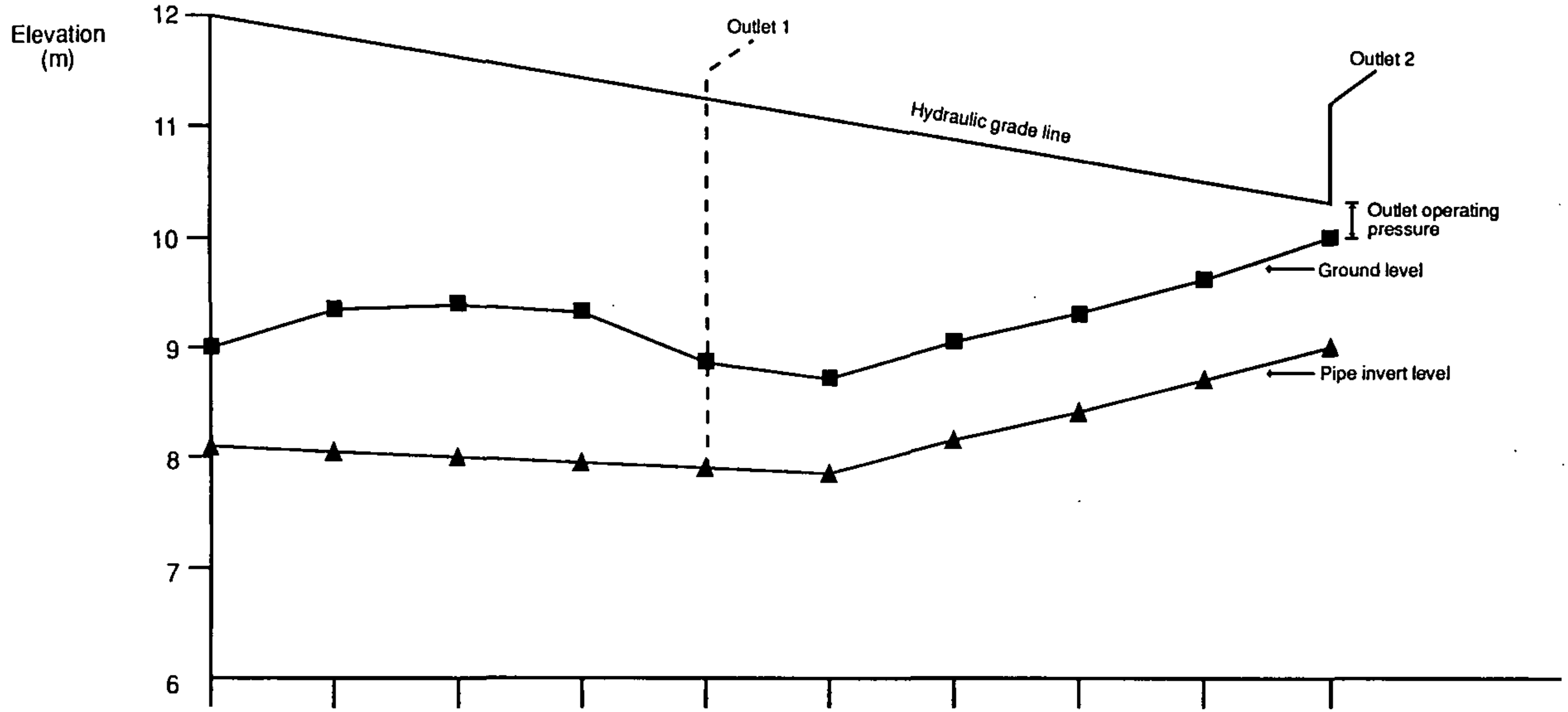
Step 5. Compare the calculated value of pressure rise with the acceptable maximum surge pressure.

If the surge pressure is still too high then a shorter distance to the free water surface must be selected. If the surge pressure is substantially lower than the acceptable value, a greater distance should be selected so that only the minimum number of surge risers are provided.

6.4.7 Pipeline Long Section

A long section is prepared for each section of the pipe network once pipe friction losses and the positions of surge risers and air vents have been determined. The long section should show the hydraulic gradeline and ground level as well as the profile of the pipeline at its recommended embedment depth and will frequently require a more detailed survey along the pipe route. An example of a typical long section and hydraulic grade line is shown in figure 6.2.

A check can then be made on the maximum height of the hydraulic grade line, and that it is within the limits of both the maximum pipe operating pressure (refer to table 3.1) and the maximum physical height of the header structures (refer to table 6.1).



Chainage (m)	0	30	60	90	120	150	180	210	240	270
Ground level (m)	9.01	9.35	9.4	9.35	8.87	8.72	9.05	9.3	9.62	10.0
Pipe invert level (m)	8.10	8.05	8.0	7.95	7.90	7.85	8.15	8.4	8.7	9.0

Pipe diameter: 280mm (non reinforced concrete) (chainage 0 to 270)

Gradient 1 in: 600 (chainage 0 to 150); -104 (chainage 150 to 270)

Figure 6.2 Long Section Profile and Hydraulic Grade Line

CHAPTER 7. Cost Analysis of Buried Pipe Distribution Systems.

7.1 Introduction

In this chapter outline costs for different types of buried pipe systems are presented and compared with open channel alternatives. Only data where both buried pipe systems and open channel systems are detailed are discussed in full.

Most of the system cost information, presented and discussed, is for systems in south Asia, and was collected either during field visits or is drawn from the collaborative research work conducted in Bangladesh. Because of the range of system designs used in the different projects described, very specific conclusions on comparative costs are not possible, however general trends and relationships can be established.

Pipe system costs are compared on the basis of their unit length as well as with regard to the overall system costs. System costs are firstly compared with the inclusion of the value of land lost and cost of water control structures provided (for open channels) and secondly compared on a per hectare basis taking into account the effect of improved transit efficiency on the command area.

Apart from capital costs other components of cost examined include the value of land taken by the distribution system, maintenance and repair costs, and expenditure on fuel for pumped systems and on labour in all systems.

7.2 General Comparison of Alternative Distribution System Costs

7.2.1 Data Sources

In the following tables 7.1 - 7.6, cost data for systems in Bangladesh, India, Indonesia and Nepal are presented. They are discussed in the sections which follow. While most of the data are drawn from Bangladesh and Nepal sources some very general costs are given for other south Asian situations. No data were obtained for systems using the newer thin walled uPVC pipe materials now available.

Each country and region will clearly have slightly different requirements for the design of their buried pipe system. When examining cost information from specific countries it is important to recognise that unique conditions will influence the choice and cost of buried pipe technology.

Specific features which are important in the choice and cost of buried pipe systems in

Bangladesh include:

1. The absence of local sources of aggregate in many parts of the country, which necessitates the use of locally manufactured brick broken into chips as aggregate for all types of concrete.

2. Because of the high level of unemployment and underemployment, labour wage rates tend to be very low, making material cost savings more valuable than labour savings.

3. The high intensity of land settlement, and the highly fragmented land ownership pattern, not only results in high land values, but is also an obstacle to the establishment of new improved irrigation distribution systems.

4. The absence of local petrochemical resources and manufacturing facilities and the shortages of foreign currency, have led the government to impose high rates of tax both on the resin raw material and finished uPVC products including irrigation pipes, to encourage the use of indigenously sourced materials.

Table 7.1 Comparative costs of distribution systems, Tangail, Bangladesh (1988)

Present value of costs in Tk per metre of canal/pipe

System	Land	Construction	Maintenance	Total(PV)
earth	33.3	16	26.7	76
BPD	nil	130	8.7	139
brick lined	26.7	340	high	400 c
in-situ conc	26.7	130	high	200 c

Source: Gisselquist, 1989.

Table 7.2 Comparative costs of distribution systems, BIADP, Bangladesh.

Distribution System	Cost in Tk per m	Right of way m	Land cost Tk/m	Total cost Tk/m
Earth Channel	29.5	3.05	64	93.5
Pucca brick lining	710	2.13	45	755
Pre-cast semicircular	240	1.5	32.1	272.1
In situ semicircular	356	1.5	32.1	388.1
low pressure concrete pipe 10"	225			225
6 " dia uPVC pipe	256			256

Source: Prokashali Sangsad, 1987.
Note: Land Value = Tk 210,000 per ha ($US 6000 per ha).

