# A RECONNAISSANCE STUDY OF THE POTENTIAL FOR LARGE SCALE IRRIGATION OF THE CANADIAN PRAIRIES

A thesis presented to the

Faculty of Engineering,

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in

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By

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# A RECONNAISSANCE STUDY OF THE POTENTIAL FOR LARGE SCALE IRRIGATION OF THE CANADIAN PRAIRIES

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# SYNOPSIS

The results of a reconnaissance study into the feasibility and possible extent of large scale development of the irrigation potential of the Canadian Prairies are presented. The study examined the potentially irrigable areas, the expected benefits and costs of the on-farm irrigation development, the costs of the conveyance systems required to develop the proposed projects, and analyzed the overall economic worth of developing the irrigation potential of the prairies. A water balance model of the prairie river network developed to examine the flow allocations required for large scale irrigation of the prairies is also presented.

The study identified approximately 4,000,000 hectares of land as potentially irrigable, and examined 41 different irrigation projects. Based on the results of the economic analysis and the flow allocations determined from the water balance model, approximately 2,965,000 hectares could be irrigated for a total cost of $8.2 billion and would produce direct net on-farm benefits having a present worth of approximately $5.6 billion, for a benefit-cost ratio of 0.68. If indirect benefits are included, the total benefits could approach $14 billion. The overall irrigation system comprises 18 discrete projects which have direct benefit-cost ratios ranging from 1.16 to 0.30 at a real effective interest rate of 4.0 percent. The remaining projects were found to have rate of returns of less than 1.0 percent for their direct and indirect benefits under present conditions, and thus were deemed economically infeasible.

All of the projects deemed economically feasible by this study were supplied with water from the Saskatchewan-Nelson river basin. Should future conditions require additional irrigation development then inter-basin diversions of water from the Smokey, the Peace, or the Churchill rivers may be required to supply these additional developments.

Based on the analysis of the various projects examined, the study concluded that the irrigation potential of the prairies warrants further, more detailed examination than was possible in a study of this nature. In comparison with the potential benefits, the expected cost of such a study would be insignificant.

## ACKNOWLEDGEMENTS

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# CHAPTER 1 INTRODUCTION TO THE STUDY

## 1.1 BACKGROUND TO THE PROBLEM

There are several factors which presently justify an examination of the large scale irrigation potential of the Canadian prairies. These factors include the recent estimates [1,2] of growing global food demand, the recurring droughts which so seriously affect the agricultural production of the prairies, the ever increasing losses of productive prairie farmland to salinization and both water and wind erosion, and the current debate over possible long term global climatic changes and their possible effects in Western Canada. A recent seminar by the Science Council of Canada concluded that "a return to more variable conditions, characteristic of much of North American climate in earlier decades and centuries, would undoubtedly produce far greater year to year fluctuations in our agricultural outputs than those to which we have become accustomed (and have taken for granted in our national and international planning)" [3].

Based on recent Agriculture Canada and Canadian Wheat Board forecasts [1,2], the prairies must increase its agricultural production by 50 percent above its 1978 level to meet the long term forecast grain export demands of 36 million tonnes. These forecasts may be extremely optimistic given the current grain export environment, which has depressed the price of wheat and cereals to their lowest levels in many years. It must be emphasized that while artificial market influences such as the export subsidies currently being offered by the United States of America and the European Economic Community can drastically affect the price and available market for Canada's agricultural production, it is impossible to forecast the long term extent and scope of these market forces [4].

Should these export forecasts prove accurate in the long term, then continued production increases can only come from increasing intensification of the prairie farm practices in conjunction with snow management and/or irrigation, since virtually all of the agriculturally suitable arable land is already in production [5].

## 1.2 PURPOSE OF THE STUDY

This study attempts to investigate the present and future feasibility and extent of large scale irrigation development on the Canadian prairies. The study examined the economic feasibility of irrigation development under various scenarios, as well as the physical limits of irrigation development given the natural resource limits of the prairies. In addition to the inherent physical constraints of the prairies, the study also briefly examined the external constraints of the political and environmental aspects of water resource development on the prairies. The intent was not to catalogue each and every impact the irrigation water allocation systems would have on the prairies, but merely to determine to what extent the system was shaped and restricted by these constraints.

The specific intent of the study was to :

- assess and identify areas which appear suitable for irrigation

- determine the change in net farm income based on the present and potential input costs, market prices, and production for both dryland and irrigated farming

- identify potential irrigated crops and their expected yields under current and potential conditions

- determine the amount of water required by each proposed area based on expected water deficits and the water requirements of the crops selected

- determine the water available for irrigation and the works required to convey the water from the source to the farmer

- briefly discuss the political and environmental constraints on the water resources of the prairies, and the impact of the proposed water allocation systems.

- estimate the on-farm supply, drainage, and distribution costs, as well as the reservoir, canal, and diversion costs of the water supply system required.

- based on the direct and indirect benefits and costs of the various components of the irrigation system, determine the rate of return, the benefit-cost ratio, and the total net benefits for the different projects.

When reviewing the results and conclusions of this study, it should be realized that to facilitate the analysis many simplifying assumptions were made. This work is not intended to be the definitive study upon the subject, but merely attempts to determine if further, more comprehensive studies of the areas identified as irrigable are warranted. As will be discussed in Chapters 2 through 6, there are many areas of this study that warrant examination in considerably more detail than was permitted by the nature of this study.

## 1.3 STUDY AREA and TOPOGRAPHY

The area examined in this study (see Figure 1 on page 5) is almost entirely contained within the Saskatchewan-Nelson river drainage basin, and contains approximately 750,000 square kilometres of land. The boundaries of the study area were the United States-Canadian border on the south, the Manitoba-Ontario border on the east, the Rocky Mountain foothills on the west, and the northern limit of prairie agriculture which presently occurs at approximately 55 degrees Latitude North. The enclosed area roughly corresponds to the present areas of agriculture production on the prairies. In general the topography of the study area consists of relatively flat rolling plains which slope in a east to north-easterly direction. The elevations range from a high of 1160 m in southern Alberta down to a low of 240 m in Manitoba. The flat and rolling plains characteristic of the prairies are a result of the numerous glaciations the region has experienced, the last of which occurred about 15,000 years ago. The thick layers of lacustrine soils now found on the prairies were formed through sedimentation in the large lakes produced by the meltwater of the final glaciation period. As this glaciation receded numerous meltwater channels were created which today provide good potential sites for water storage reservoirs on the prairies.

