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THE UNIVERSITY OF ALBERTA

FEASIBILITY OF PIPELINES FOR ON-FARM IRRIGATION WATER DISTRIBUTION IN SOUTHERN ALBERTA

by

© SALEEM AKHTAR SIAL

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled FEASIBILITY OF PIPELINES FOR ON-FARM IRRIGATION WATER DISTRIBUTION IN SOUTHERN ALBERTA submitted by SALEEM AKHTAR SIAL in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

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Supervisor

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Date. June 26, 1987........

ABSTRACT

Conveyance and distribution of water are an integral part of an irrigation project. The efficiency of conveyance and distribution, and the transport of water at minimum cost and with minimum loss, therefore essentially affects the total economy of an irrigation project. Often the most important decision to be made by managers and planners in this respect is whether or not irrigation water is to be conveyed and distributed to users in lined or unlined canals, or by pipeline.

Materials used for canal lining are of almost infinite variety, but only the most used alternatives, namely concrete lining, polyethylene membrane lining and pipelines were studied. Moreover, pipelines were of primary concern as suggested by the title of the study.

Irrigation districts in southern Alberta are installing more buried pipeline delivery systems than ever before. This part of the analysis, to be conducted on a micro scale, may serve as a guide to later, more detailed studies involving the overall investment of public and private funds in irrigation within Alberta.

Two computer programmes were written; the first one to calculate pipe sizes, friction losses, power requirements to develop required pressures and overcome friction losses in pipes, seasonal energy costs, total and annual costs using PVC and concrete pipes; the second one to calculate incremental farm benefits and costs after completion of the

project for the case study of rehabilitation of the Bow Island irrigation block.

Benefits and costs of rehabilitating existing irrigation blocks were examined using the three alternate irrigation conveyance and distribution systems mentioned earlier. The feasibility of pipelines was determined by an economic analysis of the following factors: water conservation, reduced waterlogging or lower drainage requirement, structural safety, total capital cost, annual cost, operation and maintenance cost, and the cost of production for various crops. Pipelines were found to be the most feasible option for irrigation water distribution to farm users and polyethylene lining was found to be the least feasible. However pipelines are beneficial mainly when they are pressurized.

ACKNOWLEDGEMENTS

Firstly, I wish to thank my advisor, Professor Egon Rapp for all his help and guidance during my graduate work and especially during the preparation of this thesis. Acknowledgment is due to the Alberta Agricultural Research Trust, Faculty of Graduate Studies and Research and the Department of Agricultural Engineering, University of Alberta for their financial support of this project. Appreciation is also extended to the Project Planning Branch, Alberta Agriculture for making available all its reports and files required for the production of this thesis.

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I. INTRODUCTION

The first known pipeline system was found in ancient Rome, where a remarkable stone arch drainage system was built to make the foothills habitable and drain off the water settling in the Forum (Peggs 1985). The system was known as the Cloaca Maxima. The power of the structure was worshipped in the form of a deity, Cloacina.

With the invention of the potter's wheel, cylindrical clay "pipe" with fluted bell ends was made for special drains. The length of the section was one cubit (45 to 50 cm) and was used profusely in Babylon, primarily for drainage in and around palaces, but occasionally for house sewers.

Clay pipe and stone shafts and ducts were well constructed by the ancient Cretans and much of these dating to 1400 B.C. are in a good state of preservation today. The palaces of Nizams of ancient India contained clay pipe water distribution systems throughout the structures. Water was piped by gravity to containers over open fires in the bedrooms of queens providing them with hot baths. These systems can still be seen embedded in the stone walls of the palaces of central India (Peggs 1985).

Treated potable water and natural gas necessitated the development of buried service piping for homes, commercial buildings, and industry. The use of pipes for irrigation water conveyance and distribution is relatively new and is restricted to the following conditions: to bring water to fields which are at higher topographic elevations than the water source, to irrigate land with sloping and undulating topography, to convey water across hills and valleys, to convey water across areas where the soil type makes canal construction difficult and to convey recycled sewage for irrigation purposes in a safe manner (Finkel 1982).

With the increased need for greater on farm irrigation efficiency to save water, labour, and energy, there is an increasing tendency for mechanizing and automating supply, distribution and application systems. To obtain these savings the whole system must be able to deliver water in a way that is flexible in frequency, rate and duration. For best operation, the flow must be controlled at the point of application by the irrigator so as to make on-the-spot decisions (Jensen 1980). Again a pipeline seems to be more compatible with mechanized and automated irrigation methods. There are extreme pressures being made on the available land and water, so it seems probable that much more efficient and expensive irrigation systems will be justified in the near future. The use of irrigation pipelines is rapidly increasing in countries with a highly developed irrigated agriculture. For example, in Israel almost all the irrigation water is conveyed and distributed through pipelines. The trend of using pipelines for on-farm irrigation water distribution in southern Alberta is also becoming increasingly popular, and more and more pipeline systems are being installed. There is a total of 325 km of buried pipeline systems of all kinds within irrigation districts in Southern Alberta. There are nine gravity or pump pressurized lines serving a total of 6,800 ha of irrigated land in five irrigation districts (Alberta Agriculture, internal information).

Economics is paramount in evaluating irrigation practices, for irrigation is largely for the purpose of increasing profit. Higher profits from more efficient production will ultimately result in lower prices for consumers, and lower prices result in more consumption and a higher standard of living. These factors should be kept in mind and the most effective way to accomplish this is to make economical developments (Israelsen and Hansen 1962).

The objectives of this study were to analyse the use of pipelines for on-farm conveyance and distribution of irrigation water as an alternative to open canal lining in southern Alberta from the following points of view:

1. land and water conservation,
2. capital costs,
3. operation and maintenance costs, and
4. net return to the farming enterprise.

II. LITERATURE REVIEW

A. STUDY AREA

Southern Alberta is usually the warmest area of the Prairie Provinces on an annual basis and experiences more sunshine per year than any other part of Canada. Chinooks occur most frequently in the foothills of southwestern Alberta, but the area affected extends across the entire South Saskatchewan River Basin. Frequent strong winds (from 50 to 160 km /h) also characterize the region. The mean annual precipitation in the basin varies from over 1,000 mm in the mountains to approximately 300 mm in the extreme southeast of Alberta. The foothills receive about 500 mm per annum. The extreme annual water deficit is about 200 mm throughout the region, except in the Cypress Hills where the deficit is less than 100 mm and in the Rocky Mountains where there is no deficit (Marv Anderson and Associates 1978).

The average seasonal water deficiency was determined to be a minimum of 92 mm for green peas to a maximum of 392 mm for alfalfa for the Lethbridge area (Krogman and Hobbs 1976). The Canada Department of Agriculture cites a minimum irrigation requirement of 127 mm for flax and a maximum of 406 mm for alfalfa of the crops grown in southern Alberta (Dubetz and Hobbs 1966). This shows the substantial need for supplemental irrigation and conservation of irrigation water to fulfil these requirements efficiently.

Supplemental irrigation is a practical way to increase crop production and eliminate drought hazards. Irrigation has provided security to farmers living in the irrigated areas and today irrigation has become a key factor in the agricultural economy of Alberta. Droughts and increased cost of agricultural production in recent years have made the costs of irrigating seem less prohibitive (Topham 1982).

In 1915 the province passed the Alberta Irrigation Districts Act. The act provided for the establishment of irrigation districts in which farm land could be mortgaged to provide funds for irrigation development. There are presently 13 irrigation districts in the province, all located within the South Saskatchewan River Basin. These account for 84 percent of all the irrigation undertaken in the province. The total area covered by these irrigation districts is 465,600 ha. In addition to this, there are approximately 40,500 hectares licensed for irrigation as individually owned private schemes (Thiessen 1985). The Prairie Provinces Water Board, formed in 1948, allocated 2,759,585 cubic decametres of water to irrigate 508,490 hectares in Alberta (Topham 1982). New areas can be irrigated only by improving the efficiencies of the existing irrigation systems.

B. EXISTING IRRIGATION SYSTEMS

The early irrigation systems were laid out on the contour of the land thereby creating many irregular boundaries which are not conducive to the use of modern farm machinery and large sprinkler systems.

Thiessen (1985) reported that 10 percent of the total irrigated lands were affected by seepage from irrigation canals. Stanley/SLN Consulting (1978) reported that moderate salinization was estimated to affect 25 percent of all irrigated land in the St. Mary River Irrigation District.

Yaron (1981) reports that on moderately saline soils, specialty crops (vegetables and potatoes) suffer yield losses of 50 percent or more; yield losses for alfalfa are also at the 50 percent level; wheat yield may be down by 40 percent. Yield losses for all other crops, except barley, are in the order of 30 to 40 percent.

A moratorium on irrigation expansion is in effect in many areas due to a limited supply of water and limited lateral capacities. Thus there is a need to reduce the seepage losses to irrigate the remaining irrigable area and to reduce waterlogging and salinity.

Irrigation Efficiencies

Irrigation systems in Alberta operate with efficiencies from 77 percent to 22 percent. This is the percentage of the total diversion which is actually delivered to the farm turnout. Farm efficiencies are assumed to range from highs of 60 to 65 percent to a low of 40 percent (Heywood 1978). A U. S. Department of Agriculture study of 46 irrigation projects showed that 37 percent of the diverted water was lost in conveyance, 23 percent in canal seepage and 14 percent in operation (Lauritzen and Terrell 1967).

During 1958 to 1968 the operation of the districts at Vauxhall-Hays showed that the overall irrigation efficiency was 38 percent, made up of a system conveyance efficiency of 65 percent and a farm efficiency of 58 percent. Evaporation losses in irrigation district canals were reported as 2-6 percent and seepage from canal laterals as 6-45 percent (Heywood 1978).

Seepage and return flow are two major loss factors. Seepage losses from canal laterals in southern Alberta were found to be 10-42 percent with an average of 21 percent and return flow was 14-55 percent with an average of 34 percent (Heywood 1978). Ploss et al (1979) have indicated that significant return flow volumes are not a problem since the spill water can be beneficially utilized downstream. However two disadvantages associated with return flow were discussed by Byrne (1983). Firstly, higher than required flow is inefficient in terms of required system capacity and maintenance. Secondly, seepage loss will be higher, resulting in compounded seepage related problems. The volume of water lost to seepage every year can be approximated using diversion and return flow data.

Robinson (1978) studied the gross diversion for seven irrigation districts in Southern Alberta (Eastern, Western, Bow River, St. Mary, Lethbridge Northern, United and Mountain View - Leavitt) in 1977 and found that total diversion was 214,099 ha-m. The delivery efficiency for that year was 64 percent. (The delivery efficiency is defined as the percentage of water delivered to the farmers to the total volume diverted). Hence conveyance losses, including return flow, were 36 percent. The total return flow volume was 43,612 ha-m; therefore, the seepage loss volume V_{sl} was approximately 33,464 ha-m or 15.6 percent of the total diversion. This shows the need to use facilities and equipment to optimize water use by reducing the water losses.

C. ECONOMIC IMPACT OF IRRIGATION

A study, conducted by Underwood-McLellan and Associates Ltd. (1984) for the Alberta Irrigation Projects Association, affirms the value of irrigation investments to the Province of Alberta. A conclusion was that benefits from irrigation activity extend far beyond the water users. The distribution of expected annual benefits was 15 percent for the water users, 66 percent for the province and 19 percent for other Canadian provinces. Non-measured benefits through irrigation projects include: potable water supplies to communities, reservoirs for recreation, greater crop flexibilities and agriculture production in an area with reliable harvest weather.

Irrigable area has increased from 311,600 ha in 1970 to more than 405,000 ha by 1982. This has resulted in a water demand equal to or greater than the capabilities of the existing water storage and supply facilities. The water demand is also nearing the limit of available water supply in the basins. Further increases in the irrigated area can take place only if facilities and capabilities are developed both to conserve more of the natural runoff and to better control the losses which occur within the supply, distribution and application systems. Further, sprinkler systems use a precise flow of water. Gravity systems are not so demanding. This, coupled with an ever-increasing need to conserve water, places a significantly greater requirement for water control in the distribution system.

Pipelines, modern control technology, balancing reservoirs located throughout the system and many other design features are being utilized to adequately respond to these and other expected needs.

The continuation of the present capital works rehabilitation programs of the Alberta government will have direct impacts on the farmers and on the irrigation districts that serve those farmers. These impacts were grouped (Hagan et al 1967) into three categories:

1. Improvements in the water storage and delivery systems will allow more areas to be irrigated because of better access to water supply and improved water use

efficiencies.

Underwood McLellan and Associates Ltd. (1984) reported that the increase in irrigated area in Alberta was 142,490 ha from 1970 through 1984 and projected an increase of 53,846 to 70,850 ha from 1985 through 1989.

2. Yield increases from existing irrigated acres can be anticipated with a rehabilitated delivery system. This impact includes the gain from rehabilitation in terms of better farm management, easier irrigation, more leisure time, and more time for other farming activities as well as the actual crop yield increases resulting from the potential of more precise irrigation scheduling.

Underwood McLellan and Associates Ltd. (1984) estimated yield increases for the major irrigation districts from a low of one percent of present yields for the Western Irrigation District (WID) to a high of 18 percent of present yields for the Lethbridge Northern Irrigation District (LNID) with a weighted average for all districts of 5.4 percent.

3. Reconstruction of a particular lateral or system eliminates the need for extensive maintenance activities that accompany works which are nearing the end of their useful life. This will result in savings to the irrigation district.

The estimated cost savings to the irrigation districts in Alberta range from $1 million to $3 million per year with an average of about $2.2 million per year

(Underwood McLellan and Associates Ltd. 1984).

D. MULTIPLE PURPOSE WATER SUPPLY SYSTEMS

Most major irrigation projects are part of multipurpose water supply schemes. They may supply water for recreation, municipal, wildlife and hydro-power uses, as examples, in addition to irrigation. Such multipurpose water supply development projects require long lead times for planning, promotion, design, financing and construction. Because of the long lagtime between the construction and the realization of the multiple benefits, special economic evaluation issues are raised. Recent studies conducted in Alberta and Saskatchewan concluded that 15-20 percent of the total benefits of irrigation go to the farmer with the rest going to society. The benefits to the rest of society come from additional economic activity and employment beyond the farm gate which directly depend upon the irrigation activity (Underwood McLellan and Associates Ltd. 1984).

Methodology for economic evaluation of irrigation projects is in a state of evolution. As the farm direct benefits are a small portion of total benefits, many projects only become feasible when the other beneficiaries contribute to the cost. Because these benefits are diverse and often difficult to assess, they have traditionally been carried by governments, such as through the 86-14 percent cost formula in Alberta (Hill 1986).

E. CAPITAL COST COMPARISONS OF ALTERNATIVE IRRIGATION SUPPLY SYSTEMS

The construction of pipelines is not feasible in every situation. In most cases the drop or available head will govern the choice between open channel and pipelines. Three typical examples in Southern Alberta are cited (Alberta Agriculture, internal information):

1. In a Farming for the Future Project in the Lethbridge Northern Irrigation District Lateral D1A, concrete lining cost was $201,900. The estimated cost of the pipeline was $216,000. The available head there was only 1.05 m in 1.6 km, so there were not many drop structures required and no power savings were possible for sprinkler systems. In this case the cost of the pipeline was higher than the concrete lining. The flat slopes made the open channel system less expensive.
2. In 1977, Lateral F pipeline was constructed in the United Irrigation District. The available drop there was 27 m. The capacity of the line was 2.5 m^3/s and the length was 1.1 km. The total price was $180,000 (1977 dollar). The alternative solution was to construct a series of drop structures for a total price of $310,000 with 30,600 m^3 of earth moved. Here steep slopes made the pipeline an economical choice.
3. The Magrath Irrigation District installed a gravity pressure pipeline in 1983 for a total cost of $500,000. Pressure at the deliveries varied from 310 kPa to 552

kPa. The cost of concrete lining was estimated at $525,000, which is more money for a less sophisticated system. Here again the pipeline was an economical alternative.

These examples demonstrate that under different conditions, different types of structures become economical.

F. ADVANTAGES OF IRRIGATION PIPELINES

Pipeline systems have not been used much in the past because of the high capital costs associated with them. However, they may now be feasible due to the following reasons:

High prices of farm land result in concern for areas lost to production due to right-of-ways, severance and land damages. Large farm machinery and irrigation systems require large fields free of obstacles. Higher value of capital investment results in a need to improve the system efficiencies. High costs and other problems are associated with operation and maintenance of open channel systems. Canal linings installed to reduce the canal seepage have often resulted in increased operation and maintenance problems and its effectiveness has often been disappointing (CH2M Hill Canada Ltd. 1981).

Buried pipelines have many advantages over the open channel systems. Some of them are discussed in the following passages.

Losses of water from seepage and evaporation in unlined canals and ditches are usually high. The average seepage and evaporation losses are reported to be 40 percent of the total amount turned into a ditch or canal (Kraatz 1977). A limited supply of water makes such losses more serious. Fewer hectâres can be irrigated and crops may suffer from lack of sufficient water. Seepage, moreover, often results in waterlogged fields. Where soil contains salts, the installation of expensive drainage systems becomes necessary before the land can be cropped successfully. Irrigation water conveyance with pipelines reduces seepage losses to a minimum and prevents waterlogging of the soil. Pipelines also prevent water from seeping or evaporating before reaching the crops, therefore more area can be irrigated with the available supply.

Pipeline irrigation systems can be operated under pressure. The pipe can be laid uphill or downgrade, permitting irrigation of land too rough for open ditches. With pipelines, water can be delivered to any field or any part of a field and flow can be controlled to the exact amount desired. No part need get too little or too much water.

Pipelines save land, labour and time. Open ditches take valuable land out of cultivation, estimated to be 3-5 percent of farm areas (Kraatz 1977). Pipelines are located mostly underground, permitting productive use of land above. Much time and labour is saved by using pipelines because there are no land severances and corners, and farm machinery can be used without obstruction. Pipelines also save time for the irrigator.

Pipelines aid in insect and weed control. Banks of open ditches cannot be cultivated by machinery, and unless kept clean with hand labour, grow weeds which harbour insects and scatter seed in the irrigation water.

Open ditches require considerable maintenance. A pipeline system installed by competent contractors requires minimal maintenance. This can save up to $310/km/ year (Jonas and Taylor 1978).