Table 7.3 Comparative costs of distribution systems, Tangail, Bangladesh (1990)

System	Right of way (m)	Present value of costs as at 1989-90 prices Tk/m		
		Land	Construction	Total
Unimproved earth channel	2.4	59	39	98
Improved (compacted) earth channel with control structures	3	75	105	180
Brick Lining	3	75	584	659
Pre-cast semi-circular	1.5	38	374	412
In-situ semi-circular cement concrete	1.5	38	558	596
Cement concrete buried pipe (10")	-	-	308	308
uPVC pipe 8"	-	-	770	770

Note: Land value = TK 250,000 per ha ($US 7140 per ha)
Source: Rashid et al, 1992.

Table 7.4 Suitability Comparison of Various Types of Open Channel Lining with Pipe Systems

Lining/Pipe Channel System Flow = 35 l/s	Suitability Score	Cost/m (Rp x 1000)	Ratio of pipe cost	Life expectancy without major rehabilitation
Lined Channel Alternatives				
1. concrete, insitu nonreinforced, trapezoidal thickness 50 mm	50	28.4	1.33	20
2. As for No. 1 with mesh reinforcement	55	32.4	1.51	25
3. Concrete precast,segment unreinforced, 350 bar	65	27.9	1.3	25
4. As for No. 3, reinforced 300 bar	65	31.9	1.49	30
5. concrete, precast slabs reinforced, 225 bar	37	28	1.3	10
6. Brickwork, double layer, pointed	34	24.2	1.13	10
7. Brickwork, double layer plastic layer, top layer only pointed	44	25.1	1.17	10
8. Stone masonry 1:4 mortar trapezoidal 200mm thick	37	31.2	1.46	10
9. Ferrocement, insitu, 35 mm with mesh reinforcing trapezoidal	52	26.2	1.22	15
Pipe System				
10. uPVC pipe 50 m head 1m deep	65	21.4	1	25

Source: Republic of Indonesia, 1990.

Table 7.5 Cost Summary for Buried Pipe Systems in India and Bangladesh

No.	Item	Uttar Pradesh (uPVC loop) (Rs)	US$	TADP (conc) (conc. branch) (Tk)	US$	Faridpur (conc branch) (Tk)	US$	IDA DTW II (uPVC loop) (Tk)	US$
1.	Tower or tank	19550	850	2000	57	6382	182	30800	880
2.	Cost of Pipe			114175	3262	122058	3487	451972	12913
3.	Valves			9835	281	13876	396		
4.	Jointing			19920	570	33352	953		
5.	Trenching			14363	410	29950	856	40937	1169
6.	Other structures			27708	791	15530	444	7748	221
7.	Field Channels	9750	424	10500	300	10500	300	10500	300
	Sub Totals								
	Dist Chamber	19550	850	2000	57	6382	182	30800	880
	Dist System	216200	9400	186000	5315	214766	6136	500657	14304
	Field Channels	9750	424	10500	300	10500	300	10500	300
	Total	245500	10674	198500	6300	236071	6618	541957	15483
	Command (ha)		100		40		40		40
	Cost per ha		1067		158		165		387

Note: conc. = nonreinforced concrete pipe

Source: Unpublished material from TADP and IDA DTW II Projects Bangladesh, and Uttar Pradesh Tubewell Project II, Lucknow, India.

Table 7.6 Summary of Deep Tubewell Distribution System Costs, Nepal

(Rs Nepal '000 at 1987 prices)

ITEM	300 m^3/h			150 m^3/h		
	Piped (uPVC) (Loop)	Lined (Brick)	Unlined (Earth)	Piped (uPVC) (Loop)	Lined (Brick)	Unlined (Earth)
Well						
Borehole	373.6	373.6	373.6	232.2	232.2	232.2
Pump	112.0	112.0	112.0	80.2	80.2	80.2
Electrification	300.0	300.0	300.0	172.5	172.5	172.5
Sub-total	785.6	785.6	785.6	484.9	484.9	484.9
Wellhead Works						
Pumphouse	24.4	24.4	24.4	22.4	22.4	22.4
Discharge box	0.0	7.6	7.6	0.0	5.7	5.7
Control tank	76.5	0.0	0.0	51.0	0.0	0.0
Land	5.0	5.0	5.0	5.0	5.0	5.0
Sub-total	105.9	37.0	37.0	78.4	33.1	33.1
Total Well Costs	891.5	822.6	822.6	563.3	518.0	518.0
Distribution						
Channels	6.2	1,148.0	89.6	3.1	496.0	46.2
Buried Pipes	636.5	0.0	0.0	318.2	0.0	-
Structures	0.0	123.4	110.5	0.0	70.9	66.7
Land	0.0	22.5	22.2	0.0	9.9	8.7
Sub-total	642.7	1,293.9	222.3	321.3	576.8	121.6
Totals						
Construction	1,534.2	2,116.5	1,044.9	884.6	1,094.8	639.6
Engineering (10%)	153.4	211.7	104.5	88.5	109.5	63.9
Overall total	1,687.6	2,328.2	1,149.4	973.1	1,204.3	703.5
Command Area (ha)	88	80	60	44	40	30
Costs per Hectare		(Rs '000)				
Distribution System*	7.3	16.2	3.7	7.3	14.4	4.1
Total Unit	19.1	29.1	19.2	22.6	30.1	23.5

Note: * including 10% for engineering
Source: GDC (1987).

7.2.2 Unit Capital Costs

Unit cost data is drawn largely from Bangladesh and Nepal sources, and is supported by data from a study prepared for the Indonesian government. Because the pipeline component of the buried pipe system comprises from 60 to 90% of the cost of the total system, unit length pipe or channel costs can be used to compare different pipe systems, particularly where system designs are similar. For example, table 7.5 gives the cost of uPVC pipe in the pipe system built by IDA DTW II Project in Bangladesh as 84% of the cost of the distribution system.

The unit capital costs of open channels exclude the costs of necessary water control structures, land take by the open channels or infrastructure associated with the pipe system. These costs are included in the comparison of total system costs detailed in section 7.2.3.

Bangladesh

Bangladesh data, for three different projects are detailed under the heading of construction costs in tables 7.1, 7.2 and 7.3. The data indicates the unit construction costs of earth channel systems to be some 10 to 15 % of the cost of providing nonreinforced concrete pipes.

Comparable concrete and brick lining systems are considerably more expensive than concrete pipe, because of the higher material content of brick aggregate and cement. At best (concrete precast) lining alternatives are only 20% more expensive, while at worst (total brick lined channels) they can be up to 300% of the cost of concrete pipe. Because of the high level of government tax and tariffs mentioned, uPVC pipe materials are considerably more expensive compared to concrete pipe materials particularly as pipe size increases. While data from table 7.3, indicates uPVC pipe systems to be more than twice the cost per unit length of concrete pipe systems, data from table 7.2 indicates the costs per unit length as comparable between concrete and uPVC materials, where the uPVC pipes costed were of small diameter (150 mm).

Indonesia

The notable feature of the Indonesian data presented in table 7.4, is the very competitive cost of uPVC pipe systems compared with other hard surface lining materials, suggesting either indigenous sources of uPVC resin for manufacture, and/or low rates of government taxes and tariffs.

Despite the wide range of lined channel alternatives examined, the differences in unit cost are small (10-20%), with typically the stone masonry and reinforced concrete channel segments proving the most expensive, probably because of the greater quantity of higher cost materials used.

Nepal

Scheme cost estimates, for open channel distribution systems, prepared by GDC (1987), are based on the average of unit rates collected in the Terai area of Nepal, and are given in table 7.6. Costs for buried pipe system components are based on rates for pipes, fittings and alfalfa valves at the pipe outlets, for comparable systems built in Uttar Pradesh, India.

Scheme estimates for the capital cost of lined and unlined channels set these at 178% and 14% respectively of the cost of uPVC pipes, not including the provision of control structures and the value of the land take. The channel lining in this case is half brick and relatively expensive compared to prefabricated concrete lined alternatives used in other parts of the world.