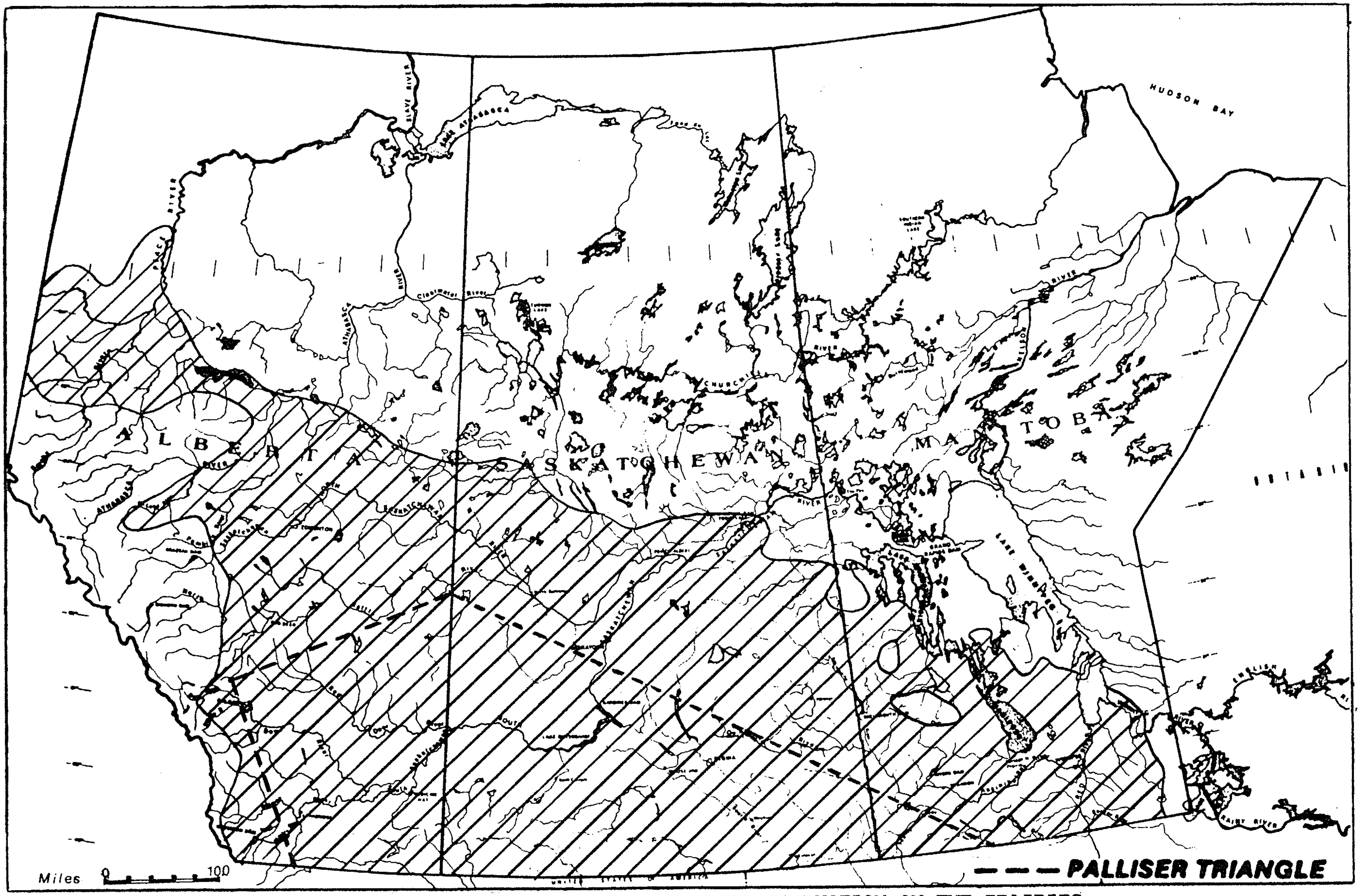


Figure 1 PRESENT AREAS OF AGRICULTURAL PRODUCTION ON THE PRAIRIES

There are three general topographical levels on the prairies, with the lowest of these being the flat featureless plains of Manitoba, which are the remains of the bottom of the former glacier-fed Lake Agassiz. This area is bounded on the west by the Duck, the Porcupine, and the Riding Mountains which comprise the Manitoba Escarpment, and are located on the western boundary of the province. The second topographic level of the prairies lies westward of the Manitoba Escarpment and consists of the gentle rolling prairies of Saskatchewan. The last of the three topographic levels lies west of the Missouri Cotteau Escarpment which cuts across central Saskatchewan in a generally north-westerly direction. This third level has quite irregular relief due to the erosion of its original glacier-planed flat surface, and contains many closed drainage basins.

## 1.4 CLIMATE and HYDROLOGIC CONDITIONS ON THE PRAIRIES

There is a considerable range in precipitation across the prairies, with the southern region of Alberta receiving an average of just 280 mm per year, while eastern Manitoba receives 560 mm per year, and the Rocky Mountain Foothills receive an average of 640 mm per year [6]. The average net evaporation on the prairies ranges from 130 to 640 mm [7]. Based on its average annual precipitation and evaporation values, the overall prairie climate is classified as semi-arid. If it were not for the "cold lows" rain storms which generally occur in the spring and fall seasons the prairies would resemble a barren desert much like the Chinese Gobi or the African Sahara. The importance of these storms to prairie agriculture was amply demonstrated during the "dirty thirties" drought when above average spring temperatures prevented these storms from occurring. The lack of these storms also greatly contributed to the recent droughts of 1977, 1981, 1984, and 1985. The delicate hydrologic balance between precipitation and evaporation frequently creates critical moisture deficits in the soils throughout the prairies. These droughts tend to be cyclical in occurrence, and droughts lasting 5 to 10 years have been observed.

The majority of the flow in the Saskatchewan-Nelson River basin is derived from the 1780 mm of precipitation which the eastern slopes of the Rocky Mountains receive on average each year. Because of the many closed basins on the prairies and the rate of evaporation, it has been estimated that all of the prairie lands contribute only 8 percent of the total annual runoff of the Saskatchewan-Nelson basin [6], although they constitute approximately 90 percent of the total drainage area of the basin.

## 1.5 SOILS of the PRAIRIES

The soils of the prairies can be classified into four broad soils groups consisting of the Brown, Dark Brown, Black, and Grey soil zones, the names of which arise from the dominant color of the topsoil. Like all soils, their properties are influenced by the parent materials from which their components were eroded, the method of deposition, the vegetation they've supported, the weathering they have undergone, their drainage, and the topography. The colors of the four soil zones correspond to the different types of vegetative cover and the climate which the soils developed in (see Figure 2 on page 8). The Brown soils correspond to dry grasslands, the Dark Brown soils were grasslands moister than the Browns, the Black soils were grass and treed parklands,

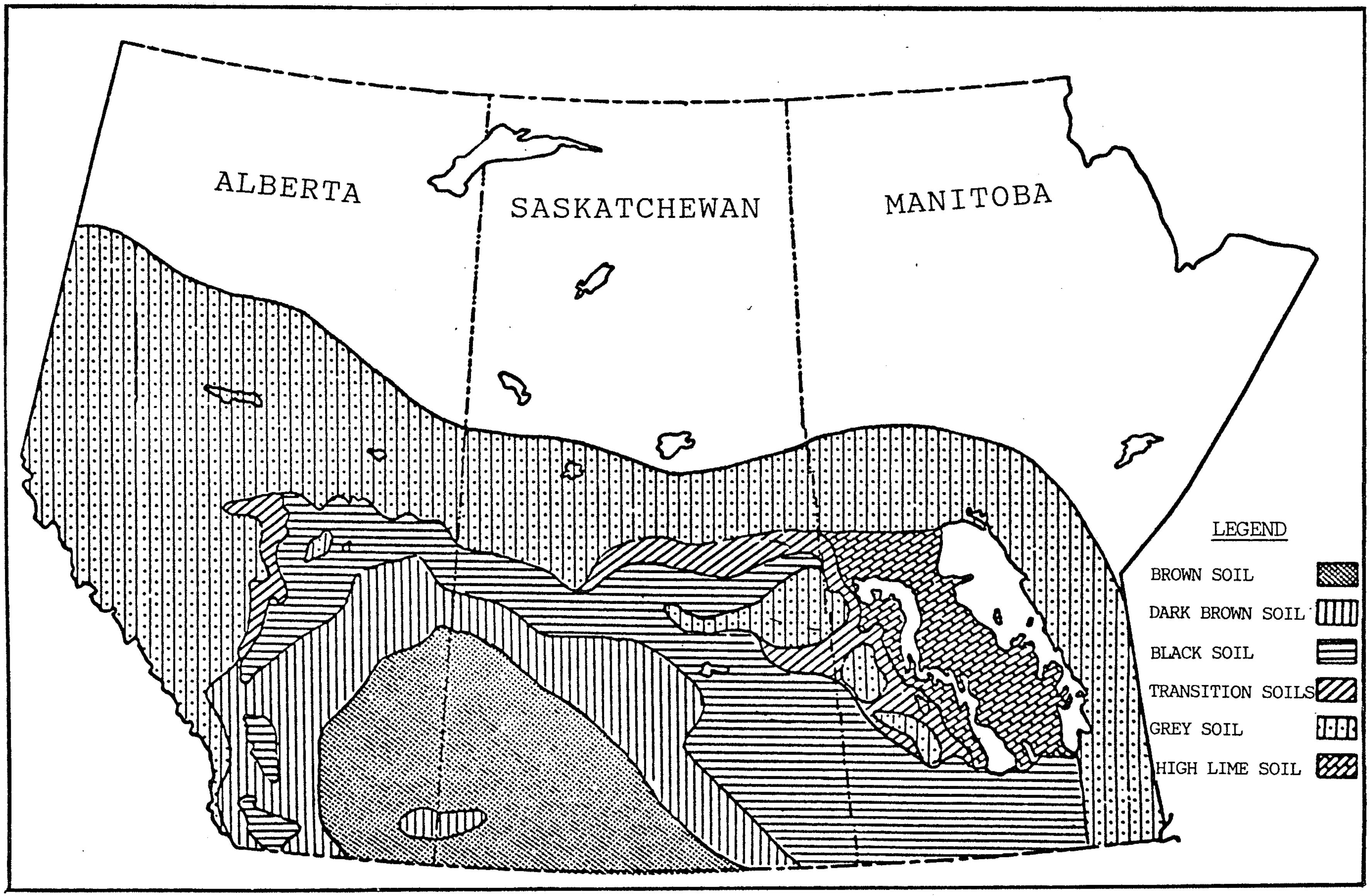


Figure 2 MAJOR SOIL ZONES ON THE PRAIRIES

and the Grey soils were boreal forest. This development pattern produced soils in which moisture, nitrogen content, and organic matter increase as one proceeds from a Brown to Dark Brown to Black or Grey soils. The crop production on most of the soils of the prairies is currently limited by the soil moisture available to the crop, but under irrigation the limiting factors would be the plant nutrients and minerals provided by the soil.