The advantage of pipelines is dual for sprinkler irrigated areas. Firstly, they save the costs of drop structures, bridges and other crossings required in the case of open channels. Secondly, they help in saving energy by utilizing the head developed due to downslopes. If slopes are steep enough, irrigation water can be supplied to each parcel with full pressure without pumping. This can result in savings of $400/quarter section/year (Jonas and Taylor 1978).

G. PIPELINE DELIVERY SYSTEMS

This section discusses the hydraulic principles of both closed and open pipelines. Various piping materials, available in Southern Alberta, and their suitability to irrigation distribution are discussed.

Open Pipeline

In an open pipeline system, the flow of water into the pipeline is controlled with an irrigation slide gate at the turnout off the supply channel. The district operating staff regulate the control gate such that the flow into the pipeline closely matches the irrigation demand of the water users. This is a form of upstream flow control.

There is a division box with a centre weir at all delivery points off the pipeline. Irrigation slide gates are installed in the box upstream of the weir, as shown in Fig. II.1 (Martin 1985). The weirs have a fixed minimum height to just below the gate invert elevation, and the head on the turnout gate is changed by adding or removing stop logs on top of the weir. The turnout gates usually connect to an adjacent dugout or head ditch.

Full supply level (F.S.L) is the level of fluid under atmospheric pressure when the system is working at full capacity. Hydraulic gradeline (H.G.L) is defined as the line representing the sum of pressure head and elevation head in a pipeline above some datum line.

The pipelines are forced to run under full flow conditions upstream of the division box due to the fixed weir. Immediately downstream of the division box, the open pipelines generally run under partial flow conditions requiring proper air vents.

Chin Lateral 4 and 5 are open pipeline systems located within the St. Mary River Irrigation District (SMRID)

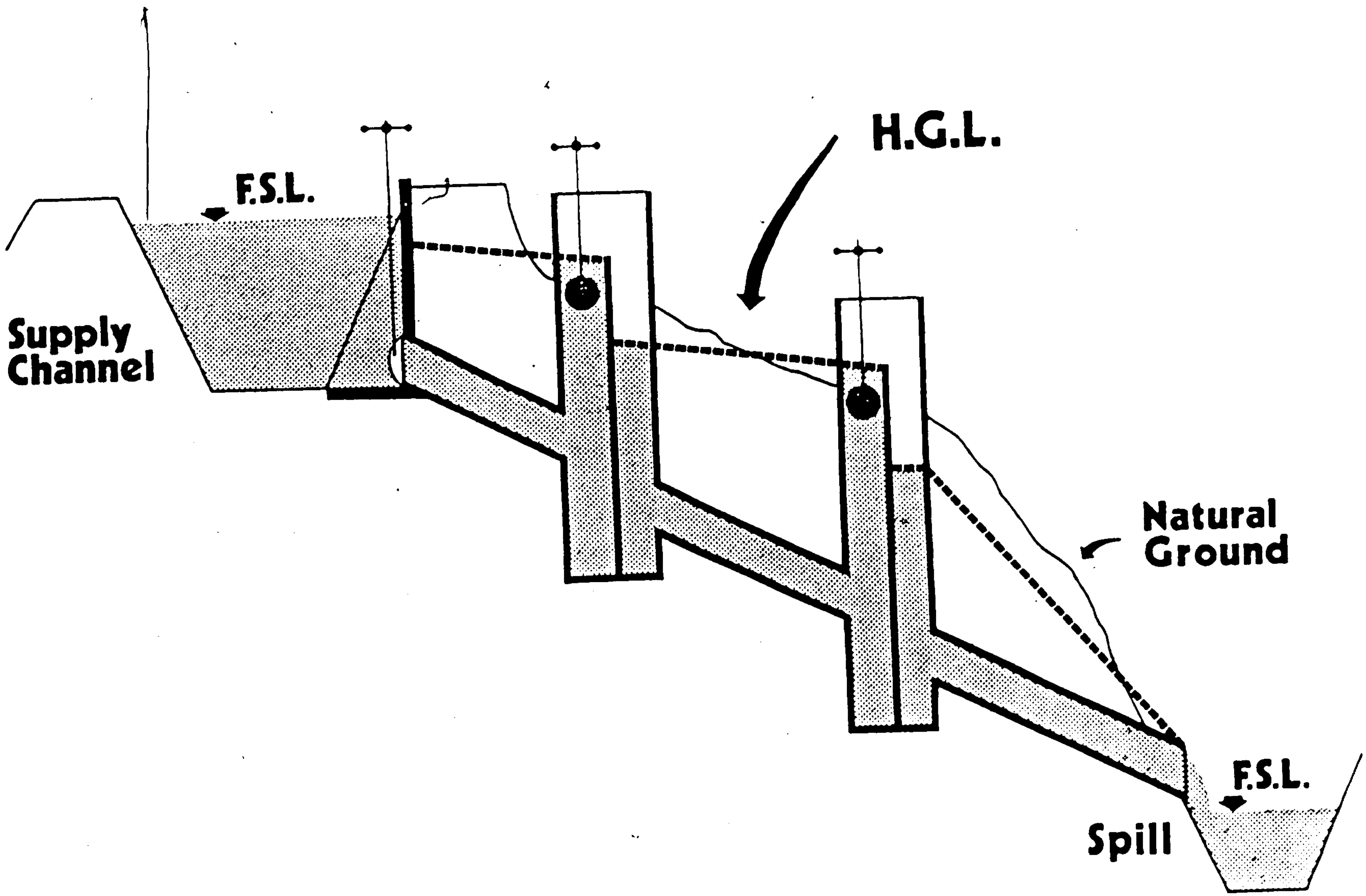

Figure II.1. Open Pipeline

Source: Martin, L.R. (1985). (No copyright involved)

southeast of Coaldale, Alberta. The pipelines consist of Series 45 polyethylene pipe ranging from 400 mm diameter to 710 mm diameter. The design capacities of Laterals 4 and 5 are 0.68 m^3/s and 0.76 m^3/s respectively (Martin 1985).

Closed Gravity Pipeline

Closed gravity pipelines operate on a totally different principle than open pipelines. Once the closed pipelines are filled, flows are regulated at the farm deliveries. This is a form of downstream control. The slide gate or valve at the inlet structure is normally operated in the open position. A schematic diagram of a closed gravity pipeline is shown in Fig. II.2 (Martin 1985).

With zero flow in the pipeline, the hydraulic gradeline or static head is level with the supply canal. As water users turn on their deliveries, the flow in the pipeline increases and the hydraulic gradeline is correspondingly lowered as part of the static head is converted to velocity head and friction headloss. The pipelines are designed with a minimum of 1.5 m of head above the natural ground, at each delivery point, when the system is at full design capacity.

Due to the high hydraulic heads on the turnouts, valves are used instead of traditional irrigation slide gates. These valves can be connected to the turnouts of sprinkler systems to utilize any surplus head off the pipeline.

Chin Lateral 6 is a closed gravity pipeline located within the SMRID southeast of Coaldale, Alberta. The

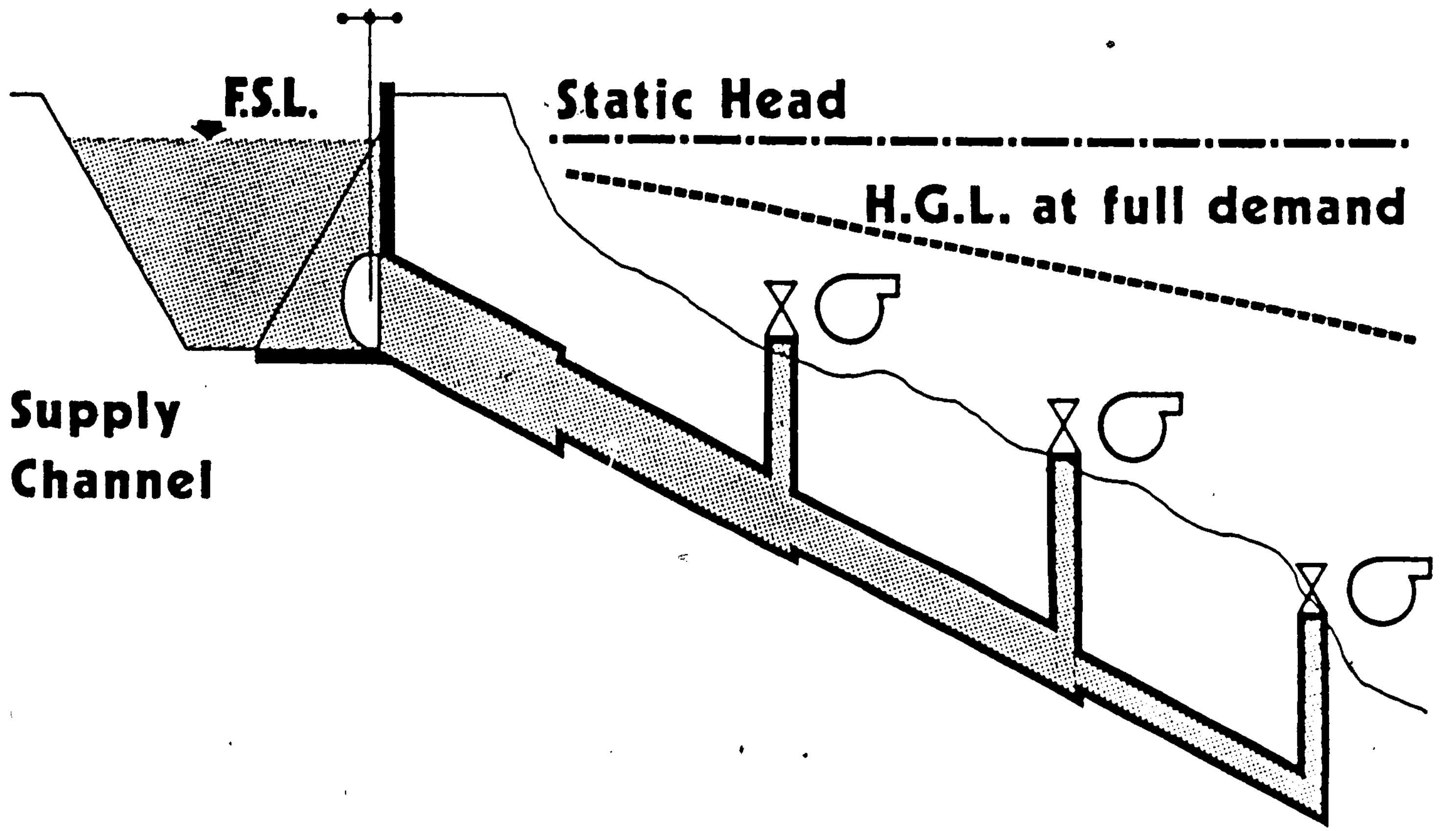

Figure II.2. Closed Gravity Pipeline

Source: Martin, L.R. (1985). (No copyright involved)

pipeline is connected directly to the SMRID main canal and flow changes in the pipeline do not significantly affect the main canal flows. The system has a design capacity of 1.32 m^3/s and the static pressure at the downstream end is 310 kPa (Martin 1985).

Closed Pressure Pipeline

The key difference between gravity and pressure pipelines is that in the latter case, the individual farm irrigation pumps are replaced with a common pump station. The on-farm sprinkler irrigation systems are then connected directly to the distribution pipeline. A schematic diagram of a closed pressure pipeline is shown in Fig. II.3.

The pump stations are designed to respond to a demand in flow created by water users turning on their systems. These pipelines are therefore downstream control, or demand type systems. The pump stations are usually automated in order that the flow rate and pressures created by the pumps match the requirements of the on-farm irrigation systems.

The Bow Island Lateral-12 pressure system is a good example, located within the SMRID immediately south of the town of Bow Island, Alberta. The pump station is located adjacent to the SMRID main canal and has a capacity of 2.3 m^3/s, with a system pressure of 500 kPa (SNC Consultants Ltd. 1984).

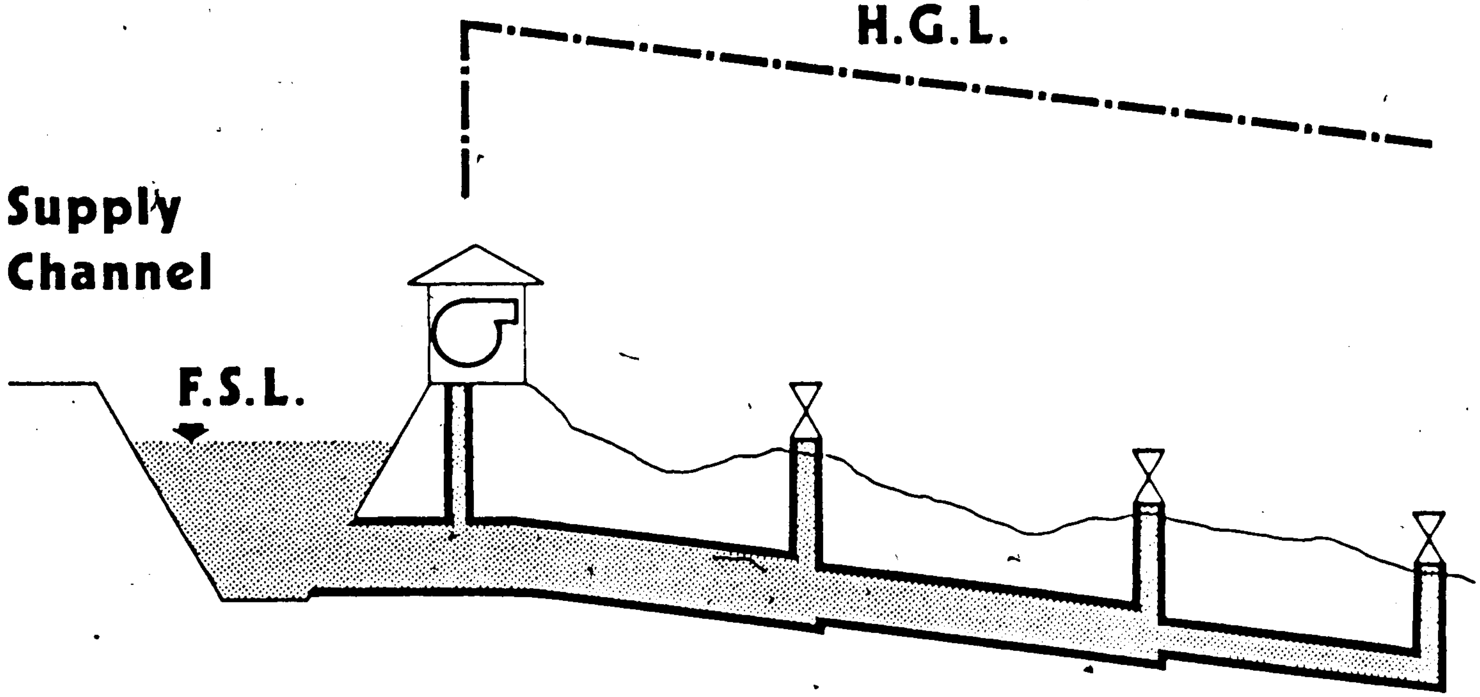

Figure II.3. Closed Pressure Pipeline
Source: Martin, L.R. (1985). (No copyright involved)

Commonly Used Pipeline Materials

The three most commonly used piping materials in irrigation distribution systems in southern Alberta are:

1. Polyvinyl Chloride (PVC)
2. Polyethylene
3. Concrete

Polyvinyl Chloride (PVC) Pipe

Solid wall PVC pipe has become more popular in recent years, mainly because it is now produced in diameters up to 610 mm. The connections are usually bell and spigot gasketed joints. The pipe is available in pressure ratings which are sufficient for any irrigation distribution system.

A new PVC pipe is the ribbed low head sewer pipe which is available up to 910 mm diameter. This pipe, which utilizes a bell and spigot gasketed joint, is appropriate for open style pipelines or low head closed pipelines (Martin 1985).

High Density Polyethylene Pipe

Solid wall high density polyethylene pipe has been used in southern Alberta for ten years in sizes up to 1,000 mm diameter. The joints are made in the field using the thermal butt fusion process (Martin 1985). This pipe has been used on both open and closed gravity pipelines.

Corrugated high density polyethylene pipe is also locally available up to 610 mm diameter and utilizes a corrugated coupler. This pipe is appropriate for low head open distribution systems.

Concrete Pipe

Reinforced concrete low-head pressure pipe is readily available in southern Alberta up to 1,050 mm diameter. The joints are the new R-4 bell and spigot design with a rubber 'O' ring gasket. The pipe is designed to handle 75 kPa of hydrostatic pressure without leakage. This pipe has been used on open distribution systems and spillways (Martin 1985).

Prestressed concrete low-head pressure pipe is also commonly used in southern Alberta. The pipe consists of a steel cylinder wrapped with prestressed wire followed by an interior and exterior coating of cement mortar. The pipe is designed for high pressures and utilizes steel bell and spigot joints with a rubber 'O' ring gasket (Martin 1985). This pipe can be used on low or high pressure systems.

H. GOVERNMENT INVOLVEMENT

In 1980 the Government of Alberta embarked on an expansion of its water resources and irrigation development program. Alberta Environment allocated $234 million for major water conveyance and storage works. An additional $100 million was provided by Alberta Agriculture to assist the irrigation districts in upgrading their delivery systems. The agriculture assistance program provides 86 percent of the capital costs for rehabilitation. The irrigation district funds 14 percent and also pays operation and maintenance costs (SNC Consultants Ltd. 1984).

I. SUMMARY OF LITERATURE REVIEW

The following conclusions are derived from the review of literature and were used in the assumptions for this study.

1. There is a substantial need for supplemental irrigation. Irrigation is a practical way to increase crop production and eliminate drought hazards in Southern Alberta.
2. There is a dire need to improve the efficiency of the existing irrigation systems so that the water saved can be used to irrigate the large irrigable dryland in the area. This will also protect the area from waterlogging and salinity.
3. Irregular boundaries created due to severance of land by the earlier irrigation systems are a hindrance to more economical farming operations with modern large size farm machinery and sprinkler systems.
4. A much larger portion of the total benefits of irrigation projects goes to society than farmers, so many projects only become feasible when the other beneficiaries contribute to the cost.