7.2.3 System Capital Costs

i) Distribution System Cost including Structures

While unit cost comparisons give an initial indication of the relative cost of buried pipe systems, they underestimate the cost of lined and unlined channel alternatives, by not including the cost of providing water control structures nor the value of land lost.

Bangladesh

When the cost of structures within the distribution system, and the value of land lost are added, Rashid et al (1992) (refer to table 7.3) suggest that earth channel systems, cost in the order of 55 to 60% of a concrete pipe system. The improved earth channel has a right of way, which at 3m, is twice the width assumed for pre-cast concrete lining and the value of the land occupied is estimated at 40% of the cost of the distribution system. Note that improved earth channel systems with water control structures are considered to be about twice the cost of unimproved earth channel systems.

Data from Gisselquist (refer table 7.1) suggest earth channel systems to be about 40% of the cost of concrete pipe systems where the difference in maintenance cost is not included. This is also supported by data from Prokashali Sangsad (1987), detailed in table 7.2.

Overall pipe system costs presented in table 7.5, indicate the substantial cost difference between concrete and uPVC pipe systems built in Bangladesh, with the uPVC pipe system being more than twice the cost.

India

Although no detailed data have been obtained for any particular system, general system costs were noted for pipe systems built using a range of designs and materials in central and northern India. In table 7.5, costs for the uPVC pipe system built in Uttar Pradesh are compared with costs for concrete pipe systems in Bangladesh (TADP and Faridpur) and a uPVC pipe system built by the IDA DTW II Project.

When considered in terms of $US per ha, the Indian uPVC pipe system is 1.7 times the cost of the concrete pipe systems built in Bangladesh, but still considerably cheaper than the uPVC pipe system built in Bangladesh, because of the different tax and tariff structures which apply. The Bangladesh pipe systems serve about 40 ha while the Indian systems serve 100 ha.

Other pipe systems in India for which overall costs were identified included the following:

No. Scheme Name	Rs per ha	$US per ha
1. Vindhyasini Akkadselarge Lift Irrigation Scheme	16560	920 (1986)
2. Pipaldagarhi Lift Irrigation Scheme	29200	1622 (1990)
3. Gadigaltar Tank Irrigation Scheme, Total scheme	40350	1614 (1991)
Gadigaltar Tank Irrigation Scheme, Distribution system	9770	390

Source: Data collected during research study trip.

Nepal

When the cost of land taken by the distribution system, and the provision of structures, is included the capital cost of lined and unlined channels rises to 198% and 35% respectively of the uPVC pipe systems considered (refer to data in table 7.6). The cost of the land take is considered to represent only 10-15% of the total cost of providing a system with earth channels.

U.S.A.

While the USA possesses the largest area currently served by buried pipe distribution systems, very little relevant cost information has been obtained for these systems. Keller (1990), summarises data on U.S.A. costs for a range of modern irrigation systems among which buried pipe systems for surface irrigation can be considered one option. These detail the cost of precision surface irrigation (precise land levelling) with buried pipe systems, as ranging from $US 800 - 2500 per ha. This is more expensive than low cost sprinkler application techniques but cheaper than solid set sprinkler systems and localised irrigation by drip or spray, which cost in the range $US 2000 - 3500 per ha.

He also concludes that costs for similar systems in developing countries will be from 25 to 100% higher because of the small farm sizes, freight costs, foreign exchange and technical difficulties.

The upper cost range for buried pipe systems refers to surface irrigation where large fields are precisely levelled by machine. If the small basin irrigation systems with pipe systems, found in developing countries, are considered to be at the lower end of the cost range, then expected costs without adjustment would be in the vicinity of $US 1000 - 1200 per ha. Only two Indian schemes (costs already summarised) have system costs which approach these. Bangladesh system costs, already mentioned, are a fraction of these, probably because of the use of a high proportion of local labour and materials, and an emphasis on system affordability.

ii) System Costs Including Improved Transit Efficiency

When the overall system costs are considered in terms of the cost per hectare of land irrigated, taking into account the higher transit efficiency of pipe systems, a slightly different picture emerges. Table 7.6 provides summary data for comparative system costs in a Nepal context while Table 7.7, provides summary data based on Bangladesh experience, and must be considered purely indicative of likely costs.

The two analyses compare capital costs for the distribution system as well as the entire surface irrigation system. The water supply in both the Nepal and Bangladesh systems comprises a deep tubewell. Costs do not include operation and maintenance expenditure, nor any allowance for depreciation and eventual system replacement.

Table 7.7 Capital Cost Comparison for Bangladesh Distribution Systems (US $ '000)

Item	Nonreinforced concrete pipe	uPvc pipe	Earth channel	Brick lining
Well, pump, motor and pumphouse	17.1-22.9	17.1-22.9	17.1-22.9	17.1-22.9
Discharge box	0.0	0.0	0.2-0.3	0.2-0.3
Header Tank	0.4-0.6	0.4-0.6	0.0	0.0
Sub-total Well costs	17.5-23.5	17.5-23.5	17.3-23.2	17.3-23.2
Distribution				
Channels	0.0	0.0	1.4-1.7	14.3-20.0
Buried Pipes	8.6-11.4	15.7-18.6	0.0	0.0
Structures	included	1.1-1.7	1.1-1.7	1.1-1.7
Sub-total Distribution system	8.6-11.4	16.8-20.3	2.5-3.4	15.4-21.7
Overall Total	26.1-34.9	34.3-43.8	19.8-26.6	32.7-44.9

Sources: Costs are drawn from a number of sources which detail costs as at June to December 1990 for Bangladesh built schemes, including MMP (1989a) and TADP (1989).
Tk 35 = 1 US $.

Transit Efficiency

In order to compare per hectare costs for buried pipe systems with both lined and earth channel alternatives, representative transit efficiencies for each system must be estimated.

Table 7.8 below gives transit efficiency estimates based on Bangladesh field work, and data from section 2.6. Average pipeline transit efficiencies of 80% for concrete pipeline systems and 90% for uPVC pipe systems are considered realistic, while earth channels and lined channels are estimated to have 50% and 70% transit efficiencies respectively. This is supported by research work conducted in Bangladesh which suggested that concrete pipe systems had at worst 25% of the losses typical on lined channel systems and less than 10% of those on earthen channel systems (Rashid et al 1992). PVC pipe system losses are assumed to total 10% based on an average rate of outlet leakage on 40% of the outlets in the system (observations of systems in Uttar Pradesh, India).

Table 7.8 Field Measurements of Transit Efficiency

Pipe Material	Seepage lps/100m	Pipe Length (m)	Discharge (lps)	Transit Efficiency (%)
1. nonreinforced plain ended concrete pipe with sacking wrapped joint				
a. average	0.33	500	35	95
b. poor	0.69	800	40	86
2. uPVC	NK	1500	56	95
3. uPVC	NK	300	20	95
4. Earth channel	7.7	3-400	45	50

NK: not known
Source: Rashid et al (1990) and south Asia study tour.

Bangladesh

The following assumptions have been made regarding the design and operation of the schemes costed:

The irrigation system distributes water from a deep tubewell with a pump discharge of 56 l/s. Four possible irrigation distribution systems are considered, including an earth channel system with water control structures, a brick lined system, a nonreinforced concrete pipe system and a uPVC pipe system.

(i) The concrete buried pipe system has a total length of 1800 m comprising three separate 600m branches.

(ii) The uPVC pipe system comprises two loops of 150 mm pipe each of which is 1300 m in length.

(iii) The earth channel system is 2000 m in length and of compacted earth and includes concrete water control and outlet structures.

(iv) The brick lined channel is also 2000 m in length and has outlet and water control structures.

The costs relate to a typical Bangladesh command area with relatively flat topography and few obstructions. Where the command is undulating or dissected to any extent the open channel distribution systems are likely to become significantly more expensive if not infeasible in some situations.

Field channel systems are considered equivalent in extent and area for each of the schemes for simplicity, although in practice differences may well exist.

The cost analysis indicates that earth channel systems are about 30 to 35% (distribution system costs only) and 70 to 80% (where well costs are included) of the cost of concrete pipe distribution systems. In this case compaction is assumed and structures for water distribution are provided.