## 1.6 HISTORY of IRRIGATION of the PRAIRIES

The practice of providing supplemental water to croplands has been well documented throughout the written history of mankind [8]. The countries of Babylon, Egypt, Syria, Persia, India, China, Italy, and Peru have records and evidence of irrigation developments dating back as far as 2200 B.C. As an example of the quality of these early works, the famous Tu Kiang Dam in China presently irrigates 200,000 hectares of rice, yet was built by a man named Li and his son in 200 B.C. In comparison to these irrigation developments, the irrigation of the Canadian prairies is very young, with the first small developments occurring around 1880.

The development of dryland and irrigated agriculture on the Canadian prairies was greatly influenced by both political and economic motives. The Dominion of Canada obtained the Hudson's Bay Company's entitlement to Rupert's Land, as Manitoba, Saskatchewan, and Aberta were then known, in 1870. To promote rapid settlement and establish a sense of national identity in these newly acquired regions, the government encouraged construction of railroads by granting large blocks of land in the region to the railway companies. In 1880, the Canadian Pacific Railway consortium agreed to link Montreal to the Pacific coast with a railway for a payment of $25 million in cash and 10.1 million hectares of land "fairly fit for settlement"[6].

Following the completion of the railroad in 1885, the prairie settlement boom began. In the early 1890's a prolonged drought threatened to drive these early settlers off their homesteads. This confirmed an earlier assessment of the region by Captain John Palliser, a British explorer who in 1857 identified a large portion of the southern Canadian prairies as being too dry to support agriculture. This area is now known as the "Palliser Triangle" (see Figure 1 on page 5) and closely corresponds to the lands which would be nearly devastated in the drought of the 1930's.

In response to the 1890's drought, in 1894 the Canadian government passed the Northwest Irrigation Act in which all riparian rights to streams were revoked and the water was declared the property of the crown. The right to use the water for perpetuity could then be granted to users from the crown, providing the user did not abandon nor waste the water rights. To assess the availability of water on the prairies, the act also created the Irrigation Branch to inventory all usable water supplies in the west, and to identify all lands in the Dominion territories which would benefit from irrigation.

The first diversions and distribution of irrigation water on a significant scale were undertaken by private entrepreneurs and railway companies attempting to increase the value of their land holdings while also increasing the economic output and freight activity of the regions. In most cases these developments were quickly found to be money losing ventures, and the provincial governments were forced to legislate the formation of irrigation districts composed of the water users themselves.

From 1910 to 1930 the growth of irrigation on the prairies was very slow as a number of wet years resulted in little demand for supplemental water in the existing developments. The following decade was the infamous "dirty thirties", in which the prairies experienced the most severe and prolonged drought on record, and thousands of families were forced off of their land. In response to this crisis, the federal government passed the Prairie Farm Rehabilitation Act in 1935, which created an agency (PFRA) whose mandate was to save and rebuild western Canadian agriculture as well as to enhance the use and development of the water and land resources of the prairies.

By the start of the post-war period of 1945 and onwards, it was apparent that large scale irrigation could only succeed if provincial or federal governments assumed responsibility for part or all of the capital costs of an irrigation development. In the period 1950 to 1978, the irrigated area on the prairies increased from 200,000 hectares to 454,000 hectares [6], a 127 percent increase which is largely attributable to government sponsored irrigation developments such as the South Saskatchewan River Irrigation Project, and the Saint Mary River Irrigation District. The recent droughts of 1981, 1984, and 1985 has ensured a continued strong interest in irrigation development.

# CHAPTER 2 AGRICULTURE ON THE PRAIRIES

## 2.1 AGRICULTURE ON THE PRAIRIES TODAY

Agriculture is one of the main components of the economy of the Canadian prairies, and prior to the quite recent development of the prairies petroleum and mining resources was virtually the sole component of its economy. Each year, the prairie provinces of Alberta, Saskatchewan, and Manitoba produce approximately 12 billion dollars of agricultural products which generally comprises 4 to 5 percent of Canada's Gross National product [9]. The cereal and oil seed production of the prairies are responsible for most of the 9.8 billion dollars of agricultural products which Canada exported in 1984 [9]. These agricultural benefits diffuse throughout the provincial and national economies to produce direct and indirect benefits to all Canadians.

The agriculture system of the prairies consists of approximately 155,000 farms which cultivate a total of over 38 million hectares (ha) of land [9]. The areal extent of prairie agriculture is shown in Figure 1 on page 5, while average and 1985 crop areas are shown in Table 2-1 on page 50. In contrast with the overall cultivated area of 38 million hectares, the most recent estimate [6] of the irrigated area on the prairies is only 454,000 hectares, or just over 1.2 percent of the total cultivated area. Of this total irrigated area, Alberta has 82 percent with 373,000 hectares, Saskatchewan has 17 percent with 76,890 hectares, and Manitoba has 4,400 hectares for 1 percent of the prairies irrigated area. The areal distribution of these irrigation areas is shown in Figure 3 on page 14, and a typical crop distribution for present prairie irrigation developments is presented in Table 2-2 on page 51.

## 2.2 DRYLAND FARM PRACTICES

Because of the long development period associated with any large scale irrigation project, the analysis of the benefits of irrigation should be based on what the present crop returns are, as well as what they may become over the development period. It has been suggested by many crop specialists [9 to 13] that the prairies could substantially increase its crop production in the next 5 to 10 years if the crop prices were sufficient to justify such an increase. Since these production increases may alter the net returns of both dryland and irrigated agriculture to the farmer, these potential methods and their possible impacts were briefly examined in this study.

### 2.2.1 Dryland Management Practices

In 1980 the Canadian Wheat Board sponsored the Prairie Production Symposium which attempted to assess the production potential of the prairies, and to determine the means by which the grain export demands originally forecast for 1985 and 1990 could be achieved. The five cropping methods which were presented as being capable of providing these required production increases were:

1) A considerable decrease in the summerfallowed area on the Black, Grey and Dark Brown soil zones (see Figure 2 on page 8)

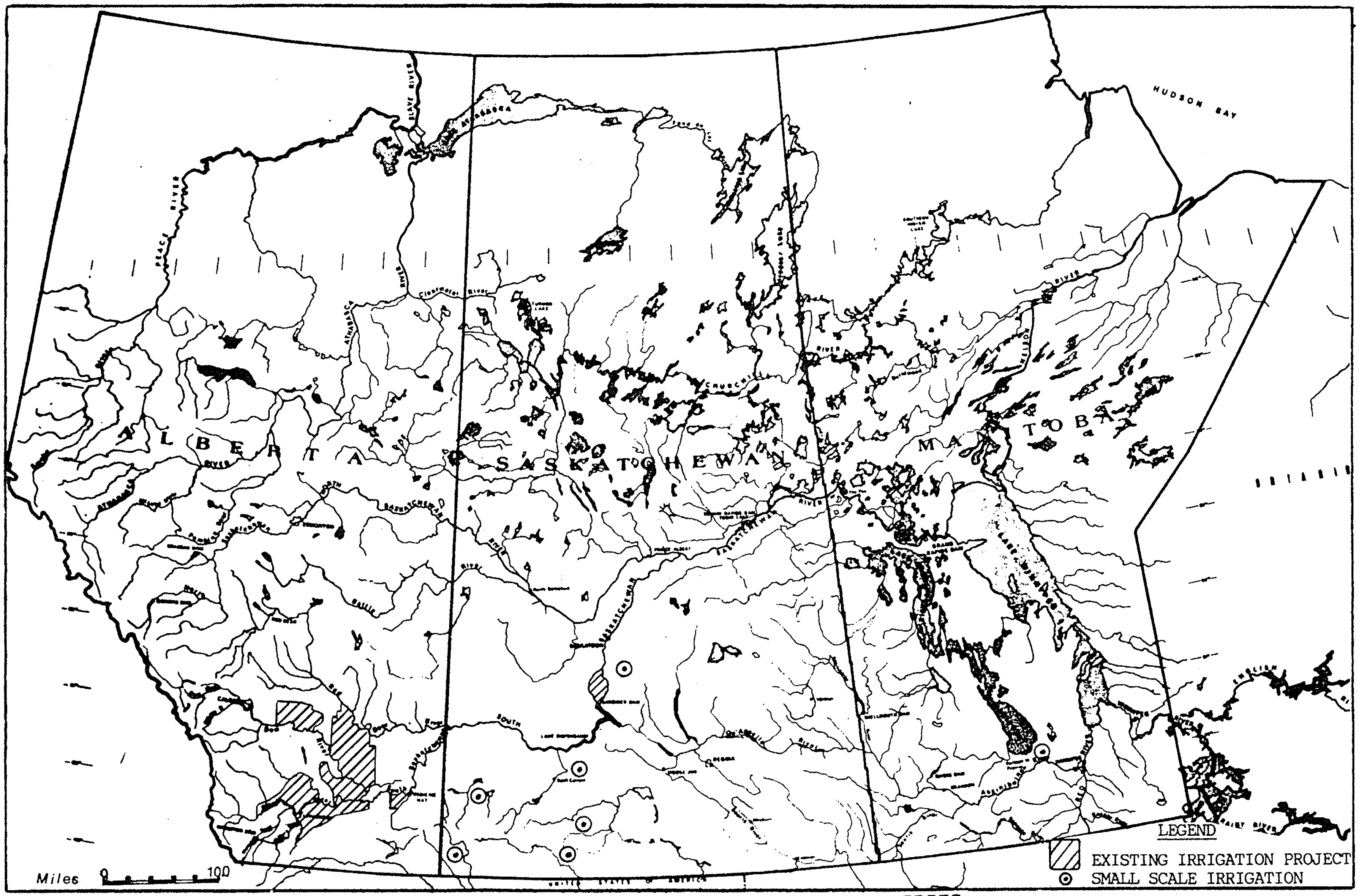


Figure 3 EXISTING IRRIGATION ON THE PRAIRIES

2) Improved yields per seeded hectare due to improved management practices and plant genetics,

3) Increased use of snow management techniques to improve the quantity of meltwater retained by the field in spring,

4) Increased use of winter cereal crops such as winter wheat,

5) Increased use of zero tillage.