5. Pipelines seem to be more compatible with the new mechanized and automated irrigation methods.

6. Pipelines are not feasible under all conditions, especially when there are no head gains due to slope and only a few drop structures are required for an open channel system.

III. DESIGN OF PIPELINES

A. STRUCTURAL DESIGN CONSIDERATIONS

Selection of Suitable Pipes

There are a number of factors that can influence the designer in selecting the type or types of pipe suitable for a particular scheme.

1. The diameters that are normally available,
2. The time taken to supply the required pipes,
3. Initial costs, including cost of pipe and necessary structures and cost of installation,
4. Maintenance costs required to repair breaks,
5. Annual cost, including interest on investment, depreciation, taxes, etc.,
6. Maximum pressure head that will be developed in each type of pipeline,
7. Possible effect of the external environment on the pipe or joints.

Basic Principles

As with other structures, underground pipe design involves firstly estimating the maximum loads and stresses to which the pipes will be subjected in service, and secondly ensuring that the pipes selected will, when installed in a specific manner, withstand these loads and stresses with a safe but not an uneconomic degree of safety.

External loads arise from the weight of the overlying soil, from external water pressures in some cases, and from any surface surcharges. In pressure pipelines the tensile stress in the walls that result from the internal pressure also have to be taken into account. The possible effects of an internal vacuum may also need consideration. Depending on the site conditions, longitudinal bending (i.e. beam effects) may occur and also axial thrust or tension. The first step must therefore be to establish as much information as possible on the site conditions that will exist.

The magnitude of an external load that develops on a pipeline from overlying fill depends to a considerable extent on the way pipe is installed. The amount of external load a pipe of given intrinsic strength is capable of carrying depends greatly on the method of bedding.

Pipe Stiffness

The most important characteristic of a circular pipe of uniform thickness, from the structural design point of view, is flexural stiffness, S_f. This is given by the equation:

$$S_f = E \cdot I/B_c^3 \qquad (3.1)$$

where E is the plain strain elastic modulus of the pipe material, I is the moment of inertia, per unit length, of the pipe wall ($t^3/12$ where t is the pipe wall thickness) and B_c is the outside diameter of the pipe (Young and Trott 1984).

When a pipe section is buried in the soil, the distribution of loads within the composite pipe-soil system is governed mainly by the relative stiffness of the pipe and the surrounding soil. This ratio (Y) is given by the expression:

$$Y = E_s / S_f \qquad (3.2)$$

where E_s = plain strain elastic modulus of the soil.

Recent work by Gumbel et al. (1982) has shown that, for a value of Y less than 10, i.e. conditions in which stiffness of the pipe is high compared with the surrounding soil, more than 90 percent of the backfill load is carried by the ring bending action of the pipe. For a value Y between 10 and 1000, the proportion of load carried by the pipe reduces from 90 percent to 10 percent, and for values of Y greater than 1000 the pipe carries less than 10 percent of the load, the greater part being transmitted to the surrounding soil.

Economic and Other Considerations

Normally the deciding factor will be the overall cost of the completed work, although with the qualification that the economy should not entail the sacrifice of performance and durability. As well as initial cost, true economy needs to take account of what may have to be spent over the years on repairs and maintenance, and of the useful life of the installation.

Important as it is, however, cost is not the only factor influencing decisions. Speed of construction, availability of pipes, materials and installation equipment, and disruption of traffic often need to be considered.

B. HYDRAULIC DESIGN CONSIDERATIONS

Selection of optimum pipe sizes, calculation of friction and other losses in the pipelines, and power requirements for pressure pipelines are important considerations for hydraulic design.

Optimum Pipe Size Selection

The three important factors for optimum pipe size selection are: least annual cost, pressure drop available and velocity allowable. Most pipelines, with the exception of those sized for strength or some similar arbitrary reason, fall into one or more of these categories (Nolte 1979).

Least cost applies when pipelines are being pressurized through pumping. The approach is to balance the costs of operation with the amortized cost of construction to provide a size which results in the lowest annual charge for the pipeline. Under the same flow rate, the amortized cost for a large pipe is greater than for a smaller pipe, while the annual operating costs are less for the larger pipe diameter. With the optimum size, the sum of the two charges will be at the minimum.

Pressure drop available applies when pressure loss may be dissipated by the pipe. Usually this is not used in conjunction with a pressurized pipeline. Conventionally, calculation procedures require at least an approximation of the length of the pipe and the quantity and nature of the fittings in the system before the selection can be made.

Velocity allowable is the most used method of optimum pipe size selection for irrigation pipelines. The purpose may be either to keep flow velocity below some upper limit or to keep the velocity above some vital minimum value. This method usually applies when two phase flow is present in the pipeline.

A minimum velocity may be needed to avoid particle deposition in the pipes. Conversely maximum velocity limits are required to be certain that velocity does not exceed that which could cause erosion of the pipe as a result of droplet (or solid particle) impingement. Other maximum velocity limits relate to avoidance of vortices at the outlets and prevention of bubble entrainment under similar circumstances.

Friction Head Loss Calculation

The capacity of a pipe of fixed dimensions depends on the total head difference between the ends. This head is consumed by friction and other losses.

The early friction head loss/flow relationships were derived from field observations. These empirical relationships are still popular in waterworks practice although more rational formulae have been developed. Assuming V is the mean flow velocity, D is the inside diameter of the circular pipe and S is the head loss gradient (in m head loss per m length of pipe), some of the equations more frequently applied as given by Stephenson (1984) are:

$$\text{Hazen-Williams } S = K_1 \; (V/C_w)^{1.85}/D^{1.167} \qquad (3.3)$$

where K_1 = 6.84 for SI units. The average values of Hazen-Williams friction coefficient C_w for concrete and PVC are 130 and 140 respectively.

$$\text{Manning } S = K_2 \; (n \; . \; V)^2/D^{1.33} \qquad (3.4)$$

where K_2 = 6.32 for SI units. Manning's n values for concrete and PVC are 0.011 and 0.010 respectively.

$$\text{Chezy } S = K_3 \; (V/C_z)^2/D \qquad (3.5)$$

where K_3 = 13.13 for SI units. Values of C_z again are a function of Manning's n.

$$\text{Darcy-Weisbach } S = f \; . \; V^2/(2 \; . \; g \; . \; D) \qquad (3.6)$$

where f is a dimensionless resistance coefficient and g is acceleration due to gravity.

Except for the Darcy-Weisbach formula, the above equations are not universal and the 'constants' in the equations depend on the units used. The friction coefficient varies with the pipe diameter, surface configuration and age of the pipe. Thus the Darcy-Weisbach equation will be the right choice for precise calculation of friction losses.

Rational Flow Formulae

Although the conventional flow formulae are likely to remain in use for many years, more rational formulae are gradually becoming popular in pipeline design calculations. The new formulae have a sound scientific basis backed by numerous measurements and are universally applicable. Any consistent units of measurements may be used and liquids of various viscosities and temperatures will conform to the proposed formulae.

The resistance coefficient f for equation 3.6 is a function of Reynold's number (Re) and relative roughness (k/D) as shown by equations 3.9 and 3.10. The Reynold's number takes into account the viscosity of fluid and k, commonly called equivalent sand roughness, takes into account the pipe material.

The Reynolds number is calculated as Re = V . D/N. The kinematic fluid viscosity N is absent in the conventional flow formulae. The basic headloss equation for turbulent flow for a pipe of length L is:

$$h_f = f \cdot L \cdot V^2/(2 \cdot g \cdot D) \qquad (3.7)$$

where f is the Darcy-Weisbach friction factor, D is the pipe diameter and h_f is the friction headloss (m) over a length L.

In the design of many irrigation pipelines, the discharge Q is determined by the irrigation requirement of the command area. V can be calculated from the simple equation:

$$V = 4\,Q\,/(3.14\,D^2) \qquad (3.8)$$

After calculating V, Re can be determined.

A close approximation of f is given by the following equation (Stephenson 1984):

$$f = 0.0055\,\{\,1 + (20000\,k/D + 10^6/Re)^{1/3}\} \qquad (3.9)$$

This approximation of f should be substituted in the right hand side of the following equation by Stephenson (1984) to obtain a better value by successive iterations.

$$1/\,f^{0.5} = -0.8686\,\ln\,\{k/3.7D + 2.51/(Re\,.\,f^{0.5})\} \qquad (3.10)$$

The computer program described in the following section includes a subroutine to calculate f with any desired accuracy.

C. COMPUTER MODEL

A computer model was designed to establish the hydraulic design parameters for pipelines and to calculate total and annual costs of pipes using different pipe materials.

The importance of proper pipe size selection in the design of pipelines can not be overemphasized. The program presented here calculates and prints the following information for every section of pipeline; diameter of pipe, velocity of flow in the pipe, headloss due to friction for PVC and concrete pipe materials, power requirements to develop the required pressure and overcome friction losses in the section and cost of pipes for PVC and concrete pipe materials. Calculations can be continued for as many pipeline sections as required until all the pipeline is complete. After all the sections are completed, the program prints the following information for the entire pipeline: total power requirements, energy cost, total cost of pipes, and annual cost of pipes for PVC and concrete pipe materials. This is major information required for hydraulic design and economic analysis of an irrigation pipeline system.

Hydraulic Design

The computer model is an interactive program. The user supplies the requested information to the computer to calculate the different parameters. The model assumes that discharge, pressure required, length and elevations of each section have already been determined. The computer program calculates pipe diameters on the basis of predetermined maximum allowable velocities. The diameter proposed by the model is matched with the commercially available pipe diameters. The commercial diameters are supplied as input to the computer for further calculations.

The program is designed to analyse the two alternate pipe materials, PVC and concrete. Friction losses are calculated using the Darcy-Weisbach formula, as discussed in the last section. Viscosity of water at 15^{o}C was used for calculating the Reynold's number, Re. For calculating the power requirements to develop the required pressure at the end of each section, the elevation and existing pressure at the beginning of the section, and the elevation and pressure required at the end of the section are supplied as input. For energy cost calculations the average seasonal irrigation water requirements are also supplied as one of the inputs to the computer.

The output for each section is discharge, length of section, pipe diameter, velocity of flow, head loss due to friction, and water power requirement using each material. At the end of the program, the total water power requirement and total and annual costs of pipes for each material are printed.

Pipe Cost Analysis

The interest rate to calculate the annual amortized cost of pipes is one of the requested inputs at the start of the program. Length of the section and cost of the given pipe size is supplied for each section of the pipeline.

The output for each section is price per metre and cost of pipe for the section and at the end of the program, total cost and annual cost of pipes amortized over 50 years is printed for both materials. The total energy cost is also calculated for each material depending upon the average seasonal irrigation water requirement. This will give an estimate of comparative costs of pipes, power requirements and energy costs for PVC and concrete pipe.

IV. ENGINEERING OF BOW ISLAND LATERAL-12 REHABILITATION

The Bow Island lateral-12 rehabilitation project, completed in 1983 is the largest, most sophisticated and most expensive pipeline for on-farm irrigation water distribution in southern Alberta. This project was taken as case example to study the feasibility of pipeline for on-farm irrigation water distribution in southern Alberta. Both the engineering design and economics of the proposed alternatives irrigation systems were analysed.

A. DESCRIPTION OF EXISTING BLOCK

The Bow Island irrigation block is located in the St. Mary River Irrigation District (SMRID) approximately 100 km east of Lethbridge and just south of the town of Bow Island. The original system was designed and constructed by the Prairie Farm Rehabilitation Administration (PFRA) and Alberta Agriculture in 1952 (Keith Consulting Ltd. 1981). The preliminary work on the new system was started in 1980 by Alberta Agriculture at the request of the SMRID to provide a long range plan for the rehabilitation of this irrigation block.

Water supply for this block is from the SMRID Main Canal. There is no on-stream storage available for this block. The block is bordered on the east, west and north by natural drains and on the south by the SMRID Main Canal. Waste water from the block is spilled into the natural drains and eventually spills into the South Saskatchewan

River. The main lateral generally followed road allowances while secondary laterals tend to follow land contours and provided irrigation by gravity means on both sides of the canal. The layout of the pre-project open ditch system is shown in Fig. IV.1. Sixteen parcels of land were suffering from land severances. This caused some problems with the mobile sprinkler irrigation systems which were being used. The previously assessed irrigation land, including terminable agreements, totals 1,623 ha. The previous main lateral varies in capacity from 2.0 m^3/s at its turnout to 0.25 m^3/s at the spillway into the drain (Keith Consulting 1981).

The main problems to be corrected in this project as discussed by Keith Consulting (1981) were:

1. Alignment of lateral and sub-laterals. The existing lateral was at the south boundary of the town of Bow Island. This lateral was causing considerable seepage in that area and was a barrier to town expansion.
2. Seepage adjacent to the canal laterals
3. Weed growth
4. Inadequate discharge capacity
5. Inadequate drainage and increasing salinization on adjacent land was also a growing concern.

The existing efficiencies of the system were 77 percent for delivery, 50 percent for on-farm and 39 percent overall (Stanley/SLN 1978). With the use of high pressure on-farm sprinkler irrigation systems, the on-farm efficiency level

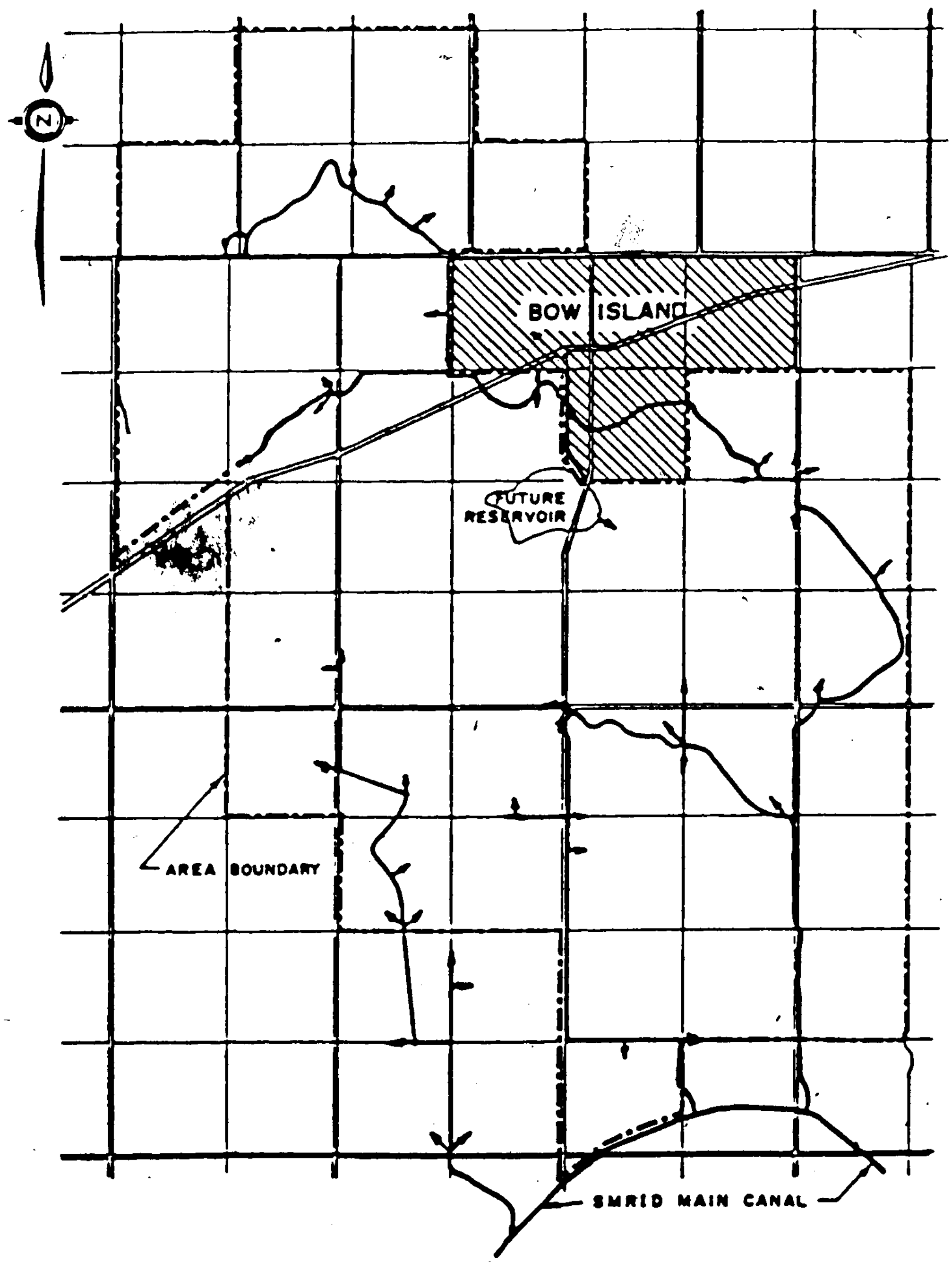

Figure IV.1. Pre-project Open Ditch System
Source: Ramsey and Gyrofi (1985). (No copyright involved)

was expected to increase to 55 percent making an overall efficiency of 45 percent by 1980 (SMRID 1981).

A summary of the existing irrigation in 1980 is provided in Table IV.1.

The majority of the irrigation in the block was by sprinklers and the potential for gravity irrigation was limited because more and more farmers were adopting sprinkler irrigation. There were 1,382 ha under irrigation and a potential for increasing the assessed area to 2,510 ha.

Three basic irrigation systems were investigated by Marv Anderson & Associates and W-E-R Engineering (1981) for rehabilitation of the Bow Island Block.

1. An open channel system with a hard surface canal lining,
2. An open channel system with a buried polyethylene lining and granular slope protection,
3. A buried medium pressure pipeline system with a pump station located either on the main feeder canal or centrally located within the irrigation block.

Seven alternative systems were examined which included the three basic irrigation system concepts with a number of alternatives for each as follows :

CONCEPT A -

Open channel system with hard surface canal lining including the following alternatives:

A1 - plain concrete slip-form lining

A2 - reinforced concrete slip-form lining

Table IV.1 Summary of Existing Irrigation of Bow Island Block

Item	Value
Total area, ha	2,870
Irrigable area, ha	2,510
Assessed area, ha	1,623
Area irrigated, ha	1,382
Irrigation water used, ha-m	627
Water used, mm	430
Land use factor*, percent	90

*Land use factor is the percentage of assessed area actually irrigated.

Source: SMRID (1981). (No Copyright involved).