Brick lined channel systems are twice the cost of concrete pipe systems, with uPVC pipe systems comparable in cost to brick lining at both the distribution system and total system (including well costs) levels.

System Costs per hectare of land irrigated

Ignoring non-engineering factors, the irrigable area for a particular discharge can be said to depend on the transit (pipeline distribution) efficiency. The net irrigable area assuming a transit efficiency of 100 %, is 50 hectares.

Poorer transit efficiencies will result in smaller command areas and higher capital costs per hectare of irrigated land as shown in table 7.9.

Table 7.9 Transit Efficiency, Irrigable Area and Costs per hectare for Bangladesh Systems.

Item	Nonreinforced concrete pipe	uPVC pipe channel	Earth	Brick lining
Transit				
Efficiency (%)	80	90	50	70
Irrigable Area (ha)	40	45	25	35
Costs per ha (US $)				
Distribution system	215-285	373-451	100-136	440-620
Well costs	438-588	384-522	692-928	494-663
Total (incl well costs)	653-873	757-973	792-1064	934-1283
Relative Costs	0.86-1.15	1.00-1.28	1.05-1.41	1.24-1.69

Source: The costs are drawn from Table 7.7.

The relative costs (which are independent of the 50 ha assumption) show clearly that the more efficient buried pipe systems should give a lower capital cost per hectare than open channel systems, as the fixed cost of the well is spread over a larger area.

When considering the distribution system alone, earth channel system costs rise to nearly 50% of the cost of concrete pipe alternatives, while uPVC pipe systems are 1.7 times and brick lining more than 2 times the cost of concrete pipe systems.

Where total well costs are included (deep tubewell) earth channel systems become comparable ($US 924 per ha), and even slightly more expensive than concrete ($US 707 per ha) and uPVC pipe systems ($US 815 per ha), while brick lining remains the most expensive alternative ($US 1104 per ha).

Similar calculations would apply in other situations, for example, if the irrigable area is fixed the source could be smaller and cheaper (whether a tubewell, canal or reservoir) with a buried pipe distribution system than with open channels, though the savings may not be as significant.

Nepal Comparison of System Cost

Data from Nepal used in the second cost comparison, and detailed in table 7.6 are based on the buried pipe systems designed and constructed in Uttar Pradesh, India and described in case study 4.6. Systems of this type with elevated tanks and loop uPVC pipelines have also been constructed on the Terai area of Nepal, under the Bhairawa Lumbini Project (GDC 1987).

The earth and lined channel systems are assumed to comprise 1300 m of channel with associated water control structures, so a similar level of water management is possible as would be available with buried pipe systems. Two different sizes of irrigation system were examined by GDC (1987), to see whether economies of scale applied. In a similar way to the Bangladesh model the differences in transit efficiency are assumed to result in a larger irrigable command area, for a fixed inflow discharge.

The relative transit efficiency estimates chosen by GDC (1987) are very conservative, in the light of the ten fold difference in seepage rates, measured between unlined channels and pipeline systems during Bangladesh based field work. Pipe systems are considered to be 90% efficient while lined and earth open channels are assumed to have transit efficiencies of 80 and 60% respectively.

If considering the distribution system costs over a fixed command, an earth channel distribution system is equivalent to 60% of the cost of a buried pipe system, while a lined system is more than twice the pipe system cost of NRs 7300/ha. When the command area is varied in relation to the transit efficiency achieved, earth channels become equivalent in cost to buried pipe systems at around NRs 20 000 per ha, while lined channel systems remain 50% more expensive at NRs 30 000 per ha.

Lower operation and maintenance costs are likely to further increase the gap between buried pipe and lined channel systems.

The above analysis of pipe system costs in Bangladesh and Nepal assumes that transit efficiency is the critical constraint. Fieldwork carried out in Bangladesh (Rashid et al, 1992) found that irrigated areas on the selected tubewells were considerably less than design, and were constrained principally by poor scheme management and inadequate extension services. This is supported by evaluations of the performance of buried pipe irrigation schemes, such as have been completed by Kolavalli and Shah (1989) on the Uttar Pradesh Project and by Pant (1989) on the new design of public tubewells in Uttar Pradesh.

Until socioeconomic, institutional and managerial issues are considered more carefully during design and resolved at an early stage, then the full potential of buried pipe systems is not likely to be realised.

7.3 Non-Capital Cost Considerations

7.3.1 Introduction

Apart from the cost of the land taken by open channel systems, data on quantified savings in non-capital costs have not been sourced. Based on the field evaluation of pipe systems visited during the research, a summary of relative costs for each of the different pipe systems is presented below in table 7.10. Real costs are not presented but rather cost ratios based on the expected cost for a uPVC pipe system expressed as 'x'. In all cases it is considered that pipe systems provide a considerable saving in maintenance and operating costs and operator and farmer labour.

Operating costs for fuel and oil are considered to be indirectly proportional to the transit efficiency though an allowance for the 3 to 4 m increase in the delivery head on pipe systems is made by reducing the open channel operating cost ratio by ten percent.

Table 7.10 Ratios of Non-Capital Costs

Item	Nonreinfor Concrete	uPVC Pipe	Earth Channel	Brick Lining
Land Take (ha)	nil	nil	0.25-0.5	0.2-0.4
Maintenance costs	1.5 X	X	3-5 X	3-8 X
Operating Costs				
Fuel	1.2 X	X	1.7 X	1.3 X
Labour (operator)	1.5 X	X	3 X	2 X
Labour (farmer)	X	X	2 X	1.5 X

7.3.2 Cost of Land Take

The information presented in tables 7.2 and 7.3 indicates the average right of way for earth and brick lined channels to be 2 to 3m. If a typical open channel distribution system serving 40 ha is assumed to have 1400 to 1800 metres of channel, then the land take would range from 0.28 to 0.53 ha (0.7 to 1.3% of the command).

Work completed in Bangladesh estimates the saving of land due to the use of buried pipe systems as averaging 1.2 % (refer to section 2.6.2). Although this represents only 0.48 ha on a 40 ha command, in some intensively settled areas very high land prices can make this a valuable saving.

For example in Kerala, India, with land values of Rs 500,000 per ha (Campbell 1984), the cost of 0.48 ha of land (Rs 240,000) represents almost the entire cost of the pipe distribution system as built in Uttar Pradesh. A similar comparison in Bangladesh can be made where land in Tangail District has a value of Tk 200,000 to 250,000 per ha. An area of 0.48 ha represents 25 and 45% of the capital cost of a uPVC and concrete pipe system respectively.

Strictly the value of the land take should be considered in terms of the income lost rather than the sale value of the land, however the comparison is illustrative and helps to assess the land's value for wealth creation and the provision of living space.

7.3.3 Maintenance Costs

Actual data on the level of maintenance costs for buried pipe systems compared to open channel systems have not been sourced, although a number of references suggest estimates based on monitoring of costs for high pressure systems. Rouke (1984), suggests that maintenance costs for high pressure pipe systems total 0.5% of the replacement cost of the pipe system.

Gisselquist assumes an annual expenditure on pipe systems of 1% of the capital cost, and for earth channel systems a sum of 25%, which is included in the costs presented in Table 7.1. Despite the differences in capital costs this gives earth channels an annual expenditure twice that of buried pipe systems.

Very limited data recorded by Rashid et al (1992), indicated maintenance costs on pipe systems to be 18% of those on equivalent earth channel systems. However because most of the expenditure on the pipe systems was connected with diesel motor and pump repair, and the method of detailing the costs does not allow pipe system maintenance costs to be separated out, these data are considered rather unreliable.

An important part of the estimate of the maintenance cost of buried pipe systems, is the expected length of service for the pipeline. As a pipe system approaches the end of its life the maintenance costs of the system can be expected to rise significantly. While the life of non-reinforced concrete pipe systems manufactured in south Asia is unclear, pipe systems built in the early 1930's and 1940's in the USA, are still functioning reliably according to reports by Baudequin et al (1990) and Merriam (1987a). High pressure uPVC pipe systems have now been in service for well over 20 years and Walton and Elzink (1988) in assessing the condition of existing pipe installations conclude that the 50 year design life currently used for uPVC pipe may be too conservative, and that under good conditions a 100 year design life is more realistic.