The effects and implications of each of these practices are discussed in detail below.

a) Decreased Summerfallow Area

Summerfallowing is the practice of leaving a field for a summer without any crop on it so as to increase the amount of moisture stored in the soil, while cultivation and/or herbicide treatments are applied throughout the summer to control weed growth. The method was first developed at the Indian Head Experimental Farm in Saskatchewan when they reported in 1889 that "our season points to only one way in which we can in all years expect to reap something ... fallowing the land is the best preparation to ensure a crop" [14]. Since 1921 Manitoba and Saskatchewan have usually fallowed at least 20 percent of their improved lands, and since the 1940's Saskatchewan has fallowed 40 to 48 percent of its improved land [15].

The early practice of "black fallowing" in which the fallow was cultivated frequently such that no trash or cover existed by the end of the summer contributed greatly [15] to the dust storms, dunes and erosion losses which occurred in the dry years of the 1930's. Since the "dirty thirties" drought, good farm practice has been to maintain a good stubble and trash cover on the fallow as this reduces the erodibility of the topsoil while increasing the amount of snowmelt stored in the soil.

The amount of land summerfallowed on the prairies has been generally reducing since 1969, and recent forecasts [11,12,13,16,17] are that the fallowed areas will greatly decrease on most of the soil types of the prairies in the future, as illustrated in Table 2-3 on page 52. It should be noted when reviewing Table 2-3 that fallowing of the Brown soils cannot be significantly altered without additional moisture being supplied to the soil, and thus no major changes in fallowing of the Brown soils were forecast. This additional water could be obtained from either irrigation or through successful management of the snowcover, the techniques of which are discussed in their respective sections subsequent to this.

While summerfallowing has allowed the Palliser Triangle to successfully produce cereal grains in the past, the practice has contributed to the salinization of Saskatchewan soils [17,18] and its high use in the Black and Grey Soils results in lower average crop yields and production than the soils are capable of. Given increased crop inputs such as fertilizer and herbicides, a decrease in the amount of summerfallow will produce a corresponding increase in grain production on the prairies.

b) Management Techniques for Increased Yields

Several recent studies of the yield potential of the prairies predict increases in the yields per seeded hectare of about 30 percent [12,13,15,19] by 1990. This increase is expected to result from increased fertilizer inputs, better weed and insect control (wild oats alone reduced Saskatchewan's wheat yields by 6.3 percent in 1979 [13]), further development of higher yielding varieties of cereals and oilseeds, and greater use of pedigreed and cleaned seeds. The increases in fertilizer use required to obtain and maintain these forecast yield increases can be estimated by the amount of nutrient material removed by each crop, which are presented in Table 2-4 on page 53. From this table it can be seen that 57-67 kg/ha of nitrogen, 25-27 kg/ha of phosphorus, 15-22 kg/ha of potassium, and 5-7 kg/ha of sulfur are typically removed by each harvest of wheat, oats, or barley. For comparative purposes the average fertilizer use for the prairies in 1979 is shown in Table 2-5 on page 53, and was assumed to be typical for present dryland farm operation.

c) Snow Management Methods to Increase Yields

The manipulation of the snowcover which blankets the prairies throughout the winter months has been estimated to provide the greatest potential to supply additional water to increase production on stubble [17] other than irrigation, and yet to date it has seen only quite limited application on the prairies. From 1960-1980 the average snowfall on the prairies was 985 mm, containing 116 mm of water, yet little of this snowmelt water is retained on the fields since the snow generally blows off the fields to fill in ditches and windbreaks. The basic premise of snow management is to retain the snowcover on the field thus allowing the fields to gain additional moisture usually lost to drainage and ditch infiltration. Table 2-6 on page 54 shows the relative redistribution of snowcover which typically occurs on the prairies. An interesting observation from Table 2-6 is that a fallowed field generally traps the least amount of snowcover regardless of the terrain. The basic technique to increase snowmelt water retention is to place barriers which will trap snow and maintain a good snowcover throughout the winter. These barriers can be subdivided into two basic categories, non-competitive and competitive, where the competition referred to is with the crop for the available soil moisture.

Two methods of non-competitive barriers have been tested in Saskatchewan, with varying results. The method of making ridges of snow (i.e. windrows) after snowfalls increased yields 2 to 10 percent but the yields were inconsistent and did not justify the fuel cost of "windrowing" the snow. Better success has been experienced at the University of Saskatchewan's Kerran farm where the crop is swathed with a tall strip of stubble remaining on the field spaced about 6 m apart. This swath pattern has produced an average of 50 percent extra water recharged in the soil compared to conventionally swathed stubble fields [17].

The competitive barriers are generally strips of vegetation grown to increase the snowcover, and include the traditional shelterbelts of trees and hedges, as well as the tall wheatgrass barriers which are currently being used with great success in Montana. While these barriers do consume water, the increase in the amount of snow meltwater retained more than compensates for that consumed. In one study, a 39.5 kg/ha increase in grain yields was observed in fields with adjacent shelterbelts [22], while in Montana the use of tall wheatgrass strips planted 9-15 m apart increased soil moisture by 50 mm, which allowed for a continuous crop rotation and produced annual yields 30 to 69 percent greater than did the conventional spring wheat-fallow rotation [23].

While it is apparent that snowcover management offers a great deal of potential production increase for the prairies, there has been no large scale use of the techniques on the prairies and thus it remains a rather unknown quantity. Research done in Saskatchewan suggests that an additional 30 mm of water could be retained by the practice, which would increase yields by roughly 10 percent [17]. It must be noted that some of the techniques of snow management can also be successfully utilized on irrigated fields, and thus the required irrigation application could be decreased by 30 mm as well.

The major difficulty with snow management is that snowfall is subject to tremendous yearly variation and given the current and predicted high input costs, a farmer may not be willing to gamble on the moisture being provided solely by this management technique. For the purpose of this study the effects of snow management were assumed to be included in the 30 percent production increase forecast.

d) Winter Wheat

Increasing the area of land seeded with winter wheat would increase the prairies grain production considerably since winter wheat generally yields 25 percent more [11] than does spring wheat, while it's deeper roots utilize the soil moisture content more efficiently than do the shallow rooted cereals such as spring wheat or barley. Currently winter wheat is only grown on the prairies in Alberta and Saskatchewan, which together planted about 486,000 hectares of winter wheat in 1985 [9].

The areal extent of winter wheat is presently quite limited as it requires either a higher winter ground temperature or greater snowcover than is generally observed in the prairies to survive the winter. It is possible that this crop could increase its suitable area through snow management and/or crop improvement. For the purposes of this study the impact of winter crops were neglected due to their presently limited significance on the prairies.

e) Zero Tillage

Zero tillage is a crop production system in which seed is planted in a seedbed that has not been tilled since the harvest of the preceding crop. All of the weed, disease, and pest control is achieved by chemical means alone, as the trash cover is not disturbed by tilling except during placement of the seed. This single tillage results in savings in fuel, time, and soil moisture while the plant residues on the soils surface greatly reduce wind and water erosion of the soil. The major disadvantages of the system are:

- existing tillage equipment can not be readily modified to perform zero tillage
- perennial weed control becomes important and expensive
- fertilizers can only be incorporated by banding near the seed
- potential problems with insect and disease control due to organisms overwintering on crop residues.

While zero tillage is now being successfully used in the United States on 4,900,000 hectares, its adoption on the Canadian prairies has proceeded quite slowly. In 1979 zero tillage was utilized on 25,000 hectares of prairie farmland, increasing in 1980 to 40,000 hectares [19]. Although this technique appears to hold great potential for the prairies, current research results have been inconsistent [19,24] as to it's real effectiveness and savings. Extensive use of zero tillage may also lead to long term environmental concerns over the percolation of any chemical residue down to the frequently shallow groundwater tables of the prairies.

Because of the uncertainty as to the long term suitability of zero tillage on the prairies, as well as the concerns expressed over the method's total reliance on chemical weed and pest control, the impact of the zero till method upon prairie agriculture was deemed to be negligible for the purposes of this study.