A3 - reinforced concrete precast lining

CONCEPT B -

Open channel system with buried polyethylene channel lining including the following alternatives:

B1 - 30 cm granular slope protection

B2 - 30 cm random material and 15 cm granular slope protection

CONCEPT C -

Buried medium pressure pipeline systems with pumping, including the following alternatives:

C1 - main canal pumping station

C2 - central pumping station with a 1220 mm diameter low pressure water supply pipe or an open delivery channel supplying water from the main canal to the pump station.

Alternatives C1 and C2 included examination of precast reinforced concrete pressure pipe and steel pipe for diameters ranging from 457 mm to 1220 mm, and PVC and asbestos cement pipe for diameters ranging from 203 to 406 mm.

Design methodology was based on " Channel System Design for Southern Alberta" (Irrigation Division, Alberta Agriculture 1979). Cost estimates were based on the latest data available in the industry for the cost of constructing canals, structures, pump stations and pipelines including information from the Irrigation Division; PFRA; Alberta Energy and Natural Resources; and pump and valve companies.

The overall topographic slope of the Irrigation Block is from south to north. The difference in elevation between the southern and northern limits of the block is about 33 metres. The gain in head was not enough to operate high pressure sprinklers used in the block, and pumping was necessary to develop the required pressures (Marv Anderson and Associates and W-E-R Engineering 1981).

B. REHABILITATION ALTERNATIVES

From the seven alternative irrigation systems examined for rehabilitating the Bow Island Irrigation Block, the following three alternatives were recommended for more intensive investigation during this stage II study (Marv Anderson & Associates and W-E-R Engineering 1981).

CONCEPT A -

Open channel systems with hard surface canal lining utilizing a plain concrete slip-form lining

CONCEPT B -

Open channel system with a buried polyethylene channel lining, utilizing 30 cm random material and 15 cm granular slope protection

CONCEPT C -

Buried medium pressure pipe systems including a central pumping station with an open delivery channel supplying water from the main canal to the pump station.

The following pipe materials and their respective size ranges were selected, since they proved to be the most economical; prestressed concrete cylinder sections for diameters ranging from 610 mm to 915 mm, Polyvinyl Chloride (PVC) pipe with diameters less than 610 mm (SNC Consultants Ltd, 1984).

Available Information

The following information was taken by Marv Anderson & Associates and W-E-R Engineering (1981) from Irrigation Division (Alberta Agriculture) documents.

1. Identification of parcels along with their locations and acreage and preliminary irrigation distribution layouts for supplying water to these parcels.
2. Criteria to be used to calculate water requirements and net unit water demand, including an allowance for on-farm irrigation efficiency, at 1 litre/sec-ha.
3. Topographic contour maps of the entire Bow Island Block providing 1.5 m contour intervals.

Assumptions

Water requirements for a given area were calculated by Marv Anderson and Associates and W-E-R Engineering (1981) according to the following assumptions:

1. The smallest economic parcel to be served by a sprinkler system was set at 16 hectares,
2. The basic amount of land to be irrigated on one quarter

section was set at 57 ha which, when multiplied by 1 L/s·ha, gives a required maximum turnout capacity of 57 L/s for each quarter section of land,

3. Water requirements for parcels of land with an area of more or less than 57 ha were calculated on the basis of the number of hectares multiplied by 1 l/s-ha,
4. Assumptions 2 and 3 above were assumed to be the same for both the open channel and pipeline systems although an additional 142 L/s of capacity was added on the end of each lateral for the open channel systems to allow for return flow and wasteway discharge,
5. The "irrigation factor" (F) was set at F = 1.0. This assumes that all farm operators will use water simultaneously on their irrigable area,
6. Allowance for channel seepage losses were not included based on extensive use of impervious canal lining.

Design Capacities

Open Channel Systems (Alternatives A1 and B2)

Two laterals were proposed by Marv Anderson and Associates and W-E-R Engineering (1981) to irrigate the block by open channel systems. The total discharge capacities for laterals A and B were 1.16 m^3/s and 1.78 m^3/s respectively, with lateral A serving 962 ha and lateral B serving 1,548 ha. The total discharge capacities included requirements of 0.22 m^3/s and 0.28 m^3/s respectively for lateral A and B for wasteway discharge. The use of two laterals instead of one may have been to avoid large drop structures that would have been required to maintain allowable slopes within the irrigation block.

Pressure Pipeline System

Conveyance efficiency for pipelines is 100 percent. The total discharge (Q) for the entire Block would be Q = 2,510 ha x 1 L/s-ha = 2.51 m^3/s as discussed in the assumptions. A factor of 0.95 was applied to the design discharge for the pumping plant to give a design capacity of 2.38 m^3/s. The need for this factor was not discussed by Marv Anderson and Associates and W-E-R Engineering (1981). One explanation is that the areas left unirrigated in the corners of a quarter section when centre pivots are used or the areas lost during construction as land damages will not require any water, which will result in reduced system capacities.

Analysis of System Capacities

July is the month of maximum irrigation water requirements. Krogman and Hobbs (1976) cited water deficiencies of 160 mm for wheat, 173 mm for rapeseed and 109 mm for peas for southern Alberta for the month of July. Wheat is the most widely grown crop in the Bow Island irrigation block. Assuming a crop mix of 80 percent wheat, 10 percent rapeseed and 10 percent peas, the average water deficiency becomes 156 mm (0.58 L/s-ha). Water deficiencies for wheat, rapeseed and peas for the month of June are 58 mm, 58 mm and 41 mm respectively, thus some moisture may be stored in the soil during the month of June for the month of July, if required. By doing so capacities of the system can be further reduced.

Assuming a sprinkler system efficiency of 80 percent, the irrigation requirements for July become 195 mm (0.725 L/s-ha). As 57 ha per quarter section were assessed for irrigation, the assessed area becomes 2,210 ha out of 2,510 ha and the total system capacity for a pressure pipeline system would be 1.60 m^3/s. The system's actual design capacity is 2.38 m^3/s (SNC Consultants Ltd. 1984), which is approximately 49 percent over the required capacity. If 100 percent of the area (2,510 ha) was to be irrigated the required capacity would have been 1.82 m^3/s, and the system would be approximately 31 percent over-designed, although it is highly unlikely that 100 percent area of the block would require irrigation at the same time.

The designed capacities for the open canal systems were 2.94 m^3/s as compared to 2.38 m^3/s for pipelines. This means that the conveyance efficiency for the open canals was assumed to be 81 percent. Using the same procedure as for pipelines the total discharge capacities for the open canals become 1.97 m^3/s, considering 2,210 ha area to be irrigated, and 2.25 m^3/s for 2,510 ha irrigated. Thus the open canals were also over-designed by the same percentage as pipelines.

Construction Materials

The construction materials for open canal alternatives were gravel, concrete, precast units for hydraulic structures and polyethylene sheeting. All of these materials were available within reasonable haul and shipping distances.

As mentioned earlier, precast concrete cylinder sections were used for diameters ranging from 610 mm to 915 mm and PVC pipes for diameters ranging from 203 mm to less than 610 mm.

C. DESIGN OF ALTERNATIVE IRRIGATION SYSTEMS

Alternative A1 - Concrete Lining

Open Channel System With Plain Slip-Form Concrete Canal Lining.

For many years concrete canal linings have been placed with longitudinally operated lining equipment, commonly called slip-forms. After excavation and trimming of the subgrade, pouring, shaping, compacting and smoothing of the concrete lining is done with a slip-form. Slip-forms are used for almost any size of irrigation canal. For small canals they are usually subgrade-guided, and for large canals, with lining perimeters exceeding 7.5 m, they are usually supported on wheels, crawlers or rails.

The total length of slip-form channels proposed by Marv Anderson and Associates and W-E-R Engineering (1981) was about 27.8 km. The lengths and sizes of the canals proposed were as follows:

- 700 lin. m of 91 cm bottom width,
- 27,036 lin. m of 61 cm bottom width,
- side slopes were assumed to be 1.5:1,
- the minimum discharge capacity at the end of each lateral would be 0.14 m^3/s.

Maximum design velocity was set at about 2.13 m/s and a minimum velocity at 0.61 m/s. The roughness coefficient, "Manning's n", was assumed to be 0.014. The longitudinal slopes of the canals range from 0.001 to 0.0018 metre per metre. The *b/d* ratios ranged from 1.0 to 1.5. Forty-five pumping units totalling 1790 kW were required to supply pressure for the sprinkler systems. Right-of-way width requirements for canals was an average of 23 m with total area of 64 ha lost to production for this purpose.

A 63 mm thickness of concrete canal lining was proposed. Two 102 mm diameter tile underdrains were to be placed along the canal to minimize hydrostatic ground water pressure against the concrete lining. The total length of drain was estimated to be 42,672 m. The canal bottom was to be situated at least 1 m above the water table to prevent damage from freezing and thawing due to frost action.

Analysis of Concrete Lined Canal Design

The design of the concrete lined canal was in accordance with international standards found in the literature, i.e. Kraatz (1977). The reported permissible flow velocities were in the range of 1.5 to 2.5 m/s for brick and concrete lining. A Manning's n value of 0.011 for exceptionally good finish to 0.018 for poorly finished or badly maintained concrete canals have been reported by ICID (1972). However, an average value of 0.014 has been adopted by the U.S. Bureau of Reclamation (1963) for well-finished straight canals. Hence the designed value of n is reasonable.

Side slope of 1.25:1 has been cited by Kraatz (1977) for canals with bottom widths of 1 to 4.27 metres, with discharges of up to 62.3 m^3/s. The project canals have bottom widths of 0.61 to 0.91 metres and a maximum discharge of 1.78 m^3/s, with side slopes of 1.5:1, which are somewhat conservative. As the canal bottom was designed at least one metre above the water table, there seems no need for underdrains to be included unless there was a real danger of the water table rising up to the canal bottom.

No general rule is available for specifying the thickness of concrete lining. A figure is given by the U.S. Bureau of Reclamation (1963) showing thickness in relation to canal capacities for several lining materials used. This figure gives a thickness of approximately 50 mm for discharges of up to 5.664 m^3/s for un-reinforced Portland cement concrete lining. Kraatz (1977) has reported thickness of 50 to 80 mm for small to medium-size canals in countries with mild climates. Thus a thickness of 63 mm is quite reasonable for Alberta climates.

Alternative B2 - Polyethylene Lining

<u>15 cm Granular and 30 cm Random Slope Protection and Polyethylene Canal Lining</u>

The basic layout and discharge capacities of the open channel system were the same for both alternative A1 and B2. The channel parameters for alternative B2 were:

- side slopes - 3:1
- bottom width (b) - 1.0 to 1.8 m
- design water depth (d) - 0.6 to 0.9 m

Canal right-of-way width requirement was an average of 30.5 m with a total area of about 85 ha lost to production. The *b/d* ratio was assumed to range from 3.0 to 3.5. The design velocity was permitted to range from 0.6 to 1.0 m/s. The roughness coefficient, "Manning's **n**", was assumed to be 0.035. The longitudinal slopes of the canals were maintained within a range from 0.001 to 0.002 metre per metre (Marv Anderson and Associates and W-E-R Engineering 1981).

Analysis of Buried Poly Lining Design

The U.S. Bureau of Reclamation (1963) recommends a maximum side slope of 2:1 for asphalt or plastic membranes. Steeper slopes are recommended for relatively unstable material, such as uniformly graded sands, fine gravels or silty sands. Lauritzen and Terrell (1967) recommended a maximum slope for earth covered membranes of 3:1 as used in this project design.

The thickness of the cover depends on the erosion resistance of the material and local conditions, such as the type of cleaning equipment, amount and type of animal traffic within the canal section, and localized scour, particularly at curves and structures. Tests carried out in India to determine the thickness of soil cover for protecting a membrane against damage from animal traffic concluded that maintaining 30 cm of "sound cover" will protect the membrane with a fair margin of safety against livestock damage (Uppal et al 1965). The American Society of Agricultural Engineers (ASAE 1982) recommended a minimum thickness of soil cover for flexible membranes of 15.2 cm. The bottom 7.6 cm should not be coarser than silty sand.

There seemed to be two problems with the designed cover depth of this project. The designed depth was 15 cm granular and 30 cm random slope protection. Firstly, it is excessive according to most standards. Secondly, difficulty has been experienced with the cover material slipping down the slopes when two layers have been used. If the erosion resistance of the local material is insufficient, it is preferable to mix gravel into the earth and place the mixture in one layer (Kraatz 1977).

Manning's coefficient of roughness (n) for buried membrane lining is reported as 0.025 for small canals and 0.020 to 0.0225 for large canals (Kraatz 1977). The Manning's n value proposed in this project design is 0.035

which is again conservative and must result in larger and more expensive canal cross-sections.

Alternative C2 - Buried Pressure Pipeline System

Central Pump Station Location with Open Delivery Channel from Main Canal

The buried medium pressure irrigation pipeline system for the Bow Island Block was designed utilizing a central pump house location supplied with water by an open canal from the SMRID main canal as shown in Figure IV.2. Precast reinforced concrete Hyprescon pressure pipe was selected for diameters of 610 mm and above for the main distribution system. Smaller diameter feeder pipes were composed of PVC pipe.

The alternative C2 designs included pump station structures and pipeline safety equipment. Pipeline pressures ranged between 517 and 686 kPa with sectional valving installation for protection against surge and water hammer. Pressure at the farm turnouts was in the order of 500 kPa.

The buried pipelines do not need a permanent right-of-way but require an easement for maintenance purposes.

Analysis of Pressure Pipeline Design

The computer model as discussed in the previous chapter was used to analyse the Bow Island irrigation block. The sections and the respective data used in the analysis is

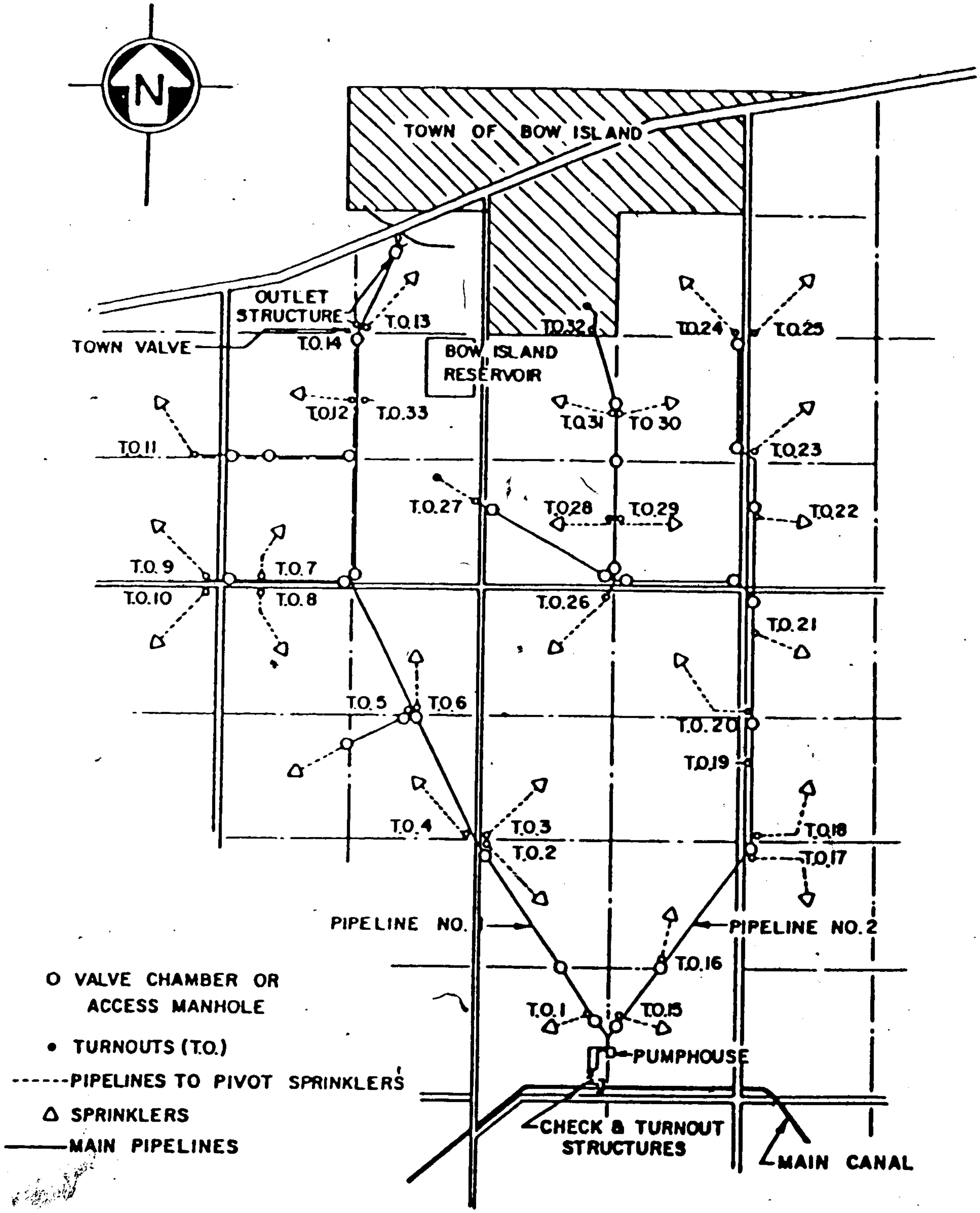

Figure IV.2. Bow Island Pressurized Pipeline Distribution System
Source: SNC Consultants Ltd. (1984). (No copyright involved)

given in Figure IV.3 and Table IV.2 respectively. Some of the information given in Table IV.2 is approximate, however the program was designed to be used in the designing process of a pressure pipeline irrigation Section is defined as length of pipeline over which discharge in the pipeline remains constant. Elevations at the start and end of the section were determined by interpolating the lengths of section over the overall slope of the irrigation block. The seasonal irrigation requirements were assumed to be 400 mm covering pumping and application efficiencies of 80 percent each. project and is very general. The annual discount rate was assumed 15 percent and maximum permissible velocity was assumed to be 2 m/s. A brief summary of the output is given in Table IV.3, and a complete output from the program is given in Appendix A. Section 25 as shown in Appendix A is the sum of farmers distribution system lengths from the main pipeline to the centre of the land parcel, assuming cemtre-pivots are used.