7.3.4 Labour Requirements

The opportunities provided by buried pipe systems to reduce the labour involved in scheme operation and maintenance are difficult to quantify. Ways in which buried pipe systems reduce the labour input to irrigation systems are described.

By cutting the length of open channels the labour required for annual maintenance is reduced.

On closed and semi-closed pipe systems where operation can be controlled from the head of the system, an operator is required to spend less time directing water to the particular part of the command, provided the necessary irrigation schedules have been agreed.

Because systems with higher transit efficiencies potentially deliver higher flow rates to the field, the farmer can spend less time irrigating and apart from the opportunity presented to improve farm water management.

7.4 Conclusions on Cost Data

i) General

With all the emphasis given to developing effective channel lining solutions, it is surprising to discover evidence for the comparability in cost of pipe systems. However because of the very limited amount of data sourced, it has not been possible within the scope of this thesis to more than suggest the cost competitiveness of buried pipe systems. This should however be sufficient to give designers and irrigation practitioners the confidence to try pipe systems, if only because the operating advantages over more traditional lining solutions, appear to be gained at little extra cost.

Unfortunately very little useful information has been obtained on the maintenance and operating costs of buried pipe systems and considerably more data will be required before conclusions can be drawn on the potential benefits quoted.

The improvements in transit efficiency demonstrated, with buried pipe systems are not always reflected in increases in the irrigated area. Spreading the cost of the water source over larger command areas and achieving more equitable flow division, will only achieve increases in irrigated area, where limited water supplies, well developed organisational structures and high value crops provide the incentive for irrigators to cooperate.

Although the cost data is limited, some general conclusions can be made regarding buried pipe systems which have been built in south Asia.

ii) Capital Cost

In all the situations examined, pipeline distribution systems can be built which are less expensive than a wide range of hard surface lining system alternatives. In general concrete pipe systems will be considerably less expensive than uPVC systems where the same level of service is provided. Whether uPVC pipe systems are competitive with open lined channel systems, will depend on pricing mechanisms in-country for uPVC pipe raw materials and the types of lining system commonly built. The brick lining systems widely constructed in south Asia, will generally be considerably more costly than buried pipe alternatives.

While earth channel systems at worst will be 50-60% of the cost of concrete pipe alternatives, if the cost of the water source is spread over the command area adjusted for the higher transit efficiency, then the cost differences are small. The lower operating and maintenance costs would be likely to favour the selection of the pipe system.

Clearly the most competitive pipe material option will vary with country and location but in all cases careful selection should enable buried pipe distribution systems to be built at a cost which is less than any hard surface lining alternative.

iii) Other Costs

The importance of other cost savings, such as land take by open channel systems, and reduced labour costs will be important in different places. Where land is limited and high in value, such as in Bangladesh and northern India, land take becomes an important consideration, while labour costs are an important constraint in countries such as Thailand.

iv) Pipe Materials

The cost reductions possible with locally manufactured nonreinforced concrete pipe, with simpler jointing and the thin walled uPVC pipe materials now becoming available, may provide opportunities for extending the use of buried pipe systems, by improving the benefit/cost ratio. Future cost analysis should examine lower cost uPVC pipe systems using the newer thin walled corrugated materials now being marketed for low pressure applications.

CHAPTER 8. Conclusions

8.1 Introduction

Buried pipe distribution systems (BPDS) for surface irrigation have been and continue to be built, in many and various forms, in a large number of countries and situations throughout the world, and interest in their applicability to different irrigation systems is growing.

Most pipe systems built in developing countries comprise outside agency and government supported pilot projects, while private irrigator funded development, with the exception of western India, has generally been limited to systems built in the U.S.A. and parts of southern Europe.

Technically pipe systems which have been built, generally function successfully in the way in which they were designed. However where pipe systems are perceived as offering the solution to the problems of low irrigation intensity on existing irrigation schemes, their performance can be disappointing where the institutional and management constraints remain unresolved.

In other situations the overall system efficiency of buried pipe systems may be less than optimum, because systems are operated in ways not intended or allowed for by the designer. This can occur for example during low demand periods or where irrigators can not agree to share water, and high discharge flows are taken in field channels which are of inadequate capacity, leading to excessive field channel seepage losses. Sensitive pipe system design can however help to resolve management and organisational problems which lead to poor levels of performance.

Poor overall system efficiencies and lower than expected irrigation intensities, may be reasons for the less than widespread adoption of buried pipe systems. Also the views of some practitioners that buried pipe distribution systems are expensive, may be based on limited cost comparisons of pipe systems and open channel systems, where the reduction in land take and cost of water control structures for open channel systems are not considered.

The literature concerning the design of buried pipe systems is generally poor and widely scattered. Those publications describing buried pipe systems, tend to consider them in a very narrow context, with little apparent awareness of the many and varied design and management alternatives available.

The absence of design procedures and definitions for the different pipe systems was clearly an obstacle to an appreciation of the role of buried pipe systems. Illustrating the range of pipe systems in existence also helps designers to diverge from the limited models of buried pipe systems which are reported in the literature. Pipe systems can be essentially designed to function in a wide variety of ways, using many different pipe materials to provide an irrigation supply as variable as exists on the open channel systems they replace, but with all the advantages of pressurised distribution, and self-regulation.

8.2 Classification and Definition of Buried Pipe Systems

Although systems of many different types have been built they can be categorised and compared within a simple framework. Essentially pipe systems can be classified on the basis of the method of pressure control (open, semi-closed and closed) and with regard to the origin of the driving head (pumped or gravity supply). This framework more clearly defines low pressure pipe systems, compared with definitions cited in the literature. The definitions and diagrams detailed, provide an improved understanding of the function and limitations of each type of pipe system, and so help to identify the situations in which particular pipe systems are suitable.

In general open pipe systems while allowing the use of very low pressure pipe materials, also require frequent adjustments to control gates and valves to balance the inflow discharge to the pipe system with the outlet discharge. Operation is therefore relatively labour intensive and the advantages of on-demand operation are not available.

Semi-closed pipe systems, though at present little known, allow open pipe systems to become self-regulating where supply is by gravity or to be regulated at the inlet to the pipe system, in the case of pump supply systems. Greater use of semi-closed systems will depend on improved availability of the proprietary float valves, and awareness of the design procedure for the valve and stand.

Closed pipe systems can also be self-regulating where there is gravity supply and have the potential to be automatically regulated where the supply is from an electric motor driven pump. They will continue to be the most favoured type of pipe system given their flexibility to accommodate very different topography, and a wide range of low pressure pipe materials.

8.3 Pipe System Benefits

General

Considerable evidence supports the contention that buried pipe systems reduce transit losses and land take by the distribution system, compared to earth and lined open channels. This will only be translated into overall efficiency improvements where earth field channels are relatively short and in good condition. Work in Bangladesh suggests that transit efficiency losses may be reduced to about a tenth of those on earth channels and a quarter of those on lined channels, while the saving in land take may be as much as 1.2% of the irrigation command area.

Low pressure buried pipe systems are an attractive alternative to open channel systems at the tertiary level particularly where water has to be pumped from the source or ground slopes are steep, and where coarse textured soils would result in high seepage losses from earth channels. This is important where water is limited and expensive as in the case of pump lift irrigation schemes.

Where the command area is undulating, pipe systems can allow an expansion into areas which could not be serviced using open channels. Where the water supply is valuable and limited, buried pipe systems allow a wider range of water sharing strategies to be adopted and make it practical to distribute water for very short periods.

Other advantages of buried pipe systems are that they can be installed much more quickly than open channel systems, require less intensive site surveying, and result in fewer delays in obtaining agreement on alignment for new irrigation systems. Where pipe systems are built with sufficient capacity and operational choice, the irrigation supply can be more flexible enabling more varied cropping patterns and improved water management practices to be adopted. Real increases in irrigated area will depend on realising higher returns for crops grown and evolving effective organisational structures for managing the schemes.

Environment

Although little specific information has been found on the environmental and health impact of buried pipe distribution systems, the documented savings of agricultural land, reduced water losses and elimination of suitable habitats for disease vectors will all have a positive impact, compared to open channels.