### 2.2.2 Long Term Crop Production Increases

If the predicted yield increases are combined with the expected summerfallowing area changes, the resulting production increases are sufficient to satisfy the Canadian Wheat Boards forecasts for cereal and oilseed production in the 1990's. Should crop demands increase beyond these forecasts at some future date, no additional land allocation transfers can occur, as the remaining land will be generally unsuitable for dryland continuous crop agriculture [11,12]. In this case, irrigation and snowmelt management will probably be required to further increase prairie crop production. With snowmelt management being very susceptible to the yearly variations in snowfall, the consequences of reduced harvests may not only carry an economic burden, but also a burden of humanity. The recent Global 2000 report [1] forecast that food will be in short supply by the year 2000, and that the extension of agriculture onto climatically marginal arable lands will result in tremendous fluctuations in global production, with extreme famines more the norm than the exception. One method of ensuring a certain base level of firm agricultural production free of the climatic variations so prevalent to prairie agriculture today would be to irrigate portions of the prairies.

## 2.3 IRRIGATED AGRICULTURE

As the farm practices required for irrigation are shaped primarily by the method of irrigation, the study briefly reviewed the irrigation methods commonly used on the prairies.

### 2.3.1 Methods of Irrigation

In the last decade virtually all of the irrigation development on the prairies has utilized sprinkler irrigation systems rather than surface irrigation methods [6]. The main advantages of sprinkler irrigation include:

- can be used on undulating fields which are difficult or impossible to use surface irrigation methods on, with little or no leveling required
- allows better control of water applications and as a result has good water use efficiency
- requires fewer and less skilled labourers thus reducing labour cost

- minimizes cultivation interference so less land is taken out of production

- facilitates relatively easy conversion from dryland to irrigated farming

- allows application of chemicals and fertilizers very effectively through inclusion in the water application.

Despite these apparent advantages, this study also considered using surface irrigation methods on some portion of the proposed areas since the sprinkler methods are much more energy intensive, a factor which may become increasingly important in the future. To determine the suitability of the irrigation methods for the envisioned developments, the study examined each method of surface and sprinkler irrigation presently used on the prairies. A brief discussion of the different methods is presented below.

SPRINKLER IRRIGATION METHODS

1) The Centre Pivot System consists of a series of sprinkler heads supported by wheeled towers which rotate about a central pivot point usually supplied with water through a buried pipeline from the edge of the field. There are currently two types of pivot sprinkler systems, a high pressure system requiring 12 Kpa (80 psi) water pressure for satisfactory spray performance, and a low pressure system which requires only 4-7 Kpa (30-50 psi) water pressure and thus uses considerably less energy for pumping. The low pressure system produces much larger spray drops and can produce puddling or erosion on undulating fields and heavy soils. Both systems have irrigation efficiencies of around 85 to

90 percent, which means that 85 to 90 percent of the water applied is available for consumptive use by the crop [25,26,27]. Because the system travels in a circle a fold back gun sprinkler is required to irrigate the corners of any square fields. The center pivot system can irrigate fields up to 260 hectares (1 section) in size, although 65 hectare fields are more typical. Center pivots require very little labour to operate, usually consisting of only casual inspection to ensure the system is working correctly.

2) A Linear Move System is virtually a center pivot type sprinkler which proceeds in a straight line down the length of the field while a flexible pipe from a mainline or an open ditch supplies the water. The system requires more labour to operate than does a center pivot, but has the advantage of being capable of irrigating any rectangular field. While this system has only recently been introduced to the prairies its efficiency is expected to approximate that of a center pivot [27].

3) A Side Roll System has a section of 100-125 mm diameter pipe acting as an axle for 1.5 to 3 m diameter wheels which are intermittently propelled across the field by a small motor located at the center of the system. The sprinkler nozzles are supplied with water through the axle/pipe, which in turn is connected to an adjacent mainline or ditch by a flexible pipe. The system requires considerably more labour than a center pivot or linear move, and also has a lower irrigation efficiency of around 75 percent [25].

4) A Big Gun System uses a single large sprinkler nozzle mounted on a chassis and supplied with water through a large flexible hose which unwinds as the chassis is propelled down the field by a small motor.

The field is irrigated in lanes approximately 90 m wide, and thus requires much more labour and supervision than do the previous methods. Big Gun Systems are generally used only to irrigate irregularly shaped fields which do not facilitate other sprinkler systems. The system has an irrigation efficiency of about 75 percent [25].

## SURFACE IRRIGATION METHODS

There are really only two methods of surface irrigation suitable for prairie cereal crop production, those of the furrow or corrugation method and the border dyke method.

1) The Furrow and Corrugation methods use small channels sloping down the fields to supply the soil with water. Furrows are used in row crops such as corn and sugar beets with the applied water flowing in the channel between each row. Corrugations are used for close growing crops such as alfalfa and wheat and act as directional guides for the flow.

2) The Border Dyke method uses parallel dykes 100-150 mm high located about 10-20 metres apart running down the slope of the field. The length of the run is dependent on the type of soil, with light soil requiring shorter lengths of run to avoid over-irrigation of the upper end of the run.

For all of the surface irrigation methods the water is usually supplied from a ditch to the top of the field through a siphon or through gated pipes across the top of the field. Since surface irrigation usually produces runoff at the bottom of the field, a reuse pit can be used to recirculate the water and increase the irrigation efficiency. Surface irrigation generally has an irrigation efficiency of 50 to 60 percent

[28], but using automatic gated (autogated) pipe with a recirculation system has produced irrigation efficiencies as high as 91 percent [29]. The major disadvantage of the surface irrigation methods is that they require considerably more land leveling and development to go from dryland to irrigated farming and their suitability is much more restricted than are the sprinkler methods. Use of the gated pipe or siphons to surface irrigate requires much more labour than does irrigation with a center pivot, but use of autogated pipes significantly reduces the labour input required.

The energy requirements, irrigation efficiencies, capital and operating costs, and labour requirements of the various irrigation methods examined in this study are presented in Tables 2-7 and 2-8 on pages 55 and 56, while Table 2-9 on page 57 presents factors which limit the applicability of the various irrigation methods. It must be noted that subsurface, solid set and trickle irrigation methods were not considered for large scale irrigation development since they are generally unsuitable or extremely expensive for irrigation of field crops [27].

The irrigation systems selected for this study were composed of both high and low pressure center pivots, linear move and big gun sprinklers, as well as autogated pipe surface irrigation. In reality the areal extent of each system within a district will be related to the topography, the interest rate available to the farmer, the capital cost of the system, the cost of the energy required, and the personal preference of the farmer. For the purposes of this study each of the proposed developments utilized the same proportion of each irrigation method, but a more rigorous study should include the effects of the above factors for each development. The percentage of the total development that each method was to irrigate was determined from a rather qualitative analysis incorporating the present dominance of the center pivot method, the relative energy, labour, and capital requirements, and the physical limitations of each method. Based on this analysis, Low Pressure Center Pivots are expected to irrigate about 35 percent of the proposed area, High Pressure Center Pivots 15 percent, Linear Move 25 percent, Travelling Gun 5 percent, and Autogated Surface methods would irrigate 20 percent of the area. While these system choices represent only one of the many possible combinations of systems, the actual prediction of how farmers will balance energy consumption, capital cost, and labour requirements is exceedingly difficult. It should be noted that the actual costs are relatively insensitive to the proportions of each system used to irrigate the proposed developments. For the purposes of this study, the irrigation systems selected were considered to be representative of the actual systems in the proposed developments.

### 2.3.2 Irrigated Agricultural Practices

A major requirement of converting from dryland to irrigated agriculture is the increase in the labour and management time which is so necessary for good irrigation production. The amount of time which a continually cropped field will require from the farmer is 2 to 3 times [30] greater than for traditional summerfallow dryland farming, and the benefits of irrigation must justify this increased time and input to the farmer. The major difficulty in shifting from dryland to irrigated agriculture is that the farmer must learn how to apply irrigation water efficiently and when the field requires it, otherwise his crop returns will not justify his increased input and capital costs. Recently there have been indications that the management responsibility of crop water applications can increasingly be shifted from the individual farmer or irrigation agency to on-farm micro-computers linked directly to field moisture indicators and supplied with climatic and crop data [31,32]. This is not to imply that a micro-computer could ever replace the knowledge and wisdom that a farmer with extensive irrigation experience will develop, but use of these fully automated systems could help to mitigate the transition difficulties of changing from dryland to irrigated farming.

The farm practices required for sprinkler irrigation are essentially similar to those for dryland farming, except that all crop inputs have to be increased, especially nitrogen fertilizer since many farmers presently do not apply nitrogen to previously fallowed fields. Both chemicals and fertilizers can be applied in solution with the irrigation water in a process generally termed chemigation and fertigation respectively. This method of application has been found to be quite efficient since the chemical can be leached to the most effective depth by varying the rate of water application [33].