Total pumping requirements for concrete pipe are 1,586 kW and for PVC pipe 1,290 kW. The actual pumping station was constructed with a total capacity of 1,556 kW and a mixture of concrete and PVC pipes. The program does not take into account minor losses due to fittings and the elevations used were only estimates, so no definite comments can be made regarding pumping requirements used in the project except that both were close to the theoretical value. The average seasonal irrigation requirements used in the analysis was

Table IV.2 Approximate Data used in the Computer Model

Section No.	Discharge (m^3/s)	Length (m)	Elevation at start	Elevation at end (m)
1	1.105	500	25.5	23
2	1.04	1650	19	15
3	0.91	505	15	12.5
4	0.845	300	12.5	11
5	0.78	505	11	9.5
6	0.715	300	9.5	8
7	0.455	805	8	8
8	0.065	960	8	6
9	0.325	400	8	6
10	0.195	805	6	2
11	0.26	405	8	6
12	0.195	400	6	4
13	0.13	805	4	0
14	0.97	200	20	19
15	0.91	1350	19	17
16	0.715	960	17	13
17	0.065	460	12	13
18	0.585	1000	12	8
19	0.26	605	8	8
20	0.13	200	8	8
21	0.325	805	8	4
22	.065	1000	4	4
23	0.26	305	4	0
24	0.13	500	2.5	0

Table IV.3 Summary of Output from Computer Model

Item	Value
Maximum permissible velocity used, m/s	2
Annual interest rate used (percent)	15
Maximum discharge, m^3/s	2.075
Average seasonal irrigation required, mm	400
Total pumping requirement for concrete (kW)	1,586
Energy cost for concrete pipe	$70,489
Total pumping requirement for PVC pipe (kW)	1,290
Energy cost for PVC pipe	$57,333
Total cost of PVC pipe	$1,388,380
Total cost of concrete pipe	$1,743,185
Annual cost using PVC pipe	$208,449
Annual cost using concrete pipe	$261,719

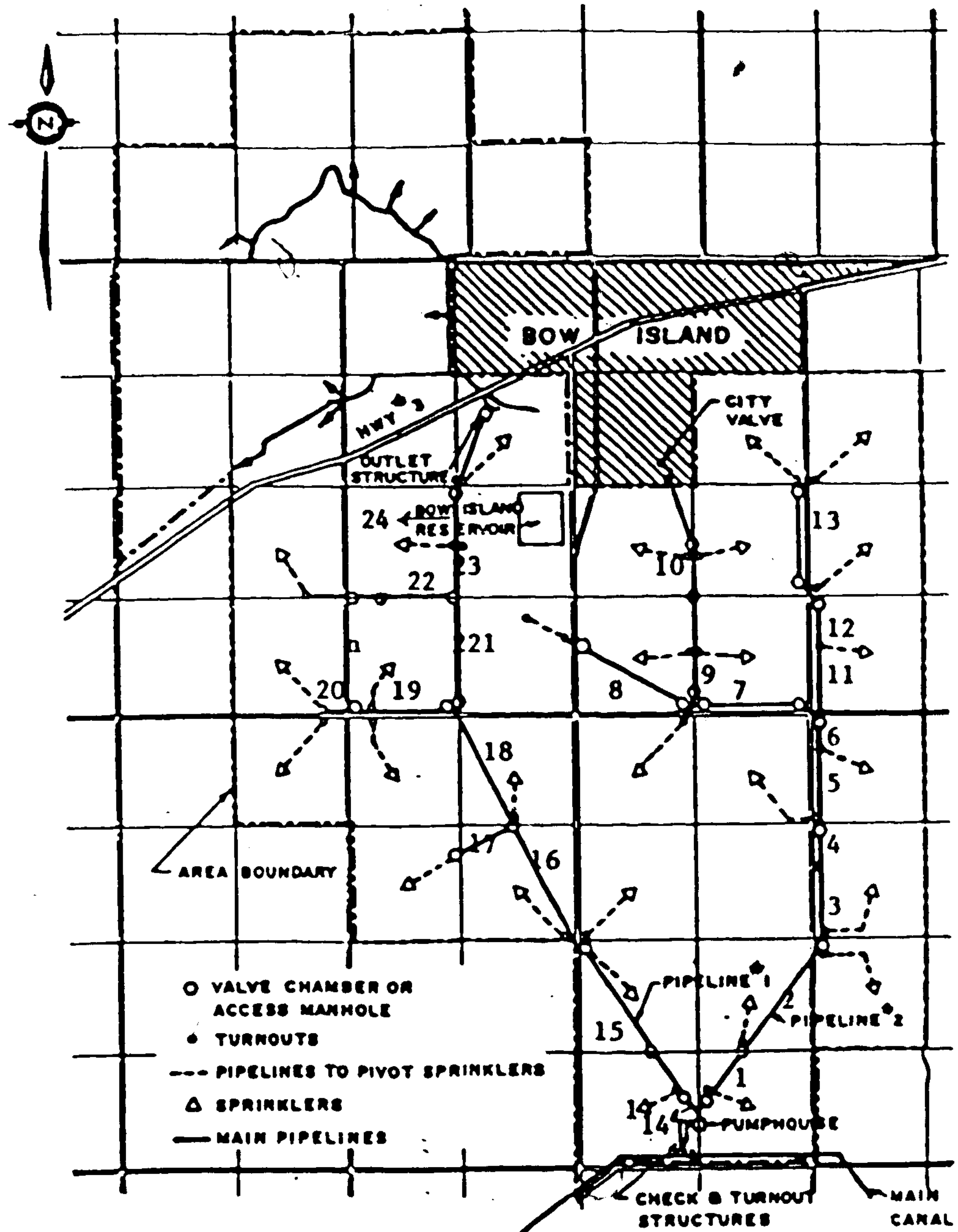

Figure IV.3. Pipeline Sections of the Bow Island Irrigation Block as Used in Computer Model

400 mm and the energy charge was $0.04/KWH.

Total cost of pipes as computed by the computer model were $1,388,380 for PVC pipes and $1,743,185 for concrete pipe. This estimate covers only 2,075 ha, the area covered by the pressurized irrigation system. The rest of the area (435 ha) is covered by a gravity pipeline. Thus the program may be used to compare PVC pipe cost with concrete pipe cost rather than comparing with the project costs which used both pipe materials.

Annual cost was $208,449 for PVC pipes and $261,719 for concrete pipes. The annual energy cost was $57,333 and $70,489 using PVC and concrete pipe respectively. Again energy costs give a measure of the savings that can result by using PVC pipe instead of concrete pipe.

D. IRRIGATION WORKS LIFE EXPECTANCY

The life expectancy of the main network as assumed by Marv Anderson & Associates and W-E-R Engineering (1981) is 30 years for concrete lining, 40 years for polyethylene lining and 50 years for pipelines. The life expectancy of pumps and motors for the pipeline network is 25 years. The life expectancy of the on-farm irrigation works is 15 years for pumps and motors, and sprinkler systems, and 50 years for dugouts and underground distribution systems.

A study conducted by Alberta Agriculture (1975) entitled "Evaluation of Concrete Slip-form Lining versus Buried Polyethylene Lining" proposed design life of concrete slip-form lining as 50 years and polyethylene lining as 25 years. If this is assumed true then the concrete slip-form lining option may be more economical than pipelines, however the feasibility of polyethylene lining will be further reduced.

The study also concluded that concrete slip-form lining has a comparatively lower initial construction, and operation and maintenance cost than buried polyethylene lining. Concrete slip-form lining also provides very good control of weed growth relative to buried membrane lining.

From the discussion in the previous sections it can be concluded that there were no serious faults in the design, however the following comments can be made:

1. Savings in cost were possible by designing the systems with smaller capacities without the danger of any water supply shortage for the crops,
2. Some of the design parameters like larger side slopes for both the open channels and higher Manning's n values and very thick slope protection for the polyethylene lining option were conservative and must result in expensive cross-sections,
3. Life expectancy for slip-form lining was under-estimated which can change the capital cost analysis of the alternatives considered. A wrong decision may have been resulted if the capital cost was a major consideration.

V. ECONOMICS OF BOW ISLAND LATERAL-12 REHABILITATION

The purpose of the following sections is to quantify and analyse all direct farm and non-farm costs associated with the three rehabilitation alternatives considered for the Bow Island irrigation block. As discussed in the last chapter, the three rehabilitation options were:

1. An open channel system with a slip-form concrete lining
2. An open channel system with a buried PVC lining and
3. A buried (Concrete-Steel-PVC) medium pressure pipeline system.

A total of 2,510 ha was considered serviceable under any or all of the above systems (Table IV.1).

A. MAIN SYSTEM COSTS

Concrete Slip-Form Lining

Engineering design specified a 75 mm thick concrete lining. Approximately 27.8 km of channels were proposed for the Bow Island rehabilitation scheme. The slip-form lining option had an estimated life expectancy of 30 years at a cost of $4.7 million (Table V.1).

Assuming an annual interest rate of 15 percent, the annual cost of the main system would be $715,811 amortized over 30 years and $706,651 (Table V.2) amortized over 50 years as proposed by Alberta Agriculture (1975).

Table V.1 Total Capital Costs for Bow Island Block Rehabilitation

($ millions)

ALTERNATIVE	MAIN SYSTEM	ON-FARM PUMPS AND MOTORS	ON-FARM SPRINKLER & DISTRIBUTION SYSTEMS	ON-FARM DUG-OUTS	TOTAL CAPITAL COST
Concrete slip-form lining	4.7	0.65	2.5	0.22	8.07
Poly liner	4.9	0.65	2.5	0.22	8.27
Pressure pipe	5.7	-	2.5	-	8.20

Source: Marv Anderson and Associates and W-E-R Engineering (1981) (No Copyright Involved)

Table V.2 Comparative Annual Capital Costs for the Irrigation Block

($ millions)

Alternative	Main System Cost	On-Farm Cost	Total Annual Cost
Concrete Lining	0.716	0.563	1.279
	0.706*	0.563	1.269
Polyethylene Lining	0.738	0.563	1.301
	0.758#	0.563	1.321
Pressure Pipe	0.858	0.419	1.277

* Considering life expectancy of 50 years

\# Considering life expectancy of 25 years

Polyethylene Lining

The polyethylene lining option was also 27.8 km in length. The estimated (mid-1981) capital cost of the polyethylene lined canal was $4.9 million,(Table V.1). Again assuming an annual interest rate of 15 percent the annual amortized cost of polyethylene lining over the useful life of the system as shown in Table V.2 would be $737,754 considering a life expectancy of 40 years and $758,027 considering a life expectancy of 25 years as proposed by Alberta Agriculture (1975).

Pressurized Pipeline

The pipeline alternative considered was a network of 21.9 km of pipe. Electrically driven district pumps were required to maintain adequate water pressure. The life expectancy of the pipeline was anticipated at 50 years and the estimated capital cost was $5.095 million. The pumps and motors for this option were expected to last for 25 years and cost $605,000 with total cost being $5.7 millions (Table V.1).

Assuming an annual interest rate of 15 percent the annual cost of the pipelines main system amortized over 50 years period would be $764,956 and annual cost of pumps and motors amortized over 25 years would be $93,593. Total annual cost of pipeline and pumps and motors became $858,549 (Table V.2)

Total capital costs were estimated by Marv Anderson and Associates and W-E-R Engineering (1981). Although no detailed analysis of these costs was done, however these costs were considered acceptable because, as will be shown in the evaluation section, the actual construction cost of pressure pipelines was very similar to these estimates. Therefore it can be presumed that the estimated costs of open channels are acceptable for feasibility analysis purposes.

Considering the main systems only, the concrete slip-form lining was the most economical alternative both on the first cost and annual cost basis and the pressure pipeline was the most expensive alternative. However, capital cost is only part of the analysis and does not give the complete picture. On-farm capital cost and annual operation and maintenance cost both for the main system and on-farm must be considered before reaching a complete decision on economic analysis.

Annual Operation and Maintenance Costs

Maintenance costs include the salaries and wages of the maintenance crew, equipment costs, materials, and vehicle costs. Associated with the upkeep of the District's maintenance functions are structure repairs, cleaning, weed control, painting, drain cleaning and upkeep. Also vehicle and equipment upkeep costs are included.

Table V.3 Annual Operation and Maintenance Costs (Main System + On-Farm)

For 2,510 Ha 381 mm Net Water Rate

ALTERNATIVE	OPERATION	MAINTENANCE	ENERGY	TOTAL	COST PER HA
Concrete slip-form lining	14,000 + 22,568	39,000 + 54,188	90,210	219,966	87.64
Poly liner	14,000 + 22,568	50,000 + 54,188	90,210	230,966	92.00
Pressure pipe	22,000 + 14,880	6,000 + 28,210	40,000	111,090	44.26

Source: Adopted from Marv Anderson and Associates and W-E-R Engineering (1981) (No Copyright Involved)

Operation costs are those costs required to operate an Irrigation District regardless of upkeep condition of that district. Estimated operation and maintenance costs (in 1981 dollars) for slip-form lining were $53,000 ($21.00 per ha), for polyethylene lining $64,000 ($25.50 per ha) and for pressure pipeline $68,000 ($27.00 per ha) as shown in Table V.3.

It must be remembered that operation costs for pressure pipeline included $40,000 as cost of energy to operate the proposed central pumping station. When this energy cost is deducted, annual operation and maintenance cost for pipelines becomes $28,000 ($11.00 per ha), approximately 40 percent of those for other options. However as will be shown in the evaluation section the cost of energy for pipelines was under-estimated as the actual energy cost during 1984 was $69,826 which is 75 percent more than the estimated cost for pipelines. This cost was even greater for the 1983 season, while the cost of energy for open canal systems was estimated at $90,210. This analysis shows that the pipeline option was given some advantage over open canal systems during the original analysis by Marv Anderson & Associates and W-E-R Engineering (1981).

B. ON-FARM COSTS AND REVENUE ESTIMATES

All costs involved in getting water from the system turnouts to the crops were considered on-farm costs. Conventional crop production costs, as well as other miscellaneous costs of on-farm irrigated crop production, are discussed in the following sections.

Irrigation Capital Costs

The on-farm irrigation system for the two open channel options included pumps and motors, dugouts, sprinkler systems, and (PVC) water lines from the edge of the quarter section to the centre of the field (assuming centre pivots were employed). In the case of the pipeline option, no pumps, motors, or dugouts were required.

The resulting total on-farm irrigation capital costs were $3.37 million for each of the open canal options and $2.5 million for the pressurized pipeline option (Table V.1). Assuming an annual interest rate of 15 percent, the annual on-farm capital costs amortized over the useful life of the equipment would be $562,756 for each of the open canal options and $418,565 for the pressure pipeline (Table V.2). Thus the pipeline has the least on-farm capital cost.

Total on-farm and main system capital costs for the pipeline option were $8.20 million, polyethylene lining costs were $8.27 million and concrete lining costs were $8.07 million (Table V.1).

Annual main system plus on-farm capital cost would be $1,277,114 for the pipeline. Annual cost of open canal systems depend on the life expectancy considered. For example, the cost of polyethylene lining would be $1,300,510 and $1,320,783 considering life expectancies of 40 years and

25 years respectively. The total main system and on-farm costs for slip-form concrete lining would be $1,278,567 and $1,268,407 for life expectancies of 30 years and 50 years respectively. A summary of these costs is presented in Table V.2.

Polyethylene lining is the most expensive option both on the first cost and annual cost basis and may not be considered any further. The concrete slip-form lining is the least expensive and may be preferable over the pipeline on this basis, however it may or may not be preferable on the annual cost basis depending on the life expectancy considered. If the useful life of concrete lining is considered to be 30 years it would cost $1,500 per year more than the pressure pipeline; while considering a useful life of 50 years it would cost $8,700 less than the pressure pipeline per annum. Thus the final conclusion should be deferred until further analysis on the basis of annual on-farm operation and maintenance costs is completed.

Annual Operation and Maintenance Costs

The total annual on-farm operation and maintenance cost estimates include labour, maintenance and energy costs for open canal options and only labour and maintenance costs for the pipeline option, because the energy cost was included in the main system operation costs in the case of pipelines. These estimates were made for the entire irrigation block by Marv Anderson & Associates and W-E-R Engineering (1981).

Estimated irrigation labour (operation) costs for the open canal systems were $22,568 each and for the pipelines it was $14,880 for the total block, a saving of 34 percent over the open canal options. Maintenance cost was estimated at $54,188 for each of the open canal options and $28,210 in the case of the pipeline option. The savings were 48 percent in favour of the pipeline option. Energy cost was estimated at $90,210 for each of the open canal options, whereas this estimate was $40,000 for the pipeline option. In other words, energy cost for the pipeline option was only 44 percent of those for open canal options. Table V.3 gives a summary of total (main system plus on-farm) operation and maintenance costs. The overall operation and maintenance costs for the pipelines become only 50 percent of those for open canal options.

Table V.4 gives comparative annual capital and operation and maintenance costs for all the three alternatives considered. Pressure pipeline has the minimum annual cost of $1,388,000. The cost of slip-form concrete lining is $101,000 to $111,000 more than pipeline per annum and the cost of polyethylene lining is $144,000 to $164,000 more than pipeline per annum depending upon the life expectancy considered. However it is established that the pressure pipeline option was really the most economical alternative on an overall basis.

Table V.4 Comparative Total Annual Costs for the Irrigation Block (Main System + On-farm)

($ millions)

Alternative	Annual Capital Cost	Operation & Maintenance	Total Annual Cost
Concrete Lining	1.279	0.22	1.499
	1.269*	0.22	1.489
Polyethylene Lining	1.301	0.231	1.532
	1.321#	0.231	1.552
Pressure Pipe	1.277	0.111	1.388

* Proposed life expectancy of 50 years

\# Proposed life expectancy of 25 years

Production Costs

Marv Anderson & Associates and W-E-R Engineering (1981) estimated cost of goods and services (including depreciation) for dryland and irrigated crop production as follows:

Dryland	$50.76/ha
Irrigated land	$331.57/ha

The unit costs of production associated with livestock enterprises were found to be:

Dryland	$7.06/ha
Irrigated land	$225.83/ha

Thus there was an additional cost of $280.81 per ha for bringing dryland under irrigation for crops and $218.77 per ha for livestock. These costs will be used to calculate the incremental benefits and costs to the farmers after completion of the project in the computer analysis given in the last section.