8.4 Pipe System Selection and Materials

Selection

The appropriate use of buried pipe systems depends on careful selection of the type of pipe system best suited to the prevailing physical, social and economic conditions. Selection and design must include the way in which the system is to be operated and controlled, as well as its suitability for the topography and water source available. This choice must be made in close consultation with the irrigators, and with an awareness of the problems which have occurred in past schemes.

In general manual regulation of inflow discharge to buried pipe systems, together with careful selection of the system of operation and control can achieve a more equitable and flexible supply compared to equivalent open channel systems. Flexibility is considered to be the ability to switch water from one part of the command area to a another with the minimum loss of time and water.

While a flexible supply is seen as important in the move to more diversified cropping systems, with the wider range of different soil and water requirements, most pipe systems still serve cropping systems irrigating relatively extensive cereal crops.

Automatic control of electric pump supply systems is possible, though it is seldom completely reliable, and will be less important to the success of the scheme than the ability of irrigators to cooperate in operating the scheme as it was designed to operate.

In terms of system operation wherever the inflow discharge to the pipe system is greater than the flow which can be comfortably handled by one irrigator, flow division is best achieved at the head of the pipe system, by dividing water into separate pipe networks. Other alternatives while practical, appear to result in conflict and modes of operation which do not allow the higher transit efficiencies of buried pipe systems to improve overall scheme irrigation efficiencies.

Pipe Materials

Although asbestos cement pipe has been used in situations where other pipe materials are not available, current material choice is between lower cost nonreinforced concrete pipe with its problems of joint leakage and higher cost uPVC pipe materials. More expensive uPVC pipe systems are considerably quicker and easier to install successfully and achieve higher transit efficiencies, which is important where a loop layout is to be used.

Alternative thin walled corrugated uPVC pipe materials are now being manufactured and used for low pressure water distribution. They merit evaluation because of the considerable potential for capital and installation cost savings over more traditional rigid plane walled uPVC pipe, particularly for pipe sizes greater than 250 mm diameter.

Nonreinforced concrete pipes can be manufactured reliably by a range of methods including low cost pipe spinning technology, given adequate attention to the composition of the concrete mix and curing of the finished pipe. The quality of pipeline installation and the choice of the jointing system also appear to be critical to the final performance of the pipe system, by influencing the frequency with which leaks develop. Tongue and groove concrete pipe, jointed with a mortar seal, appears to offer a more reliable joint alternative to the plain mortar band used on plane ended concrete pipe.

8.5 Pipe System Design and Construction

Outlet selection and pipeline layout preparation depend on reconciling beneficiary requirements with rationalising the complexity of the pipe system. Apart from the design of open stand pipes and float valve stands for open and semi-closed systems, hydraulic design relies on matching the available driving head at the inlet to the pipe system with the allowable friction losses for flow to the critical outlet.

Elements of system design which differ from more traditional pipe system design, include water hammer protection and the design of open and semi-closed pipe systems and their associated pressure control structures.

A wide range of specifications and construction practices are in use and designers admit to significant uncertainties. Opportunities clearly exist through the sharing of information on proven aspects of buried pipe system selection and design to reduce the cost and improve the quality and performance of the buried pipe systems currently being constructed.

Given the large and growing level of interest in the technology and its impact on the performance of new and existing irrigation systems, there is a clear need to continue evaluation of particular systems and extend the survey of pipe system design and construction to countries and situations not yet covered. Monitoring and evaluation studies which have been identified during this research exercise have concentrated on the impact of irrigation in general and do not allow for the effect of the buried pipe system in particular to be separated out.

8.6 Pipe System Costs

Buried pipe systems built in a range of situations and countries in south Asia in all cases cost less than lined channel alternatives. The capital cost saving to buried pipe systems, ranges from 10% less than low cost ferrocement lining as used in Indonesia, to 50% less than the cost of brick lining systems as built in Bangladesh and Nepal.

Although earth channel systems are considered low cost, when the land take and required water control structures are included, system costs range from 35 to 50 % of comparable nonreinforced concrete pipe systems. When the higher distribution efficiency of pipe systems is taken into account so that the cost of the water supply (reservoir, tubewell or secondary canal) is spread over a larger command area then pipe systems are comparable in cost to earth channel systems. The relative cost of uPVC pipe systems will depend on duty and tariff structures present in the countries concerned and the relative cost of local alternatives. Costs of uPVC pipe systems range from 10% less than concrete lining alternatives (Thailand) to being comparable to the cost of expensive brick lining alternatives (Bangladesh).

While concrete pipe systems can be recommended over lined channel alternatives on cost grounds, uPVC pipe systems may be justified when higher levels of performance and more reliable installation are important.

Unfortunately the impact of buried pipe systems on maintenance and operating costs of irrigation distribution structures could not be properly assessed given inadequate data. Maintenance problems and costs are incurred on all pipe systems. It may be reasonable to suppose that maintenance costs would decline as the level of technology used in manufacturing and constructing the pipe system increased, but this has not yet been established. Careful specification, design and construction of pipe systems can avoid most maintenance problems. Their importance however will relate not so much to relative cost but to the ease with which repairs can be completed.

In common with any other infrastructural investment, adequate maintenance of buried pipe systems will depend on the existence of effective community organisation and commitment.

8.7 The Future for Buried Pipe Systems

Low pressure buried pipe systems represent a neglected opportunity, but despite their long history are still largely unknown in many parts of the world. It is hoped that awareness of the types of pipe system and their suitability for different situations will encourage pipe systems to become part of the feasibility assessment for every irrigation scheme to be constructed or rehabilitated. Sufficient design information has been assembled and organised to allow engineers and irrigation practitioners to consider buried pipe systems alongside more traditional open channel options.

Field evaluation has shown that buried pipe systems can be constructed successfully in a wide range of situations, to achieve significant savings in land and water while delivering a more flexible and reliable irrigation supply to the irrigator, compared with traditional open channel systems. By incorporating more recent design, construction and material innovations, the opportunity exists to make pipe systems which are lower in cost, simpler in concept and more suited to the needs of the irrigators using them.

If buried pipe systems are to adopted more widely than at present, not only do savings in capital cost, maintenance and labour need to be demonstrated compared to current open channel alternatives, but clear improvements to farm profitability must be apparent. While the ability to carry out diversified crop production is an important advantage for buried pipe systems, this will only be realised where there are markets for the produce grown, an adequate transport infrastructure and well developed levels of farmer cooperation.

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Appendix A.

Detail on pipe materials in use for low pressure buried pipe distribution systems.

A.1 Nonreinforced Concrete Pipe

A.1.1 Mechanised Vertical Moulding Techniques

Koluvek (1970) describes two methods which have been and continue to be widely used in the USA, namely the tamp stick and the packer-head vertical mould methods.

With the tamp stick process an internal form is used in addition to the outer mould, and stiff low slump concrete is slowly added while a series of rods are moved continuously inside the annular space, to compact the concrete. The interior pipe shutter or core, which defines the inside diameter of the pipe, is a cylindrical tube made of cast iron or fabricated steel. The exterior form or jacket comprises two halves which can be separated or stripped from the pipe after the form is removed from the machine and set vertically on the ground. The whole manufacturing process for one pipe takes as little as a minute. To achieve adequate curing and as an alternative to the daily application of water, in high humidity conditions newly manufactured pipes can be sealed within a plastic sheet covering (Koluvek 1990).

Tamp Stick

Koluvek (1970) notes that the first tamp stick machines used in the USA, which included concrete batching equipment, were not automated but had relatively low labour requirements. Current pipe factories are largely automated with much higher outputs of finished pipe. In a typical installation, pipe ranging in diameter from 200 mm to 350 mm can be produced, to a standard which conforms to ASTM hydrostatic test pressures of 30 m. Pipe is usually manufactured with tongue and groove joints and in lengths of about 1.3 m.

Packer Head

The alternative packer head method replaces the internal pipe form with a rotating mechanical trowel. Similar quality pipe is manufactured though the technique can accommodate a larger range in pipe size and reduces the expenditure on pipe forms. The equipment is more complex than the tamp stick equipment, but widely used in newer more automated pipe factories in the USA (Koluvek, 1970). Georgi (1989) mentions the existence of concrete pipe manufacturers with modern packerhead machines in operation in Bangladesh.