The surface irrigation methods require either furrows or corrugations be plowed into the soil or dykes formed around the individual fields. In both cases the actual change in farm practices is minor, except for the additional labour required to form and maintain the dykes or corrugations each crop year and to irrigate the fields. Because of its higher efficiency and lower labour requirements the only surface irrigation system chosen for the proposed developments was that of autogated pipes with a recirculation system. This system greatly reduces the amount of labour and supervision required to surface irrigate when compared to siphons. It should be realized that the system works equally well on furrow, corrugation, and border dykes and since the costs and management practices required are virtually identical, no differentiation was made between the various surface irrigation methods.

It must be stressed that good on-farm management is the key to increased net returns from irrigation, for "regardless of the [irrigation] system chosen, it cannot be overstated how important good management is. Management is the key as money has been made, and lost, with almost all types of systems on all types of crops" [34].

The most effective way to convince farmers to convert from dryland to irrigated agriculture is expected to be through demonstration farms located throughout the potential developments. The rate of conversion would also be greatly aided by trained field personnel acting as advisors to the inexperienced farmers [35]. No costs for this support have been included in this study since the costs are expected to be relatively small, and the duties would overlap with the provincial and federal agricultural support staff presently assisting with dryland agriculture.

### 2.3.3 Rate of Farm Conversion

Even if the demonstration farms and advisors can prove to the farmers in a potential irrigation development that their income will increase under irrigation, there are several reasons which may limit the rate and extent of conversion from dryland to irrigated agriculture. One of the major limitations may be the farmers unwillingness or inability to become even more capital intensive than they presently are. Since the 1970's farmers have been utilizing more and more credit each year, and the recent reductions in net returns for dryland farming is causing many farmers considerable financial hardship since they are unable to make the payments on their borrowed capital [5]. The recent formation of national farmers groups aimed at preventing bank foreclosures on farms is but a symptom of this problem. It is quite possible that financial inducements such as tax credits, grants, or financing of the capital for farm conversion at reduced borrowing rates may be necessary.

An additional limitation to irrigation conversion is the present age distribution of prairie farmers. In 1981, only 45 percent of the farmers in the prairies were less than 45 years old, and only 24 percent were less than 35 years old [9]. Given the 10 to 15 year development period generally observed for large irrigation districts, it is apparent that many of the older farmers will retire before they can take full advantage of the benefits of the investment in conversion. There may also be some reluctance to convert since it will mean relearning farm management all over after 30 or more years of dryland farming. It is because of the long development and learning period that irrigation conversion is sometimes called two generation farming, in that it is only the subsequent generation of farmer who will see the full benefits of the investment in conversion.

Due to the discussions above, the development period for each irrigation district was assumed to be 15 years.

2.3.4 Selecting Irrigable Areas

Determining the suitability of a soil for irrigation has generally been done on the basis of a broad set of defined criteria such as PFRA's or Alberta Agriculture's criteria for the classification of irrigable soils [36,37]. In general, the methodology is to rank the soil into classes based on how well it satisfies criteria of soil moisture storage, texture, salinity, topography, drainage, cover and depth of soil. In the PFRA criteria, which is presented in Table 2-10 on page 58, the possible soil classes range from 1 to 4, in order of decreasing suitability for irrigation. These criteria identify the best irrigable soils (i.e. class 1) as fine sandy loams to clay loams at least .9 m thick over a pervious layer, with more than 150 mm of moisture storage, with a slope less than 1 percent, while only light land leveling and no drainage works are required. The criteria for classification of irrigable soils are currently undergoing evolution due to the increasing use of sprinkler irrigation, as much of the criteria were originally developed to survey land for its suitability for surface irrigation methods.

The potential irrigation developments studied in this report were based on several recent investigations of the soil suitability in each of the prairie provinces [38 to 45]. Only those areas identified as well suited for irrigation (i.e. classes 1 or 2 only) by these previous investigations were examined by this study. The areas examined by his study are shown on Figure 4 on page 32.

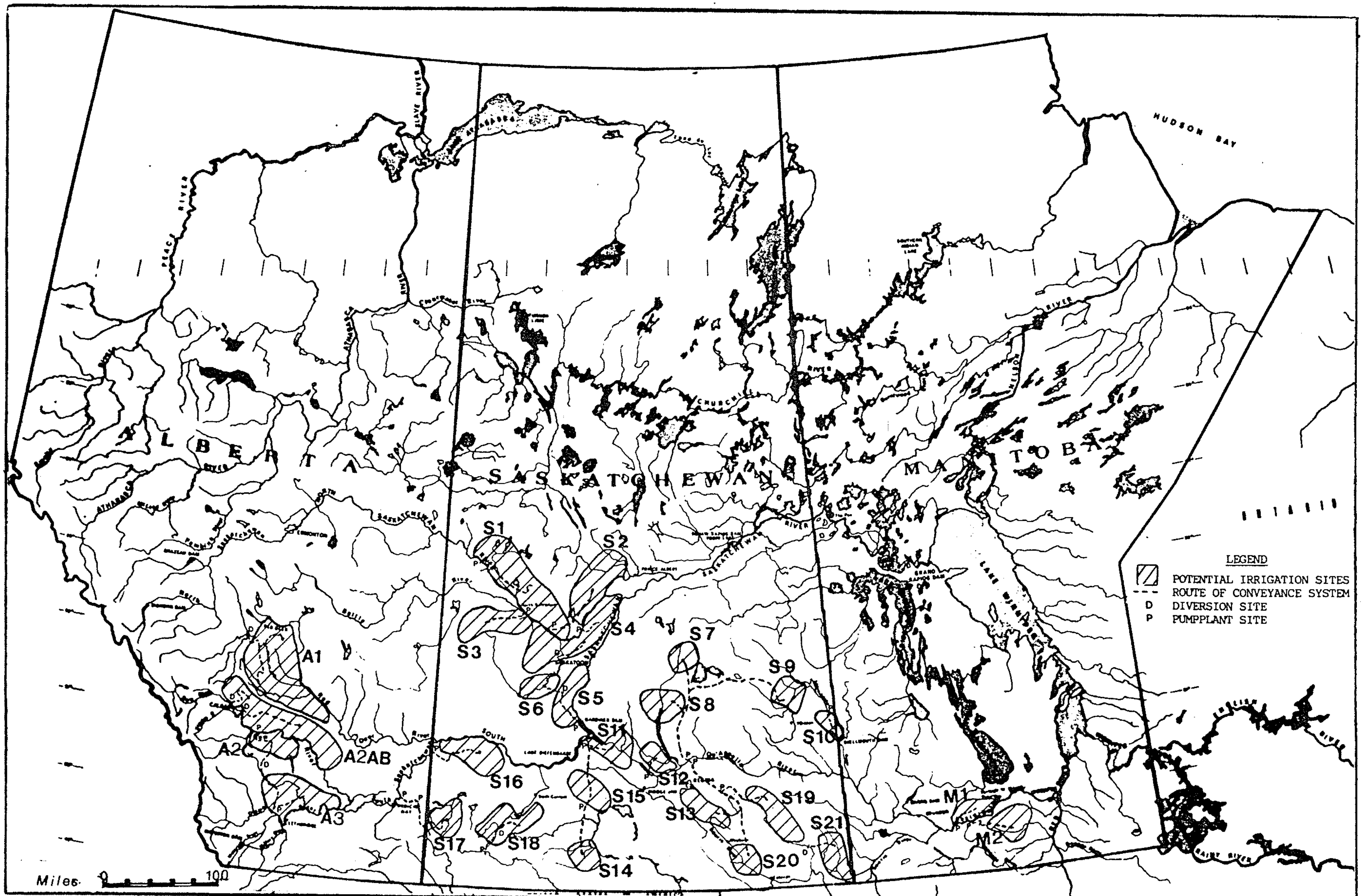


Figure 4 POTENTIAL IRRIGATION SITES EXAMINED IN THIS STUDY

The areas identified and shown on Figure 4 are the total area which the irrigation development would cover, and thus includes the farm buildings, roads, graineries, ditches, shelterbelts, and gardens commonly observed on the prairie farms. To determine the actual net area of the fields suitable for irrigation the gross areas were multiplied by a factor of 0.70, since it unlikely all of the fields will be entirely suitable for irrigation [44]. The gross and net areas of each of the potential developments is presented in Table 2-11 on page 60. The total net amount of potentially irrigated area examined in this study is approximately 4,000,000 hectares for the prairies, with Manitoba having 210,000 hectares, Saskatchewan 1,885,000 hectares, and Alberta 1,890,000 hectares. These potential irrigation developments represent an increase of roughly 800 percent from the existing irrigated area of 454,000 hectares. It should be noted that the total net irrigable area examined by this study represents only 10 percent of the total area of farmland currently cultivated on the prairies. The majority of the remaining farmland would benefit from supplemental water provided the water was of good quality, but the costs of the drainage works required and/or the difficulty and cost of supplying water to these areas will be much greater than for the areas examined in this study. Should the development of the class 1 and 2 irrigable areas examined in this study prove insufficient to satisfy future grain production requirements, then these class 3 and 4 areas may warrant additional study. The irrigation of the class 3 and 4 areas was deemed beyond the scope of this study, but should be examined in a more comprehensive examination of the irrigation potential of the prairies.