On-farm Revenue Estimates

The crops and livestock production gross revenue estimates derived by Marv Anderson & Associates and W-E-R Engineering (1981) were used to calculate the incremental net benefits and costs. The estimates of gross revenue per ha for irrigated and dryland crop production were determined to be as follows:

Dryland -------------------	$96.55/ha
Irrigated land -----------	$614.98/ha

and estimates for livestock production were:

Dryland ---------------------- $9.81/ha

Irrigated land ----------- $313.64/ha

This means there was an increase in farm revenues of $518.33 per ha through crops and $303.83 per ha through livestock for the additional irrigated area.

C. ECONOMIC AND FINANCIAL ANALYSIS

A financial analysis of the revenue and expenditure implications for affected producers was undertaken to determine the benefit/cost ratios for the three alternatives considered.

Irrigation District Dues

There were two costs which must be recovered by the District to supply water at the farm turnouts:

(i) 7 percent of initial capital cost, and

(ii) 100 percent of operation, maintenance and administration cost.

Assessed areas considered were 2,441 ha for slip-form lining, 2,421 ha for polyethylene lining and 2,498 ha for pressure pipeline after deducting land damages during construction. Inflating all main system costs from Table V.2 at 6 percent per annum, the annual development cost per ha, for the main systems after completion of the project in 1983, to the farmers would be $21.44 for slip-form lining, $23.24 for polyethylene lining and $25.48 for pressure pipelines.

The estimated water rate for the first operating year (1983) including 100 percent of operation, maintenance and administration for the assessed areas was $33.58/ha for slip-form lining, $39.63/ha for polyethylene lining and $40.82/ha for pressure pipeline (Marv Anderson & Associates and W-E-R Engineering 1981). Thus total full cost water rates and development levies per ha for 1983 would be $55.02 for slip-form lining, $62.87 for polyethylene lining and $66.30 for pressure pipelines. These were the costs to be compared to on-farm benefits to calculate the benefit/cost ratios of the proposed options from a farmer's point of view.

Computer Analysis of On-farm Incremental Costs and Benefits

Some of the important questions to be addressed at the farm level are:

- What were the net benefits to Bow Island farmers if any one of the rehabilitation schemes were implemented?
- Were the net benefits sufficient to allow farmers to pay their "fair" share?

The following items are important to analyse the direct incremental benefits to local farmers after completion of the project.

- increase in the irrigable area,
- increase in the yield due to better water availability,
- lower costs of production,

land conservation.

The irrigated area was expected to increase 1,060 ha using slip-form lining, 1,039 ha for polyethylene lining and 1,117 ha for pipelines after completion of the project (Marv Anderson and W-E-R Engineering 1981). Existing irrigated area was 1382 ha, thus total land damages during construction would be 68 ha for slip-form lining, 89 ha for polyethylene lining and 11 ha for pressure pipeline.

The farm delivery for the existing system was 430 mm and farm efficiencies were 55 percent (SMRID 1981) making 236 mm of water available for plant use. On the other hand, the new system was designed to provide 518 mm at the farm and assuming 75 percent farm efficiency, the amount of water available for plant use was about 390 mm. In other words, each of the three options was designed to deliver an extra 154 mm of water to the crop which can be assumed to increase the yield. Again the production increase would probably result in higher incomes for the farmers in the Bow Island block.

The saving in costs of production due to rehabilitation proposals (excluding SMRID main canal) estimated by Marv Anderson & Associates and W-E-R Engineering (1981) were $5.31/ha for slip-form lining, $5.36/ha for polyethylene lining and $6.30/ha for pipeline. Furthermore, the obvious advantage of the pipeline option may still be under-estimated because of constantly changing land ownership and future technological changes (e.g. 800 metre centre pivots), which are more economical to use and require even larger unobstructed fields.

A program was designed to approximate the on-farm incremental costs and benefits of each of the rehabilitation options considered. Annual costs were calculated by amortizing at an interest rate of 15 percent over the useful life of the items being considered. The total area was divided into two parts, expansion (newly irrigated area) and intensification (existing irrigated area with intensive irrigated agriculture) after completion of the project. The area for intensification was 1382 ha and area for expansion was estimated by deducting the land damages during construction from the remaining irrigable area. For expansion, extra costs and benefits to the farmers due to irrigation were calculated by deducting the dryland agriculture cost and revenues from the intensive irrigated agriculture cost and revenue estimates. Programs used and output for each option are given in Appendix B. The data for all the expenses and revenues was taken from Marv Anderson & Associates and W-E-R Engineering (1981).

The net benefits of rehabilitation which could accrue to average farmers in the Bow Island Block in a median year if one of the rehabilitation proposals was actually implemented as given by computer calculations are as follows:

Slip-Form	$42.97/ha
Poly Liner	$43.55/ha
Pipeline	$100.47/ha

These estimates are a good measure of the relative profitability of each alternative system and represent the best estimate of the average farmer's *"ability to pay"* for irrigation rehabilitation in the Bow Island block. These can then be compared with the financial requirement according to the 86-14 formula.

Considering for example, the first full year of operation for a new system (1983), the following incremental benefits, costs and benefit/cost ratios were calculated:

Option	Net Benefits per ha	Net Cost per ha	benefit/cost ratio
Slip-Form	$42.97	$55.02	0.78
Poly Liner	$43.55	$62.87	0.69
Pipeline	$100.47	$66.30	1.51

The relative magnitude of these benefit-cost comparisons are noteworthy. Although the per ha costs of various proposals are similar, the per ha benefits are different, re: open channel versus pipeline. This showed that if the 86-14 cost sharing formula was applicable for both open channel and pipeline systems, farmers in the Bow Island Block should have a strong preference for the pipeline alternative.

The "premium" which farmers could apparently pay for pressure pipeline (versus open channel options) might be as high as \$56.84/ha, principally because this particular proposal is characterized by:

1. no on-farm pumps, motors, dugouts, or related operation & maintenance costs,
2. slightly lower production costs due to no linear disturbances, and
3. slightly higher revenue projections due to a slightly larger irrigated area.

These estimates are very specific to the Bow Island Block in that the proposed development would effectively increase the area by 80 percent.

However, about 50 percent of the *special* farm benefits of a pipeline are realized because the pipeline is pressurized, not because it is a pipeline.

VI. EVALUATION OF THE BOW ISLAND PROJECT

Water is drawn from the SMRID main canal and delivered to a computer controlled pumping station equipped with six 224 kW and two 112 kW pumps capable of discharging 2.38 m^3/s at a minimum pressure of 500 kPa.

From the time design work was started in January 1982 until construction was completed in time for the 1983 irrigation season, everything went according to schedule. The project is in its fourth year of operation. The total project cost, as completed in 1983, was $6.44 million (SNC Consultants Ltd. 1984) whereas the estimated cost was $5.7 million (1981 dollars), an increase of approximately 6 percent per annum which is not unexpected. In accordance with the 86-14 plan, the Government of Alberta contributed $5.54 million to the project. The remaining $900,000 was shared equally by the SMRID and the landowners, including the Town of Bow Island. The landowners contributed $254 per ha. Every farmer arranged his own financing of this cost.

The project expectations are difficult to assess in a comparative way with the alternative options examined for rehabilitation of lateral-12 in the Bow Island Block. However, after two years of operation, some observations were made by Ramsey and Gyrofi (1985) with regard to efficiency, effectiveness and cost per ha. Financially, the land owners are paying exactly what they agreed to, namely actual energy cost plus 1 percent for operation and maintenance. In 1984, the following costs were levied:

1 percent of Capital Cost	$61,752.24
Energy for Pumps	$69,826.38
Total	$131,758.62
Total Amount of Water Delivered	792.2 ha-m
Cost per hectare-metre	$166.29

Ramsey and Gyrofi (1985).

In 1983, the cost per ha-m was $179.32 and in 1985 the cost per ha-m was $163.37.

A. EVALUATION OF PROJECT IN RELATION TO STUDY OBJECTIVES

This section discusses the rehabilitation project in relation to the objectives of the study, the use of pipelines for on-farm conveyance and distribution of irrigation water as an alternative to open canal lining as it affects:

1. land and water conservation,
2. capital costs,
3. operation and maintenance costs, and
4. net return to the farming enterprise.

Land and Water Conservation

Estimated land losses in right-of-ways and dugouts for this project were 67.5 ha for the slip-form lining, 88 ha for the polyethylene lining and only 11 ha for the pipeline option. Thus 56.5 to 77 ha of land were saved by choosing the pipeline option for rehabilitation of the block.

Similarly, water delivery efficiency after rehabilitation was estimated at 81 percent for open canal options and 100 percent for pipelines. Thus 19 percent of the water was saved by using pipelines. This water can be utilized to bring more dryland area under irrigation using the same amount of irrigation water.

Capital Costs

Considering the main system only, the slip-form concrete lining was the most economical option both on the first cost and annual capital cost basis, and pipeline was the most expensive option. The total capital cost of pipeline was $5.7 million with an annual cost of $858,549 amortized at the discount rate of 15 percent over the life of the system, whereas the total capital cost of concrete lining was $4.7 million with an annual cost of $705,651 to $715,811 for life expectancies of 50 years and 30 years respectively (Tables V.1 and V.2). Thus slip-form concrete lining was a better choice if capital cost was a major concern.

These cost differences become marginal when on-farm capital costs are added to the main system costs. The total main system plus on-farm capital cost were $8.07 million for slip-form concrete lining, $8.27 million for polyethylene lining and $8.20 million for pressure pipeline (Table V.1). Annual main system and on-farm costs were $1,277,000 for pressure pipeline. The annual costs for slip-form lining were $1,269,000 to $1,279,000 and for polyethylene lining were $1,301,000 to $1,321,000 depending upon the life expectancies considered (Table V.2). Again slip-form concrete lining was most economical on the first cost basis but it may or may not be economical on an annual basis. For example, slip-form lining could save $8,000 per annum over pressure pipeline considering a life expectancy of 50 years but will cost $2,000 more than pressure pipeline considering a life expectancy of 30 years for slip-form lining.

Operation and Maintenance

Total main system and on-farm operation and maintenance costs per season were estimated at $88/ha for slip-form lining, $92/ha for polyethylene lining and $44/ha for pressure pipelines (Table V.3). This shows annual operation and maintenance costs for pressure pipelines were 50 percent or less than those for open canal options.

Considering total annual estimated capital and operation and maintenance costs, for slip-form lining the costs were $1,489,000, for polyethylene lining $1,552,000 and for pressure pipeline $1,388,000 (Table V.4). There were savings of $101,000 to $164,000 per annum through use of pipelines. Thus a pressure pipeline was the best choice from a farmer's point of view.

Net Return to the Farming Enterprise

Pipelines also showed a maximum net return to the farmers in the irrigation block. The estimated annual net benefit in the case of slip-form lining was $42.97/ha, in the case of polyethylene lining $43.55/ha and in the case of pipelines $100.47/ha (page 78). Thus the net return for the pipelines option was twice as much as for the open canal options.

From the previous discussion it is obvious that pipelines were the best alternative for rehabilitation of the block on an overall basis.

Effectiveness and Efficiency Values to the Landowners

The pressurized pipeline system has increased efficiency in farm operations. There is no need to move around open ditches and dugouts. Sprinkler systems can now be set to irrigate complete fields without obstruction. Individual sprinklers can be turned on or off in minutes without affecting the main delivery system. For example, a farmer can request water for 50 percent of his irrigated land and then rotate delivery to his individual sprinklers as needed. In this way, operation of the SMRID main system can be maintained at a much steadier flow.

Another value to the landowners has been a noticeable decline in salinity problems. After only two years of operation, some saline areas adjacent to the old open ditch laterals had been reclaimed because of no seepage. Also, the weeds along the open channels no longer exist, thus reducing on-farm weed control problems.

Fielder soft white spring wheat and rapeseed are the major crops grown in the block. The average yield of Fielder wheat was 5.4 tonnes/ha (80 bushels per acre) and rapeseed averaged about 2.52 tonnes/ha (45 bushels per acre) in 1983. The average yields in the area for that year were 2.42 toonnes/ha for wheat and 1.3 tonnes/ha for rapeseed (Alberta Agriculture 1984). Other crops grown in the block include sugar beets, corn, malting barley, field beans and peas, although soft white spring wheat is the major one. Most crops are grown under contract and continuous cropping is normal (Bradley 1984).

Possible Improvement in Future Systems

One suggested improvement that should be considered in any similar system relates to the location of the farm turnouts. The turnouts in the Bow Island block were located near mid-quarter section boundaries to capitalize on existing on-farm piping. This has created a minor problem when centre-pivot sprinklers are in opera[illegible]. The turnout valves and area are continually wet. It would be better to locate the farm turnouts at the quarter section corners, at the junction of the main line and farm turn-out.

VII. SUMMARY AND CONCLUSIONS

A study review was undertaken to ascertain the need for irrigation system rehabilitation and the status of existing irrigation systems. The objective was to analyse the cost effectiveness of pipelines for on-farm irrigation water conveyance and distribution. A review of some previous rehabilitation projectsin southern Alberta, where alternative irrigation systems were studied, was also undertaken.

This information was used to analyse and evaluate the rehabilitation of the Bow Island block. The original study conducted by Marv Anderson & Associates and W-E-R Engineering was further analysed to validate their results, both for the engineering design and economic analysis. Three irrigation system options, concrete slip-form lining, buried polyethylene membrane lining and pressurized pipelines were considered and studied in detail. Evaluation of the irrigation block after rehabilitation was also presented. The following conclusions were drawn from the study.

1. Land lost in rights-of-way and dugouts was a minimum in the case of pipelines. It was 68 ha for slip-form lining, 88 ha for ployethylene lining and only 11 ha in the case of pressure pipelines.
2. The system seems over-designed approximately 31 to 48 percent for the discharge capacities. This is more serious because there is no more expansion of the irrigation block possible to utilized the extra capacity

of the system.

3. Concrete slip-form lining was the most economical and polyethylene lining was the most expensive on a capital cost basis. Total capital costs (main system plus on-farm) were $8.07 million for slip-form lining, $8.27 million for polyethylene lining and $8.20 million for pressure pipelines (Table V.1).
4. Annual operation and maintenance costs for the irrigation block were minimum for the pressure pipeline option, and were 50 percent or less of those for the open canal options. Total on-farm and main system costs per season were estimated at $88/ha for slip-form lining, $92/ha for polyethylene lining and $44/ha for pressure pipelines (Table V.3).
5. Pressure pipelines were found significantly more economical on the overall annual cost (capital plus operation and maintenance) basis. The total annual cost for pressure pipeline was $1,388,000, for polyethylene lining $1,532,000 to $1,552,000 and for concrete lining $1,489,000 to $1,499,000, depending upon the useful life considered (Table V.4).
6. Pressure pipelines also showed maximum net returns to the farmers in the irrigation block. The estimated annual net benefits were $42.97/ha in the case of slip-form lining, $43.55/ha in the case of polyethylene lining and $100.47/ha in the case of pressure pipelines.
7. Pressure pipelines gave the maximum benefit/cost ratio

from the farmer's point of view. The estimated net benefit/cost ratios were 0.78 for slip-form lining, 0.69 for polyethylene lining and 1.51 for the pressure pipelines.

8. Pipeline systems are most beneficial when they are centrally pressurized because they eliminate the need for on-farm pumps and motors, dugouts and related operation and maintenance costs.

The choice of irrigation system that should be employed is dependent upon the topography of the irrigation block and the method of irrigation used. For example, if there are steep slopes in the area which will require many drop structures, crossings and inverted siphons, the open canal systems may be too expensive. Then the choice of pipelines may be economical because there will be no need for drop structures, crossings and siphons. Moreover, pipelines can result in energy conservation by utilizing the head developed due to the slopes if sprinkler systems are used.

VIII. RECOMMENDATIONS FOR FURTHER WORK

As a result of various observations and conclusions obtained from this study, some recommendations for further work have been developed.

1. Evaluation of the rehabilitated areas where pipelines are used should be done to affirm any significant increases in farm income due to intensive irrigation practices after rehabilitation of the irrigation blocks.
2. The savings in the cost of production in the rehabilitated areas due to less weeds, less labour requirements and less linear disturbances in the use of large farm machinery should also be evaluated.
3. Since the use of plastic pipes for irrigation water conveyance and distribution is relatively new, there is a need to study the deformation of pipes under farm machinery or soil loads, which may change the flow conditions in the system.
4. Buried pipelines should also be studied for the deterioration of pipe materials under the action of soil and water in southern Alberta to determine the life expectancies of the pipe materials.