Both these techniques enable concrete of relatively low slump to be compacted to give high quality low pressure pipe. Merriam (1991) suggested costs for equipment made in the USA to manufacture this type of pipe, in the range of US$ 30 000 for reconditioned equipment and more than US$ 60 000 for new machinery (1991 prices) to manufacture pipe of 100-400 mm diameter and up to 1.3 m in length. This does not however include the cost of moulds and accessory equipment.

Alternative vertical mould manufacturing methods use vibrators and vibrating tables to achieve improved compaction of low slump concrete, usually by mounting the mould on a vibrating table or within a special housing. Chinese researchers (Dept. Sci. Tech. China, 1990) in Hebei province have developed a small vertical pipe making plant, which uses a modified vibrating table, and lifting equipment able to be operated by two people. Data regarding the cost and performance of this equipment, has however not been obtained.

A.1.2 Vertical Moulds, Hand Rammed

Georgi (1989) describes pipe manufactured by compacting hand batched concrete using hand held rods, inside a mould comprising both core and jacket forms. The pipe moulds can be made from different materials such as wood, iron sheets, and plastic though fabricated steel is the most common, and durable. However the only information obtained concerns the use of steel forms in Bangladesh. Georgi (1989) while describing pipe manufactured by this technique with different joint types such as socket and spigot, tongue and groove, and plain ended pipe, concluded that plain ended pipe was the easiest to manufacture. Forms for pipe incorporating alternative joint types were complicated and costly to manufacture.

Georgi (1989) describes briefly pipe manufacture with vertical shutters, whereby the core comprising several longitudinal mild steel sections, collapses into the interior of the pipe for easy removal. Burnt oil is specified for application to the formwork surfaces to prevent the concrete adhering, and compaction is achieved using rods agitated inside the mould space all the while concrete is poured into the mould.

Gisselquist (1989) in describing early TADP pipe manufacturing activities, reports that only grouting of the entire surface of the vertically cast pipes could ensure adequate sealing of the pipe. An early decision was also made to shift from spigot-socket to tongue and groove joints, in the light of difficulties encountered by masons constructing the system.

Achieving adequate compaction appears to be the major problem with vertical pipe manufacture carried out be hand, and a high proportion of the pipes manufactured have too high void space and hence are not water tight (Rashid et al 1992). In discussions with TADP engineers, the practice of lowering the water:cement ratio to ease compaction, was cited as a reason for the resulting weak and porous concrete pipe.

Experiences with this technique in the pilot phase of the project, led the Tangail Rural Development Project in Bangladesh to abandon vertical moulds in favour of centrifugally spun pipe (Georgi, 1989).

A.1.3 Machine Spun Pipe

The manufacture of concrete pipe by machine spinning is a well developed technique particularly for nonreinforced concrete pipe, in the south Asia region (Gisselquist 1989).

Most large diameter low pressure pipe and the full size range of high pressure pipe is manufactured using this technique. In some countries, including India and Bangladesh, the technique has been modified to make nonreinforced pipe in smaller diameters. Though the process is rather slow, tongue and groove, and spigot and socket pipe can also be made in this way (Gisselquist 1989).

In common with other pipe spinning techniques, a stiffened outer mould is spun by mounting it between two axles, one of which is turned by a belt drive from a small stationary motor. Once the mould is spinning at around 200 to 300 RPM, hand mixed concrete is shovelled into the spinning form from either end. The centrifugal force developed ensures the retention and spread of the low slump concrete within the mould, while a long steel bar is used to achieve an even wall thickness and smooth finish.

Good quality pipe can be produced provided attention is given to material and manufacturing quality (MMI 1990a). Concrete batching can help avoid some of the variation that occurs with hand mixing. On occasion pipe may be of variable quality, because of shortcuts taken by plant operators for example to reduce the quantity of cement used, to use poorly graded aggregate and to increase pipe output.

In Bangladesh, India and Pakistan small private workshops exist using motor driven pipe spinning equipment to manufacture non-reinforced concrete pipe. Much work has been done to scale down the size and complexity of equipment needed to manufacture pipe by this method, so that pipe quality relies heavily on close process and material control.

Considerable work has been conducted in Bangladesh to establish recommendations for pipe manufacture in general and the machine spinning process in particular. The results from this work are detailed in MMI (1990a), but care should be taken before extending these results to other situations as the recommendations apply to manufacture with aggregate composed of brick chips.

A.1.4 Hand Spun Pipe

Work in Bangladesh has led to development of hand spinning equipment, with the aim of providing village level employment (Georgi, 1989 and IDP, 1990). Although the hand spinning plant will have a lower output (20 pipes per day) than the motorised equivalent (40 to 50 pipes per day depending on the number of moulds) it is of particular interest, because of its lower capital cost and greater portability compared to the larger mechanised pipe spinning plants.

Tangail Agricultural Development Project has been using this technique successfully for over five years in Bangladesh to manufacture plain ended pipe of satisfactory quality for low pressure buried pipe distribution systems.

Private sector manufacturing of nonreinforced and reinforced concrete pipe in south Asia often provides pipe of low quality (MMP 1989a). Areas for improvement include careful batching of materials and adequate curing, while cost reductions would be provided by eliminating the reinforcement and enabling the irrigation system users to manufacture their own pipe.

1.5 Cast-in Place Pipe

The American Concrete Institute (1980) defines cast-in place pipe as an "underground continuous nonreinforced concrete conduit having no joints or seams except as necessitated by construction requirements."

The use of cast-in-place concrete pipe has been an established technique for over 25 years. In California reference is made to its use for more than 40 years in the San Joaquin Valley (ACI 1980). In the USA, initial hand construction methods, have been replaced by mechanised techniques.

The construction of cast-in-place pipe is a relatively sophisticated technology and the pipe is particularly sensitive to stresses due to temperature and moisture gradients. Although a wide range of diameters have been built, from 300 mm to 3000 mm, most of the pipe constructed is of sizes greater than 600 mm in diameter, and mainly used for conveyance pipelines. The minimum pipe diameter in the USA is considered to be that which allows access for a person to carry out any necessary repairs during the lifetime of the pipeline (Univ. Cal. 1977).

More recently Chinese researchers have developed low cost techniques for constructing cast-in place pipe by hand and using small scale machine methods. Although quoted Chinese costs are low, performance data is not available (Dept of Sci. Tech. 1990). It is considered that cast-in-place concrete pipe is likely to be less reliable than rigid pre-cast concrete pipe, given the sensitivity of the technique to construction methods and soil conditions and the difficulty of making joints and junctions which are leak free.

Design Considerations.

American standards (ACI 1980) state that cast-in place pipe is intended for a maximum head of not more than 4.6 m including the effects of pressure surge and water hammer. Necessary concrete quality is specified as having a compressive strength of 20.7 MPa. Commonly cast-in place pipe is used for conveyance pipelines, on low head closed pipeline systems, with open pipe stands constructed at any water control structures or shut off valves. The pipe is considered to be able to withstand heavy traffic loads with a minimum pipe cover of 600 mm, though it must be considered to be of lower strength than comparably installed precast concrete pipe.

Chinese researchers (Dept. Sci. Tech. China 1990) describe the successful manufacture of cast-in-place concrete pipe in diameters from 150 to 350 mm using a pressurised plastic sleeve. Limited test data on the pipe gives safe working pressures in the range of 1 - 2 kg/cm^2. Chinese low pressure pipe systems are typically open pipe systems with maximum working pressures seldom exceeding 5 m (Dept. Sci. Tech. China 1990). Clearly even if cast-in-place pipe can be successfully installed, it will only be useful for very low pressure situations. The major concern with the use of cast-in-place concrete pipe will be pipe life, given its susceptibility to soil movement and the quality of initial construction. In the small pipe sizes used in buried pipe systems it will be impossible to repair cracks and leaks which occur, by the internal plastering method used in the larger diameter pipes (ACI 1980).

Specifications and recommendations concerning cast-in place pipe as used in the USA are covered by standards produced by the American Concrete Institute (ACI, 1980).