It should be noted that several discrete but adjacent areas were occasionally grouped as one area with the same total area as the individual areas to facilitate the analysis, since the task of evaluating the approximately 70 areas identified in the reports was deemed to be excessive for a study of this nature.

## 2.4 SOIL SALINITY AND DRAINAGE

During the last two decades dryland salinity has become a major problem on the Prairies, with recent estimates of 2.2 million hectares of land being affected [46]. Crop yields on these affected areas have decreased by an average 50 percent [47], while the areas continue to grow at a rate of 1 to 10 percent per year in Saskatchewan and 10 percent per year in Alberta [46,48]. The areal extent of the potential and the existing saline soils on the prairies are shown in Figure 5 on page 35.

The majority of the saline areas appear to result from saline seep, in which groundwater containing dissolved salts rises to the surface and evaporates and leaves the salts on the soil surface. This seepage is produced by recharge water percolating beyond the root zone, then mixing with the groundwater overtop of the bedrock and till. As the groundwater flows it dissolves the soluble salts in the bedrock and tills, and these salts are then deposited on the soil surface when the groundwater reaches a low lying point and evaporates. The excess salts in the soil produce an osmotic pressure differential that restricts the plants ability to take up water through its roots, thus severely affecting its growth. This excess groundwater seepage has been greatly aggravated by summerfallowing, snow melt accumulation in ditches and shelterbelts, and irrigation [49]. The saline seep process appears to

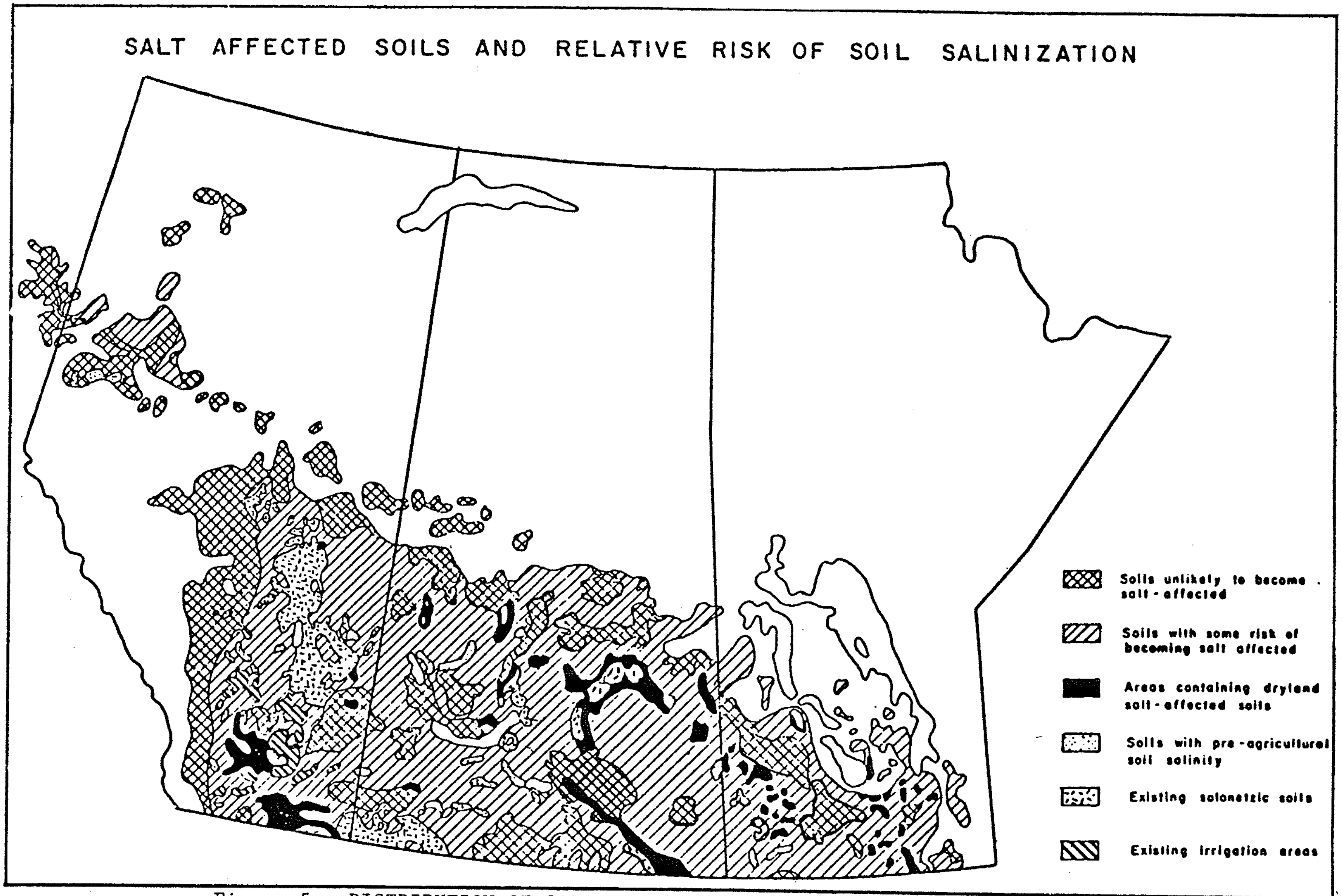


Figure 5 DISTRIBUTION OF SALT AFFECTED SOILS ON THE PRAIRIES, FROM [46]

be responsible for the majority of the salinity problems currently experienced in many of Alberta's irrigation districts, where the primary source of the excess groundwater has been losses in the unlined distribution systems and main canals. Many of these unlined systems are currently being upgraded to reduce or eliminate these losses. One successful solution to these saline seepage problems on the irrigated lands has been to install subsurface drainage at shallow depths (1.0 to 1.5 m) in the affected fields to intercept the seepage [50,51].

The usual response to salinization of irrigated lands is to increase the leaching requirements, so as to flush the salts below the root zone, but this is only effective in combination with an adequate natural or artificial drainage system, otherwise the additional leaching fraction results in increased saline seepage elsewhere or waterlogging of the soil. In recognition of the potential for future salinization problems, all of the proposed developments have subsurface drainage works as well as lined main and distribution canals. A leaching fraction of 10 percent of the average annual crop demand was assumed to be applied as necessary to leach the buildup of any salts to below the root zone. This would generally take place in a non-drought year when the crop water requirements are reduced and the water supply is plentiful, and thus no special provision was made to provide a leaching fraction during the average and drought design years.

As a result the above discussions, all of the envisioned projects will utilize drainage pipes located 1 to 1.5 m below the soil surface. These drains discharge into surface laterals which convey the project's effluent discharge into a water source for dilution. Given the scale of these developments, it is apparent that some water quality problems may result from this practice. This problem and its mitigation are briefly discussed in section 6.6 of this report.

For the purposes of this study it was assumed that 25 percent of the net irrigated area would be drained as the development proceeded, with another 35 percent of the net area being drained 20 years after its initial irrigation development. The remaining soil is assumed to consist of soils with adequate natural drainage or mitigating topographical features such as hill tops. These assumptions are comparable to recent forecasts [48] and preliminary projects in Manitoba and Saskatchewan [49]. To determine the sensitivity of the drainage costs of the projects to this assumption, a second case was analyzed assuming that initially 35 percent of the irrigated area would be drained, and a further 45 percent of the area would have subsurface drainage installed 20 years after the initial development.

The capital cost for the subsurface drainage was based on recent reports [51,52] which utilized capital costs of $1250 to $1600 (1982 $) per hectare. For the purposes of this study, the median cost of $1,425 per hectare, plus an additional cost of 10 percent for engineering for a total cost of $1,570 per hectare, was used in this analysis, with no adjustment for escalation since the USBR escalation index for drainage laterals and conduits is approximately 1.02 for 1982 to 1987 costs [80].

The drains were assumed to have a life of 50 years, while annual maintenance costs were expected to be about 0.75 percent of the capital costs.

## 2.5 PRESENT AND POTENTIAL CROP YIELDS

The crop yields on the Prairies are generally determined by the moisture, the temperature, the solar radiation, and the soil nutrients which each field provides to the crops. For the majority of the Brown and Dark Brown soils, the limiting factor to crop production is the available soil moisture, which is why supplementary irrigation water provides large increases in crop yields for these soils. An additional production increase associated with irrigation of the Brown soils is that if irrigation provides sufficient water for continuous cropping then the average production per cultivated hectare will be increased 67 percent above the average annual production for the 2.5 year summerfallow cycle typically observed in the Brown soil zones.