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APPENDIX A. COMPUTER MODEL FOR PIPELINES

```
10 'PROGRAM       DESIGN
15 'Purpose         To calculate diameter, friction loss
20 '               loss and cost of concrete and pvc
pipelines
25 'Programmer        Saleem A. Sial
30 'Programmed for      Thesis
35 'Language       Micro soft Basic (Basica)
40 'Designed for       IBM-PC
45 'Date completed       June 1987
50 '-------------------------------------------
100 '** MAIN SECTION **
105 DEFDBL A-Z       ' All double precision
108 OPEN "DATA1"FOR OUTPUT AS #1
110 GOSUB 200        'Initialization of variables
111 GOSUB 300
112 SECT =SECT + 1
115 GOSUB 310        'INPUT system parameters
120 GOSUB 900
172 INPUT "MORE SECTIONS ? 0 FOR NO, 1 FOR YES";MORE
174 IF MORE = 1 THEN GOTO 112
176 GOSUB 800
177 CLOSE#1
178 BEEP
180 END
200 '** Initialization of Variables
201 SECT = 0       'Pipe section number
```

```
202 TCP = 0          'Total cost of pvc pipe
203 TCC = 0          'Total cost of concrete pipe
204 TPRP = 0          'Total power requirement for pvc pipe
206 TPRC = 0          'Total power requirements for concrete
                pipe
220 KP = 0.00003       'Roughness of pvc pipe in m
222 N = 50          'Useful life of pipes in years
225 KC = 0.0006        'Roughness of Concrete pipe in m
240 TOL = 0.000001      'Tolerance in Darcy roughness factor
245 NEU = 1.15*10^-6 'Kinematic viscosity of water at 15
                  degree C m^2/s
255 PI = 3.141593       'constant pai
260 G = 9.81         'Acceleration due to gravity
295 RETURN
300 '** Input System parameters **
301 INPUT "Give maximum permissible velocity m/s "; VP
302 INPUT "Give annual interest rate (decimal) "; I
303 INPUT "Give seasonal irrigation required mm "; IR
304 INPUT "Give total assessed area ha ";TAREA
305 INPUT "Give total discharge m^3/s ";TQ
306 INPUT "Give energy charge $/KWH "; ERATE
308 RETURN
310 INPUT "Give discharge of the section m^3/s "; Q
315 D = (4 * Q/(VP * PI))^0.5
320 PRINT "Calculated diameter is "; D
325 INPUT "Give the next higher diameter available in m "; D
330 INPUT "Give the length of the section in m ";L
```

```
335 INPUT "Give price of pvc pipe $/m "; PP
340 INPUT "Give price of concrete pipe $/m "; PC
345 INPUT "Give elevation at the start of this section m ";
        BE
350 INPUT "Give elevation at the end of this section m "; EE
355 INPUT "Give pressure required at the end of section
        kPa"; PE
360 INPUT "Give existing pressure at the start of section
        kPa";PB
395 RETURN
400 '** Definition of variables **
402 V = 4 * Q /(PI * D^2)
405 RE = V * D / NEU        'Reynold's number
410 NK = K/(3.7 * D)
415 NR = 2.51/RE
420 F = 0.0055 * ( 1 + (20000*K/D + 10^6/RE)^(1/3))
425 X = (1/F)^0.5
490 RETURN
500 '** Calculate Darcy friction factor F by iterations
505 NUM = X + 0.8686 * LOG(NK + NR * X)
525 DENUM = 1 + 0.8686 * (NR /(NK + NR * X))
530 NX = X - (NUM / DENUM)
531 NF = (1/NX)^2
535 DIF = ABS(NF - F)
540 NTOL = TOL * (1 + ABS(F))
545 F = NF
595 RETURN
```

```
600 PRINT "** RESULTS **
605 HF = F * L * V^2/(2 * G * D) 'friction head loss
610 PH =HF + (PE - PB)/9.8 + (EE - BE) 'pumping head
612 PH = PH * Q *1000/102.2  'Water power (kW)
615 PCOST = L * PRICE        'pipe cost
620 TCOST = TCOST + PCOST        'Total pipe cost'
625 TPH = TPH + PH        'TotalWater power requirements
630 PRINT "Discharge Q ";Q ;"m3/s
635 PRINT "Length of section L "; L;"m
640 PRINT "Diameter of the section D "; D ; "m
645 PRINT "Velocity of flow V "; V ; "m/s
650 PRINT "Head loss due to pipe friction HF "; HF;"m
655 PRINT "Power requirement for this section PH "; PH
          ;"kW
660 PRINT "Cost of pipe for this section ";PCOST;"$
690 RETURN
700 WRITE#1,
705 WRITE#1, "Discharge Q (m3/s): ";Q
710 WRITE#1, "Length of section L (m): "; L
715 WRITE#1, "Diameter of the section D (m): "; D
720 WRITE#1, "Velocity of flow V (m/s): "; V
725 WRITE#1, "Head loss due to pipe friction HF (m): "; HF
730 WRITE#1, "Power requirement for this section (kW):"; PH
735 WRITE#1, "Price of pipe PRICE ($/m): ";PRICE
740 WRITE#1, "Cost of pipe for this section: $ ";PCOST
745 WRITE#1,
750 RETURN
```

```
800 WRITE#1, "**** RESULTS FOR COMPLETE PIPELINE ****"
805 WRITE#1,
810 TPRC = CINT(TPRC)
812 HOURS = IR * TAREA/(TQ * 360)
815 TPRP = CINT(TPRP)
817 WRITE#1, "Maximum permissible velocity m/s "; VP
819 WRITE#1, "Annual interest rate "; I
821 WRITE#1, "Seasonal irrigation required mm "; IR
823 WRITE#1, "Total pumping requirement for concrete
          (kW)";TPRC
824 ECOSTC = HOURS * TPRC * ERATE
825 WRITE#1, "Energy cost using concrete pipe";ECOSTC
830 WRITE#1, "Total pumping requirement for pvc pipe KW
          ";TPRP
832 ECOSTP = HOURS * TPRP * ERATE
834 WRITE#1, "Energy cost using PVC pipe $ "; ECOSTP
835 WRITE#1, "Total cost of pvc pipe $ ";TCP
840 WRITE#1, "Total cost of concrete pipe $ ";TCC
845 ACP = TCP * I/(1 - (1/(1+I)^N)) 'Annual cost of pvc pipe
850 ACC = TCC * I/(1 - (1/(1+I)^N)) 'Annual cost of concrete
pipe
855 WRITE#1, "Annual cost using pvc pipe $ ";ACP
860 WRITE#1, "Annual cost using concrete pipe $ ";ACC
872 WRITE#1,
875 WRITE#1,"********************************"
895 RETURN
900 K = KP
```

```
905 PRICE =PP
910 TCOST =TCP
915 TPH = TPRP
920 GOSUB 400 'Define variable
922 GOSUB 500
925 WHILE DIF>NTOL
930 GOSUB 500
935 WEND
936 WRITE#1, "SECTION No. ";SECT
937 WRITE#1,
938 WRITE#1, "**** PVC PIPE *** "
940 GOSUB 600
941 GOSUB 700
942 TPRP = TPH
943 TCP = TCOST
946 K = KC
947 PRICE =PC
948 TCOST =TCC
949 TPH = TPRC
950 GOSUB 400 'Define variables
952 GOSUB 500
954 WHILE DIF > NTOL
960 GOSUB 500
962 WEND
964 WRITE#1,"**** CONCRETE PIPE ***"
966 GOSUB 600
968 GOSUB 700
```

```
970 TPRC = TPH
975 TCC = TCOST
980 WRITE#1, "--------- --------------------"
985 WRITE#1,
995 RETURN
```

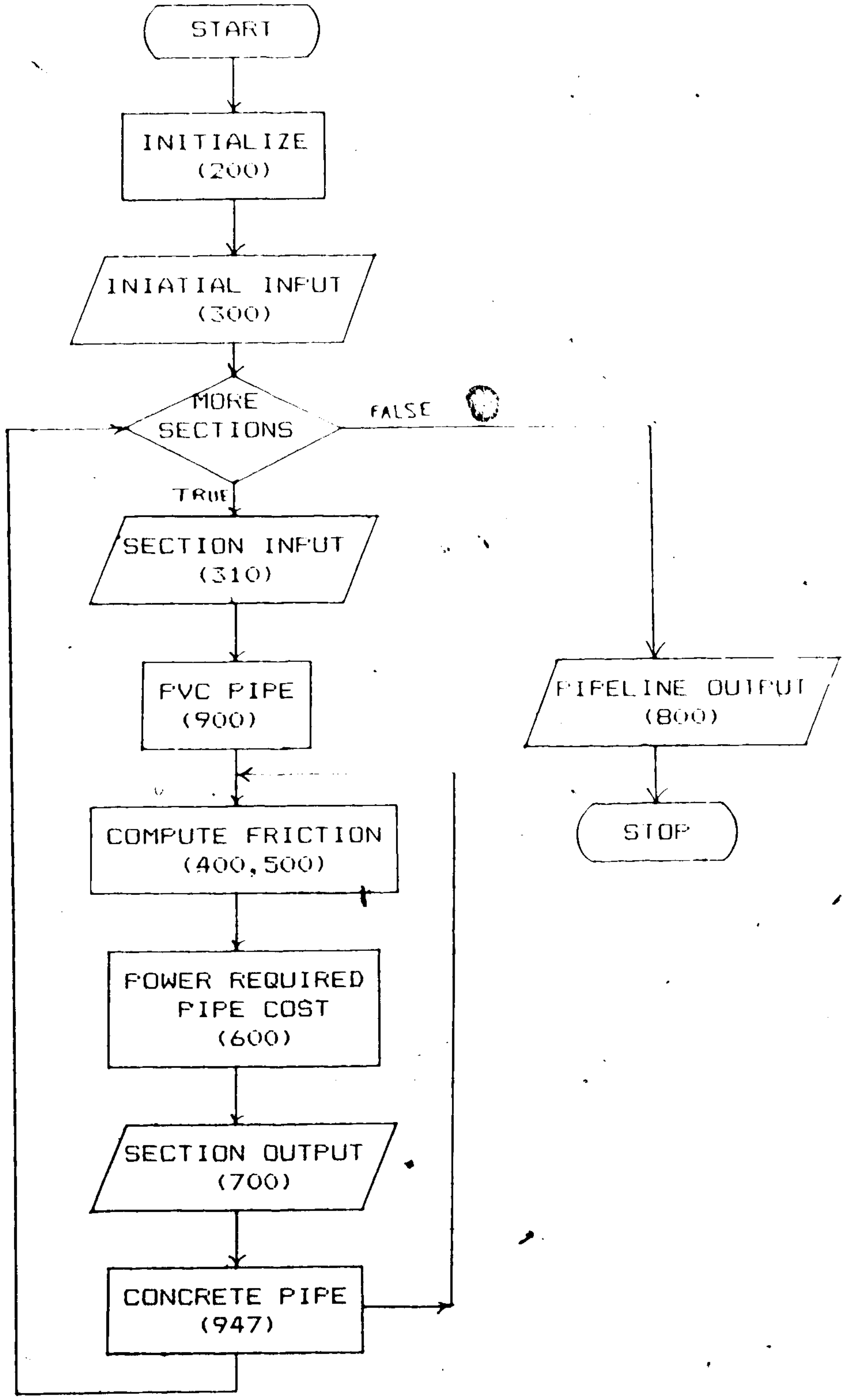

Figure A.1 Flow Chart for Computer Model

Table A.1 Output from Computer Model For Bow Island Block

Item	Value
SECTION No. 1	
**** PVC PIPE ***	
Discharge Q (m^3/s):	1.105
Length of section L (m):	500
Diameter of the section D (m):	.85
Velocity of flow V (m/s):	1.947
Head loss due to pipe friction HF (m):	1.348
Power requirement for this section PH (kW):	561.245
Price of pipe PRICE ($/m):	150
Cost of pipe for this section PCOST: $	75000
**** CONCRETE PIPE ***	
Discharge Q (m^3/s):	1.105
Length of section L (m):	500
Diameter of the section D (m):	.85
Velocity of flow V (m/s):	1.947
Head loss due to pipe friction HF (m):	2.086
Power requirement for this section PH (kW):	569.230
Price of pipe PRICE ($/m):	180
Cost of pipe for this section PCOST: $	90000
SECTION No. 2	
**** PVC PIPE ***	
Discharge Q (m^3/s):	1.04
Length of section L (m):	1650

Diameter of the section D (m):	.8
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	5.356
Power requirement for this section PH (kW):	13.800
Price of pipe PRICE ($/m):	140
Cost of pipe for this section PCOST: $	231000

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	1.04
Length of section L (m):	1650
Diameter of the section D (m):	.8
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	8.368
Power requirement for this section PH (kW):	44.451
Price of pipe PRICE ($/m):	170
Cost of pipe for this section PCOST: $	280500

SECTION No. 3

**** PVC PIPE ***

Discharge Q (m^3/s):	.91
Length of section L (m):	505
Diameter of the section D (m):	.75
Velocity of flow V (m/s):	2.060
Head loss due to pipe friction HF (m):	1.754
Power requirement for this section PH (kW):	-6.641
Price of pipe PRICE ($/m):	130
Cost of pipe for this section PCOST: $	65650

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.91

Length of section L (m):	505
Diameter of the section D (m):	.75
Velocity of flow V (m/s):	2.060
Head loss due to pipe friction HF (m):	2.749
Power requirement for this section PH (kW):	2.221
Price of pipe PRICE ($/m):	150
Cost of pipe for this section PCOST: $	75750

SECTION No. 4

**** PVC PIPE ***

Discharge Q (m^3/s):	.845
Length of section L (m):	300
Diameter of the section D (m):	.75
Velocity of flow V (m/s):	1.913
Head loss due to pipe friction HF (m):	.906
Power requirement for this section PH (kW):	-4.911
Price of pipe PRICE ($/m):	130
Cost of pipe for this section PCOST: $	39000

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.845
Length of section L (m):	300
Diameter of the section D (m):	.75
Velocity of flow V (m/s):	1.913
Head loss due to pipe friction HF (m):	1.410
Power requirement for this section PH (kW):	-.745
Price of pipe PRICE ($/m):	150
Cost of pipe for this section PCOST: $	45000

SECTION No. 5

**** PVC PIPE ***

Discharge Q (m^3/s):	.78
Length of section L (m):	505
Diameter of the section D (m):	.7
Velocity of flow V (m/s):	2.027
Head loss due to pipe friction HF (m):	1.846
Power requirement for this section PH (kW):	2.639
Price of pipe PRICE ($/m):	125
Cost of pipe for this section PCOST: $	63125

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.78
Length of section L (m):	505
Diameter of the section D (m):	.7
Velocity of flow V (m/s):	2.027
Head loss due to pipe friction HF (m):	2.900
Power requirement for this section PH (kW):	10.685
Price of pipe PRICE ($/m):	140
Cost of pipe for this section PCOST: $	70700

SECTION No. 6

**** PVC PIPE ***

Discharge Q (m^3/s):	.715
Length of section L (m):	300
Diameter of the section D (m):	.7
Velocity of flow V (m/s):	1.858
Head loss due to pipe friction HF (m):	.930
Power requirement for this section PH (kW):	-3.984
Price of pipe PRICE ($/m):	125

Cost of pipe for this section PCOST: $	37500
**** CONCRETE PIPE ***	
Discharge Q (m^3/s):	.715
Length of section L (m):	300
Diameter of the section D (m):	.7
Velocity of flow V (m/s):	1.858
Head loss due to pipe friction HF (m):	1.449
Power requirement for this section PH (kW):	-.353
Price of pipe PRICE ($/m):	140
Cost of pipe for this section PCOST: $	42000
SECTION No. 7	
**** PVC PIPE ***	
Discharge Q (m^3/s):	.455
Length of section L (m):	805
Diameter of the section D (m):	.55
Velocity of flow V (m/s):	1.915
Head loss due to pipe friction HF (m):	3.517
Power requirement for this section PH (kW):	15.659
Price of pipe PRICE ($/m):	96
Cost of pipe for this section PCOST: $	77280
**** CONCRETE PIPE ***	
Discharge Q (m^3/s):	.455
Length of section L (m):	805
Diameter of the section D (m):	.55
Velocity of flow V (m/s):	1.915
Head loss due to pipe friction HF (m):	5.574
Power requirement for this section PH (kW):	24.816

Price of pipe PRICE ($/m):	108
Cost of pipe for this section PCOST: $	86940

SECTION No. 8

**** PVC PIPE ***

Discharge Q (m^3/s):	.065
Length of section L (m):	960
Diameter of the section D (m):	.2
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	16.240
Power requirement for this section PH (kW):	9.057
Price of pipe PRICE ($/m):	30
Cost of pipe for this section PCOST: $	28800

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.065
Length of section L (m):	960
Diameter of the section D (m):	.2
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	27.802
Power requirement for this section PH (kW):	16.410
Price of pipe PRICE ($/m):	50
Cost of pipe for this section PCOST: $	48000

SECTION No. 9

**** PVC PIPE ***

Discharge Q (m^3/s):	.325
Length of section L (m):	400
Diameter of the section D (m):	.45
Velocity of flow V (m/s):	2.043

Head loss due to pipe friction HF (m):	2.506
Power requirement for this section PH (kW):	1.610
Price of pipe PRICE ($/m):	78
Cost of pipe for this section PCOST: $	31200

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.325
Length of section L (m):	400
Diameter of the section D (m):	.45
Velocity of flow V (m/s):	2.043
Head loss due to pipe friction HF (m):	4.048
Power requirement for this section PH (kW):	6.513
Price of pipe PRICE ($/m):	98
Cost of pipe for this section PCOST: $	39200

SECTION No. 10

**** PVC PIPE ***

Discharge Q (m^3/s):	.195
Length of section L (m):	805
Diameter of the section D (m):	.35
Velocity of flow V (m/s):	2.0268
Head loss due to pipe friction HF (m):	6.700
Power requirement for this section PH (kW):	5.150
Price of pipe PRICE ($/m):	47
Cost of pipe for this section PCOST: $	37835

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.195
Length of section L (m):	805
Diameter of the section D (m):	.35

Velocity of flow V (m/s):	2.027
Head loss due to pipe friction HF (m):	10.991
Power requirement for this section PH (kW):	13.339
Price of pipe PRICE ($/m):	85
Cost of pipe for this section PCOST: $	68425

SECTION No. 11

**** PVC PIPE ***

Discharge Q (m^3/s):	.26
Length of section L (m):	405
Diameter of the section D (m):	.4
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	2.989
Power requirement for this section PH (kW):	2.515
Price of pipe PRICE ($/m):	60
Cost of pipe for this section PCOST: $	24300

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.26
Length of section L (m):	405
Diameter of the section D (m):	.4
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	4.870
Power requirement for this section PH (kW):	7.301
Price of pipe PRICE ($/m):	92
Cost of pipe for this section PCOST: $	37260

SECTION No. 12

**** PVC PIPE ***

Discharge Q (m^3/s):	.195

Length of section L (m):	400
Diameter of the section D (m):	.35
Velocity of flow V (m/s):	2.0268
Head loss due to pipe friction HF (m):	3.329
Power requirement for this section PH (kW):	2.535
Price of pipe PRICE ($/m):	47
Cost of pipe for this section PCOST: $	18800

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.195
Length of section L (m):	400
Diameter of the section D (m):	.35
Velocity of flow V (m/s):	2.0268
Head loss due to pipe friction HF (m):	5.461
Power requirement for this section PH (kW):	6.604
Price of pipe PRICE ($/m):	85
Cost of pipe for this section PCOST: $	34000

SECTION No. 13

**** PVC PIPE ***

Discharge Q (m^3/s):	.13
Length of section L (m):	805
Diameter of the section D (m):	.3
Velocity of flow V (m/s):	1.839
Head loss due to pipe friction HF (m):	6.708
Power requirement for this section PH (kW):	3.445
Price of pipe PRICE ($/m):	40
Cost of pipe for this section PCOST: $	32200