A.2 Unplasticized Polyvinylchloride

A.2.1 Introduction.

Nearly all the plastic pipe used in low pressure pipe systems to date has been unplasticised or rigid PVC. It is manufactured in a wide range of sizes though pipe for irrigation use seldom exceeds 250 mm in diameter, as manufacturing and transportation costs increase dramatically in the larger sizes. Joints are usually of the spigot and socket type with solvent cement glue although rubber ring joints (z joints) have been used in some applications.

uPVC has several advantages over concrete and asbestos-cement alternatives including:
-its easier handling and lighter weight
-its smooth bore and low friction loss
-fewer joints and easier jointing

Its major disadvantage is its cost. In the projects identified as using uPVC pipe, in Indonesia (Republic of Indonesia, 1990), India (Cunningham, 1986) and Thailand (HHP/HTS, 1988) the pipe which has been installed is typically that rated to 25 or 40 m (2-4 Bar) allowable working head which is well in excess of the hydrostatic pressure requirements of the system. Thicker walled or higher pressure rated pipe is chosen more for its stiffness and resistance to damage during handling and installation, than for its hydrostatic strength.

PVC pipe manufacturers have over recent years developed a range of thinner walled uPVC pipes with equivalent dimensional properties (eg. stiffness) to those of thicker walled rigid uPVC. To reduce the quantity of PVC raw material per lineal metre the alternative pipe products utilise a corrugated outer wall, or a lower density cavity wall. Although in general the pipes are of lower cost for the same diameter, the lower material costs are partly negated by higher manufacturing and processing costs (refer to table A.1).

uPVC pipes of this type can be categorised into three groups:

-smooth bore and corrugated external wall
-smooth bore spirally wound corrugated pipe
-smooth bore and outer wall, with foam or cavity fill

These are discussed in turn below. Specifications for uPVC pipe are covered by several standards including,

-ASAE S376.1 Design, Installation and Performance of Underground Thermoplastic Irrigation Pipelines. June 1988. American National Standards Approved

-British Standards 312:1972 Code of Practice for Plastic Pipework
Part 1. General Principles and Choice of Material
Part 2. uPVC Pipework for Conveyance of Liquids under Pressure

-ASTM F1176 Design and Installation of Large Diameter Thermoplastic Irrigation Systems (Max Pressure 63 psi), November 1990.

A.2.2 Lighter Weight uPVC Pipes

i) Smooth bore and corrugated external wall

Plastics manufacturing companies in a number of countries have developed a number of thin walled uPVC pipe materials, which are smooth inside and have a corrugated external wall. Applications include sewer relining, new stormwater drains, road culverts and irrigation water conveyance pipelines. Differences between pipes on the market relate to the relative reduction in weight of uPVC material per unit length, and the methods and costs of production compared with equivalent rigid uPVC pipe (Järvenkylä 1988).

Any assessment of the suitability of any or all of the products for low pressure pipe distribution systems requires a detailed consideration of the location of the proposed pipe system and the properties of the particular pipe material. However an indication of the cost saving which may be possible can be gained from the summary of weight reduction in table A.1. It should be remembered that raw material cost is but one, though in most cases the largest, element of the cost of any uPVC pipe installation. A more complete comparison can only emerge when costs of manufacture, transportation and installation are also taken into account.

Some of the currently available uPVC pipe alternatives listed by brand name include:

-Ribstruct
-Dynamit Nobel
-DSA
-Ultra-Rib
-Double Skinned Pipe (by Drossbach)
-Sonrib
-Bauku
-Permaloc

Although currently these pipe materials are largely used for drainage, sewerage and ducting purposes, reference is made to the production, testing and use of such pipe in low pressure irrigation systems in China (Dept Sci. Tech., China 1990).

ii) Smooth bore spirally wound corrugated pipe

This group of uPVC pipes are constructed by extruding uPVC into various standard profiles. The profiles once transported to site can be wound using portable equipment to produce finished pipe in a wide range of diameters. The fastening system uses both a mechanical push-fit groove and chemical adhesive bonding to lock the profile into its finished shape.

Although a number of companies are working on pipes of this type, information has only been sourced from one (Jain, 1991) on the successful use of the product on low pressure piped distribution systems for surface irrigation in Spain, Australia and India (Jain, 1989 and Riblok, Aust. 1990).

iii) Smooth bore and outer wall, with foam or cavity fill

The third group of lighter weight uPVC pipes retain the smooth external and internal wall properties of rigid uPVC. The weight reduction is achieved by introducing either cavities into the pipe wall, longitudinal or concentric, or by producing a lower density "foam" like uPVC material for the wall. Several different products are currently available and they are known by the following product names:

-Bipeau (important in the French sewage pipe market)
-Wavihol
-Petzetakis

No information on the use of the pipe materials for low pressure water distribution has been obtained.

iv) Internally corrugated pipe

The last group of lighter weight uPVC pipes are those with both external and internal corrugated walls. Such pipes have been in use for many years in land drainage applications where the rebates have been regularly perforated to allow the entry of soil water. These pipes have the greatest weight reductions compared to rigid plain walled uPVC pipe but of course lower flow capacities compared with smooth bore pipes, because of the non-planar internal surface. Several variations of this pipe are currently being produced though their use is at present restricted to storm water drainage systems (Jain 1989).

Where the higher friction losses are not a problem and problems of siltation of the pipe are very unlikely, then these pipes are a very attractive option for new buried pipe systems. Pipes currently in production include:

-Nordisk corrugated pipe

-Brandon and Pressigny corrugated pipe

Table A.1. Comparison of the Raw Material Content of uPVC Pipes with Rigid uPVC

Weight Savings of Light Weight Pipes (having the same two year stiffness)

1. Smooth Inside	Weight	Weight Saving (%)
Solid Wall PVC	100	-
Bipeau	80	20
Wavihol	75	25
Rib Lock (Mabo)	65 (?)	35
Ultra Rib	55	45
Double Skinned Pipe		
(Drossbach)	45	55
2. Corrugated Pipe		
Nordisk Corrugated Pipe	35	65
Brandon and Pressigny		
Corrugated Pipe	25	75

Note: Comparison based on approximately the same inside diameter.
Sources: Jain (1990) and selected manufacturers data.

A.3. Asbestos Cement Pipe

A.3.1 Introduction.

Asbestos-cement pipe though widely used for high pressure irrigation, municipal and industrial applications, has been little used in low pressure irrigation applications. Lower pressure pipe (maximum working pressure 12 m) is manufactured, for sewerage and drainage applications typically in sizes ranging from 100 mm to 750 mm.

Although asbestos-cement pipe is usually more expensive than concrete or uPVC alternatives, adequate quality concrete and competitively priced uPVC pipe may not always be available. While claims of long life and low maintenance costs for asbestos cement pipe supported by many years of filed experience are made (Univ. Cal. 1977), few buried pipe systems built using asbestos cement have been identified.

Commercially produced asbestos-cement pipe is smoother than similarly spun concrete pipe, resulting in a lower coefficient of friction and allowing smaller pipe sizes to be specified with a consequent saving in the cost of the pipe network (Hydraulics Research 1990b).

A.3.2 Construction Considerations.

Pipes typically vary in length from 2 to 4 m and are normally joined and sealed using a range of rubber gasket joints (Plusje, 1981 and Everite 1986). These comprise an exterior asbestos-cement collar or sleeve with rubber gasket inserts sealing against each pipe.

Care needs to be taken to minimise the health risks of using asbestos-cement pipe although manufacturers (Everite 1986) are adamant that there is no evidence that water quality is affected by the pipe material, and any health risks are minor provided necessary precautions are adhered to during normal handling and installation of standard pipes and fittings. Everite (1986), manufacturers of asbestos-cement pipe, detail the use of a hand saw, or a power driven disc cutter which has a continuous water feed attached, to keep the dust level to a minimum, when cutting asbestos cement pipe. If dust levels are significant during any part of the installation, the work area should be kept damp and a dust mask worn.

Particular specifications for the use of low pressure asbestos-cement pipe in irrigation have not been found but should be covered by the following standards for low pressure sewerage and drainage pipe:

-BS 3656
-IS 243
-ISO 881 (sulphate resistant cement)