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.13
Length of section L (m):	805
Diameter of the section D (m):	.3
Velocity of flow V (m/s):	1.839
Head loss due to pipe friction HF (m):	11.011
Power requirement for this section PH (KW):	8.918
Price of pipe PRICE ($/m):	60
Cost of pipe for this section PCOST: $	48300

SECTION No. 14

**** PVC PIPE ***

Discharge Q (m^3/s):	.97
Length of section L (m):	200
Diameter of the section D (m):	.8
Velocity of flow V (m/s):	1.930
Head loss due to pipe friction HF (m):	.569
Power requirement for this section PH (KW):	499.525
Price of pipe PRICE ($/m):	140
Cost of pipe for this section PCOST: $	28000

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.97
Length of section L (m):	200
Diameter of the section D (m):	.8
Velocity of flow V (m/s):	1.930
Head loss due to pipe friction HF (m):	.883
Power requirement for this section PH (KW):	502.506
Price of pipe PRICE ($/m):	170
Cost of pipe for this section PCOST: $	34000

SECTION No. 15

**** PVC PIPE ***

Discharge Q (m^3/s):	.91
Length of section L (m):	1350
Diameter of the section D (m):	.75
Velocity of flow V (m/s):	2.060
Head loss due to pipe friction HF (m):	4.690
Power requirement for this section PH (kW):	23.945
Price of pipe PRICE ($/m):	130
Cost of pipe for this section PCOST: $	175500

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.91
Length of section L (m):	1350
Diameter of the section D (m):	.75
Velocity of flow V (m/s):	2.060
Head loss due to pipe friction HF (m):	7.350
Power requirement for this section PH (kW):	47.637
Price of pipe PRICE ($/m):	150
Cost of pipe for this section PCOST: $	202500

SECTION No. 16

**** PVC PIPE ***

Discharge Q (m^3/s):	.715
Length of section L (m):	960
Diameter of the section D (m):	.7
Velocity of flow V (m/s):	1.858
Head loss due to pipe friction HF (m):	2.978
Power requirement for this section PH (kW):	-7.153

Price of pipe PRICE ($/m):	125
Cost of pipe for this section PCOST: $	120000
**** CONCRETE PIPE ***	
Discharge Q (m^3/s):	.715
Length of section L (m):	960
Diameter of the section D (m):	.7
Velocity of flow V (m/s):	1.858
Head loss due to pipe friction HF (m):	4.638
Power requirement for this section PH (kW):	4.466
Price of pipe PRICE ($/m):	140
Cost of pipe for this section PCOST: $	134400
SECTION No. 17	
**** PVC PIPE ***	
Discharge Q (m^3/s):	.065
Length of section L (m):	460
Diameter of the section D (m):	.2
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	7.782
Power requirement for this section PH (kW):	5.585
Price of pipe PRICE ($/m):	30
Cost of pipe for this section PCOST: $	13800
**** CONCRETE PIPE ***	
Discharge Q (m^3/s):	.065
Length of section L (m):	460
Diameter of the section D (m):	.2
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	13.322

Power requirement for this section PH (kW): 9.109

Price of pipe PRICE ($/m): 50

Cost of pipe for this section PCOST: $ 23000

SECTION No. 18

**** PVC PIPE ***

Discharge Q (m^3/s): .585

Length of section L (m): 1000

Diameter of the section D (m): .6

Velocity of flow V (m/s): 2.069

Head loss due to pipe friction HF (m): 4.560

Power requirement for this section PH (kW): 3.206

Price of pipe PRICE ($/m): 110

Cost of pipe for this section PCOST: $ 110000

**** CONCRETE PIPE ***

Discharge Q (m^3/s): .585

Length of section L (m): 1000

Diameter of the section D (m): .6

Velocity of flow V (m/s): 2.069

Head loss due to pipe friction HF (m): 7.244

Power requirement for this section PH (kW): 18.570

Price of pipe PRICE ($/m): 125

Cost of pipe for this section PCOST: $ 125000

SECTION No. 19

**** PVC PIPE ***

Discharge Q (m^3/s): .26

Length of section L (m): 605

Diameter of the section D (m): .4

Velocity of flow V (m/s): 2.069

Head loss due to pipe friction HF (m): 4.464

Power requirement for this section PH (kW): 11.357

Price of pipe PRICE ($/m): 60

Cost of pipe for this section PCOST: $ 36300

**** CONCRETE PIPE ***

Discharge Q (m^3/s): .26

Length of section L (m): 605

Diameter of the section D (m): .4

Velocity of flow V (m/s): 2.069

Head loss due to pipe friction HF (m): 7.274

Power requirement for this section PH (kW): 18.506

Price of pipe PRICE ($/m): 92

Cost of pipe for this section PCOST: $ 55660

SECTION No. 20

**** PVC PIPE ***

Discharge Q (m^3/s): .13

Length of section L (m): 200

Diameter of the section D (m): .3

Velocity of flow V (m/s): 1.839

Head loss due to pipe friction HF (m): 1.667

Power requirement for this section PH (kW): 2.120

Price of pipe PRICE ($/m): 60

Cost of pipe for this section PCOST: $ 12000

**** CONCRETE PIPE ***

Discharge Q (m^3/s): .13

Length of section L (m): 200

Diameter of the section D (m):	.3
Velocity of flow V (m/s):	1.839
Head loss due to pipe friction HF (m):	2.736
Power requirement for this section PH (kW):	3.480
Price of pipe PRICE ($/m):	78
Cost of pipe for this section PCOST: $	15600

SECTION No. 21

**** PVC PIPE ***

Discharge Q (m^3/s):	.325
Length of section L (m):	805
Diameter of the section D (m):	.45
Velocity of flow V (m/s):	2.043
Head loss due to pipe friction HF (m):	5.044
Power requirement for this section PH (kW):	3.320
Price of pipe PRICE ($/m):	78
Cost of pipe for this section PCOST: $	62790

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.325
Length of section L (m):	805
Diameter of the section D (m):	.45
Velocity of flow V (m/s):	2.043
Head loss due to pipe friction HF (m):	8.146
Power requirement for this section PH (kW):	13.186
Price of pipe PRICE ($/m):	98
Cost of pipe for this section PCOST: $	78890

SECTION No. 22

**** PVC PIPE ***

Discharge Q (m^3/s):	.065
Length of section L (m):	1000
Diameter of the section D (m):	.2
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	16.916
Power requirement for this section PH (kW):	10.759
Price of pipe PRICE ($/m):	30
Cost of pipe for this section PCOST: $	30000

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.065
Length of section L (m):	1000
Diameter of the section D (m):	.2
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	28.961
Power requirement for this section PH (kW):	18.419
Price of pipe PRICE ($/m):	50
Cost of pipe for this section PCOST: $	50000

SECTION No. 23

**** PVC PIPE ***

Discharge Q (m^3/s):	.26
Length of section L (m):	305
Diameter of the section D (m):	.4
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	2.251
Power requirement for this section PH (kW):	-4.450
Price of pipe PRICE ($/m):	60
Cost of pipe for this section PCOST: $	18300

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.26
Length of section L (m):	305
Diameter of the section D (m):	.4
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	3.667
Power requirement for this section PH (kW):	-.846
Price of pipe PRICE ($/m):	92
Cost of pipe for this section PCOST: $	28060

SECTION No. 24

**** PVC PIPE ***

Discharge Q (m^3/s):	.13
Length of section L (m):	500
Diameter of the section D (m):	.3
Velocity of flow V (m/s):	1.839
Head loss due to pipe friction HF (m):	4.167
Power requirement for this section PH (kW):	2.120
Price of pipe PRICE ($/m):	40
Cost of pipe for this section PCOST: $	20000

**** CONCRETE PIPE ***

Discharge Q (m^3/s):	.13
Length of section L (m):	500
Diameter of the section D (m):	.3
Velocity of flow V (m/s):	1.839
Head loss due to pipe friction HF (m):	6.839
Power requirement for this section PH (kW):	5.520
Price of pipe PRICE ($/m):	60

Cost of pipe for this section PCOST: $	30000
SECTION No. 25	
**** PVC PIPE ***	
Discharge Q (m^3/s):	.065
Length of section L (m):	12800
Diameter of the section D (m):	.2
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	216.531
Power requirement for this section PH (kW):	137.715
Price of pipe PRICE ($/m):	0
Cost of pipe for this section PCOST: $	0
**** CONCRETE PIPE ***	
Discharge Q (m^3/s):	.065
Length of section L (m):	12800
Diameter of the section D (m):	.2
Velocity of flow V (m/s):	2.069
Head loss due to pipe friction HF (m):	370.696
Power requirement for this section PH (kW):	235.766
Price of pipe PRICE ($/m):	0
Cost of pipe for this section PCOST: $	0
**** RESULTS FOR THE COMPLETE PIPELINE ****	
Maximum permissible velocity used m/s	2
Annual interest rate used	.15
Maximum discharge m^3/s	2.075
Total pumping requirement for concrete (kW)	1586
Energy cost for concrete pipe $	70488.89
Total pumping requirement for pvc pipe (kW)	1290

Energy cost for PVC pipe $	57333.33
Total cost of PVC pipe $	1388380
Total cost of concrete pipe $	1743185
Annual cost using PVC pipe $	208449.36
Annual cost using concrete pipe $	261719.26

APPENDIX B. PROGRAM: ECONOMICS

```
10 'PROGRAM         ECONOMICS
15 'Purpose         To calculate the annual costs
17 '                and benefits of project
20 'Language        Micro soft Basic (Basica)
25 'Designed for    IBM-PC
30 'Date Completed       June 1987
35 '---------------------------------------------
100 ' ** Annual Costs to the Farmers **
102 I = .15          'Annual interest rate
135 TAREA = 2498     'Total irrigable area after completion
140 EAREA = 1382    'Existing irrigated area
145 NAREA = TAREA - EAREA    'Newly irrigated area
200 ' ** EXTRA COSTS AND INCOME FOR NEWLY IRRIGATED AREA **
205 CDLC = 50.76  ' production/ha for crops, dryland
210 CILC =331.57    '- - - - - - - - - - irrigated land
215 CDLL = 7.06    ' - - - - - - Livestock, dryland
220 CILL = 225.83    '- - - - - - - - - - irrigated land
225 ECIC = (CILC - CDLC) * NAREA   ' crops newly irrig-land
230 ECIL = (CILL - CDLL) * NAREA   ' livestock - - - - - - -
235 GIDC = 96.55   'Gross income/ha from crops dryland
240 GIIC = 614.88  '- - - - - - - - - - - irrigated land
245 GIDL = 9.81   '- - - - - - - - - livestock dryland
250 GIIL = 313.64  '- - - - - - - - - - - - -irrigated
255 EIC = (GIIC - GIDC) * NAREA  'Extra income from crops
260 EIL = (GIIL - GIDL) * NAREA  '- - - - - - - - livestock
265 NREV = EIC + EIL    'Extra revenues from new area
```

```
270 CSS = 46000 * NAREA/57    'Cost of sprinkler systems
275 LSS =15    'Useful life in years
280 ACSS = CSS * I/(1 - (1/(1+I)^LSS))    'Annual cost
285 CFDS = 9500 * NAREA/57    'Cost of farm distribution
290 LFDS = 50    'Useful life in years
295 ACFDS =CFDS * I/(1 - (1/(1+I)^LFDS))    'Annual cost
300 NLAB = 28.31 * NAREA    'Extra labour cost
305 NTAX = 8.05 * NAREA + (0.025 * NREV)    'Extra taxes
310 NINT = 14.20 * NAREA    'Extra intrest
315 NOM = 11.20 * NAREA    'O &.M cost
320 NSAV = 6.30 * NAREA    'Saving in cost of production
325 MCOST = ECIC +ECIL +ACSS +ACFDS +NLAB +NTAX
330 NCOST = MCOST + NINT +NOM -NSAV
400 ' ** EXTRA COSTS AND INCOME FOR EXISTING AREAS **
405 EOM = 5.06 * EAREA    'Extra O & M cost
410 IREV = 417.87 * EAREA    'Revenues from existing area
415 EPCC = 149.20 * EAREA    'Cost for crops production
420 EPCL = 101.66 * EAREA    'Cost for livestock production
425 ESAV = 6.3 * EAREA    'Savings in cost of production
430 ETAX = 0.025 * IREV    'Extra taxes
435 EINT = 14.20 * EAREA    'Extra interest
440 ELAB = 29.45 * EAREA    'EXtra labour cost
445 ICOST = ELAB + EINT +ETAX +EPCL +EPCC + EOM -ESAV
450 TGR = NREV +IREV    'Total gross revenue
455 TCOST = ICOST +NCOST
460 CPH =TCOST/TAREA
465 BPH = (TGR - TCOST)/TAREA
```

```
500 PRINT    "Cost per ha: $"; CPH
505 PRINT    "Benefit per ha: $"; BPH
550 OPEN "DATA"FOR OUTPUT AS #1
555 WRITE #1,    "OUTPUT"
600 WRITE #1,    "Total irrigable area after completion",
                TAREA
602 WRITE #1,    "Existing irrigated area", EAREA
605 WRITE #1,    "Newly irrigated area", NAREA
612 WRITE #1,    "** Extra cost for newly irrigated area **"
615 WRITE #1,    "Annual cost of sprinkler systems", ACSS
617 WRITE #1,    "Annual cost of farm distribution, ACFDS
620 WRITE #1,    "Cost for crop production", ECIC
625 WRITE #1,    "Cost for livestock production", ECIL
630 WRITE #1,    "Labour cost", NLAB
640 WRITE #1,    "Taxes", NTAX
645 WRITE #1,    "Interest", NINT
650 WRITE #1,    "Irrigation O & M", NOM
655 WRITE #1,    "Savings in cost of production", NSAV
660 WRITE #1,    "Total costs for new area", NCOST
665 WRITE #1,    "* Extra cost for existing irrigated area *"
670 WRITE #1,    "Irrigation O & M", EOM
675 WRITE #1,    "Cost of crop production", EPCC
680 WRITE #1,    "Cost of livestock production", EPCL
685 WRITE #1,    "Savings in cost of production", ESAV
690 WRITE #1,    "Taxes", ETAX
695 WRITE #1,    "Interest", EINT
700 WRITE #1,    "Labour cost", ELAB
```

```
705 WRITE #1,   "Total costs", ICOST
710 WRITE #1,   "** EXTRA REVENUES **"
715 WRITE #1,   "Crops from new area", EIC
720 WRITE #1,   "Livestock from new acea", EIL
725 WRITE #1,   "Total Crops- livestock", NREV
730 WRITE #1,   "Crops-Livestock from existing area", IREV
735 WRITE #1,   "Total Revenue", TGR
740 WRITE #1,   "Total Cost", TCOST
745 WRITE #1,   "Cost per ha", CPH
750 WRITE #1,   "Benefit per ha", BPH
760 CLOSE #1
```

Table B.1 Output from Program Economics for Slip Form Concrete Lining

Item	Value
Existing irrigation area	1,382 ha
Total irrigable area after completion	2,442 ha
Newly irrigated area	1,060 ha
** Extra cost for newly irrigated area **	
Annual cost of sprinklers, pumps & motors	$192,409
Annual cost of farm distribution & dugouts	$40,485
Cost for crop production	$297,659
Cost for livestock production	$231,896
Labour cost	$30,009
Taxes	$30,320
Interest	$15,052
Irrigation O & M	$62,010
Savings in cost of production	$5,682
Total costs for new area	$894,158
** Extra cost for existing irrigated area **	
Irrigation O & M	$35,794
Cost of crop production	$206,194
Cost of livestock production	$140,494
Savings in cost of production	$7,338
Taxes	$14,437
Interest	$19,624
Labour cost	$40,699

Total costs	$449,906
** EXTRA REVENUES **	
Crops from new area	$549,430
Livestock from new area	$322,060
Total Crops livestock	$871,490
Crops-Livestock from existing area	$577,496
Total Revenue	$1,448,986
Total COST	$1,344,064
Cost per hectare	$550.40
Benefit per ha	$42.97

Table B.2 Output from Program Economics for Polyethylene Lining

Item	Value
Existing irrigation area	1,382 ha
Total irrigable area after completion	2,421 ha
Newly irrigated area	1,039 ha
** Extra cost for newly irrigated area **	
Annual cost of sprinklers, pumps & motors	$188,597
Annual cost of farm distribution & dugouts	$39,683
Cost for crop production	$291,762
Cost for livestock production	$227,302
Labour cost	$29,414
Taxes	$29,720
Interest	$14,754
Irrigation O & M	$60,782
Savings in cost of production	$5,569
Total costs for new area	$876,444
** Extra cost for existing irrigated area **	
Irrigation O & M	$35,794
Cost of crop production	$206,194
Cost of livestock production	$140,494
Savings in cost of production	$7,408
Taxes	$14,437
Interest	$19,624
Labour cost	$40,699

Total costs	$449,837
** EXTRA REVENUES **	
Crops from new area	$538,545
Livestock from new area	$315,679
Total Crops- livestock	$854,224
Crops-Livestock from existing area	$577,496
Total Revenue	$1,431,721
Total COST	$1,326,280
Cost per hectare	$547.82
Benefit per ha	$43.55

Table B.3 Output from Program Economics for Pressure Pipeline

Item	Value
Existing irrigation area	1,382 ha
Total irrigable area after completion	2,498 ha
Newly irrigated area	1,116 ha
** Extra cost for newly irrigated area **	
Annual cost of sprinkler systems	$154,023
Annual cost of farm distribution system	$27,926
Cost for crop production	$313,384
Cost for livestock production	$244,147
Labour cost	$31,594
Taxes	$31,922
Interest	$15,847
Irrigation O & M	$12,499
Savings in cost of production	$7,031
Total costs for new area	$824,312
** Extra cost for existing irrigated area **	
Irrigation O & M	$6,993
Cost of crop production	$206,194
Cost of livestock production	$140,494
Savings in cost of production	$8,706
Taxes	$14,437
Interest	$19,624
Labour cost	$40,700

Total costs	$419,737
** EXTRA REVENUES **	
Crops from new area	$578,456
Livestock from new area	$339,074
Total Crops- livestock	$917,531
Crops-Livestock from existing area	$577,496
Total Revenue	$1,495,027
Total COST	-$1,244,049
Cost per hectare	$498.01
Benefit per ha	$100.47