The average yields per cultivated hectare (i.e. crop and fallow area) for dryland farming in each of the proposed areas is shown in Table 2-12 on page 61. Since the development period of large irrigation projects is generally 10-15 years, the potential dryland production for the crops is presented in Table 2-13 on page 62. These potential yield increases represent the assumed 30 percent yield increase per seeded hectare as well as the predicted reduction in fallowing as previously discussed in section 2.2 of this report. The present irrigated crop yields that are expected for each development are presented in Table 2-14 on page 63, along with the potential irrigated yields, which are projected increases in yield of 5 percent for wheat, 10 percent for barley, 13 percent for the oilseeds, and 10 percent for all other crops because of expected genetic improvements in the seed [10].

## 2.6 FARM INPUTS FOR DRYLAND AND IRRIGATED AGRICULTURE

The components of the input costs for each crop under the existing and potential dryland, as well as the existing and potential irrigated conditions, are presented in Tables 2-15 and 2-16 on pages 64 and 65. It should be realized that the actual crop input costs will be different for each farmer, however the overall aggregate costs are expected to approximate those listed in the tables and used in the study. The potential dryland crop production input costs differ from the present dryland costs in that the 30 percent yield increases are expected to result from a combination of improved management and weed control along with increased fertilizer applications. The amount of fertilizer which would be applied varied with the crop, and was based upon the nutrient removal rates presented in Table 2-4 on page 53, while the costs of increased weed control was assumed to correspond to a 25 percent increase in chemical costs.

The present and potential irrigated crop input costs presented in Table 2-16 differ only in the cost of the applied fertilizer, the requirements for which are roughly proportional to yield [20].

When reviewing the crop input costs of Tables 2-15 and 2-16, it must be noted that these costs are assumed to be in constant dollars. This does not imply that the input costs are not expected to increase, but rather, they will not increase at a rate greater than other components of the economy. Based on the Canadian Grains Council farm input indexes [9], the input cost increases have historically closely followed other indexes of inflation such as the consumer price index, and therefore the assumption of relatively constant input costs was deemed acceptable for a study of this nature, since the effects of inflation are accounted for in the selection of the interest rates, as is discussed in Chapter 5.

## 2.7 CROP MARKET VALUES

Like all products sold in a competitive marketplace, the price of Canadian agricultural products are subject to continual change in response to the supply and demand influences on the market. Since Canada exports over 50 percent of its grain production [9], its crop prices are largely determined by the global rather than the domestic grain marketplace. Global factors which can tremendously affect the market values of Canadian crop exports include the weather experienced by the consumer or competing producer nations, the population growth and economic productivity of the consumer nations, and government assistance or subsidies to alter the cropping patterns or costs for competing nations. A current example of government intervention in the global market is the grain export subsidies presently being offered by both the United States and the European Economic Community, which have severely impacted on the market value of Canada's grain exports, and eventually may impact on the marketability of Canada's agricultural production should Canada be unwilling or unable to match these subsidies.

Because of the volatile market prices experienced over the last 10 years, the crop values used for this study were based on the average of the previous 5 years crop prices. The market prices used in this study should be in relatively constant dollars, but it must be realized that grain prices are subject to natural fluctuations which may greatly deviate from these prices in any given year. Since these fluctuations can not readily be predicted [4], the averaged market prices presented in Table 2-17 on page 66 were utilized in the economic analysis of the present conditions.

Due to the long development period envisioned for these irrigation projects, the economic analysis of these projects also had to examine the positive or negative impacts which variations in future crop prices would exert upon the economic viability of the projects. Recent forecasts [1] have called for a 21 to 63 percent increase in the real crop market value by the year 2000. The given range corresponds to the assumed increase in energy prices, with the 21 percent price increase assuming constant real energy prices while the 63 percent price increase corresponds to increases in the real energy price. These increased crop prices are expected to result from an increased growth in global food demand largely due to population and economic growth in the developing nations. Based upon these estimates, Table 2-18 on page 66 presents the forecast grain export demands for the years 1990 and 2000, as well as the actual grain exports of 1985.

Because of the difficulty of forecasting long term price movements, this study used the current average prices for the majority of the analysis, however crop price changes ranging from -25 percent to +100 percent were also used to examine the sensitivity of the developments to such a change.

## 2.8 CROP WATER REQUIREMENTS

Water is a major factor in plant growth since it contributes to the dry weight of the plant material and serves as the medium of transfer through which the essential soluble nutrients and minerals are conducted to the plant. These water uses account for less than one percent of a plant's total water use, the remainder is lost through evaporation from the leaf surfaces, primarily through the stomata. This transpiration of water facilitates the entry and solution of carbon dioxide, thus aiding the rate of photosynthesis and the plant's growth. The amount of water which is transpired is basically determined by the amount of energy available for evaporation from leaf surfaces, the availability of water at the leaf surfaces, and the existence of a transfer medium to remove the water vapour from the plant surfaces. In terms of inputs commonly observed in the field, the amount of transpiration is determined by the air temperature, the solar radiation, the soil moisture, the air humidity, the plant height, the leaf surface area, the stage of growth, and the wind.

In addition to water transpiration through the crop, evaporation through the soil surface will also decrease the moisture available to the plants. The summation of the water transpired and evaporated from a crop is termed the consumptive use of the particular crop. The amount of water which must be provided to a crop through irrigation is the moisture deficit between the crops consumptive use, and the precipitation during the period examined along with the change in the moisture stored in the soil.

The consumptive water use of a crop can be estimated in basically only three ways: (1) from actual field trials in lysimeters; (2) from calculation of the potential evapotranspiration (eg. Blaney - Criddle, or Penmans method [8]) or open pan evaporation measurements, and consumptive use crop coefficients relating the potential evapotranspiration to a specific crop; and (3) observation from existing irrigation districts where the percolation losses can be measured. An examination of several sources utilizing all of the above methods produced reasonably consistent consumptive uses on the prairies for the different crops examined, and are presented in Table 2-19 on page 67 along with the crop consumptive use factors utilized in this study.

The water holding capacity of a soil is usually expressed in terms of inches of water stored per 4 feet (1.2 m) of soil, and is primarily determined by the soils porosity, texture, structure, and its chemical composition. The storage capacity of prairie soils is site specific, but a value of 4 inches (100 mm) is generally considered as being representative for the prairies in crop moisture studies [63]. A soil with a large amount of moisture storage capacity requires less frequent applications of irrigation, and requires less irrigation water than will a field with a low storage value since more of the natural "effective" rainfall will be stored and used by the crop over the irrigation period. Because of the scale of this study all of the potential irrigation sites were assumed to have 4 inches (100 mm) of moisture storage.

The moisture deficits which irrigation was to replenish were based on several sources [45,66] and were specific to each site, as presented in Table 2-20 on page 68. These moisture deficits are for a crop with a consumptive use coefficient of 1.0, which corresponds to the heavy water-use crop of alfalfa. The actual deficits must be adjusted by the consumptive use coefficients in Table 2-19 for the crops selected to be grown in each area.

The element of risk and irrigation was included into the study by using the moisture deficits for an average year, which was defined to have a probability of exceedance of 50 percent, and the deficit for a drought year, which was defined to be the deficit with a probability of exceedance of only 10 percent. Both the average and drought water deficits are presented in Table 2-20. The determination of the acceptable risk of water shortages for design of an irrigation system is a complex blend of economic and social considerations on the part of the farmer, the management of the irrigation system, and ultimately the various levels of government. Due to the difficulty in determining the acceptable probability of a water shortage, the study only utilized the water requirements for the drought ($p<10\%$) and average ($p<50\%$) crop moisture conditions.

The required rate of water application is related to the soil, the particular crop, and its stage of growth. The water required in each month by each crop is shown in Table 2-21 on page 69. Given the probable cropping pattern for each district, as determined in the subsequent section, and using the monthly crop requirements of Table 2-21, the monthly water requirements of each potential development can be determined.

It must be noted that the crop water yield response is generally non-linear with the crop reaching an optimal yield point beyond which any further increase in water applications will only reduce the yield [65]. The values specified as consumptive uses generally correspond to the water required to produce these optimal yields, but the crop yields generally decrease at a rate less than the water applications can near the optimal yield point. This implies that occasionally it may be better to reduce the water applications by 10 percent if the the yield only reduces 5 percent, since you could irrigate 10 percent more land with the water conserved. This assumes that the occasional reduction in water application will not increase the salinity of the soil, and that in other non-drought periods the salts will be flushed down. This type of analysis is relatively straight forward for a single field but gets exceedingly complex on a large scale since the economics and the crop responses will vary throughout the prairies. For the purposes of this study it was assumed that any reduction in water to extend the area irrigated would produce the same benefits and costs as if the "optimal" water requirement was applied to the defined irrigable areas.

## 2.9 ON-FARM ECONOMIC BENEFITS OF IRRIGATION

To determine the net on-farm benefits (positive or negative) associated with converting from dryland to irrigated farming requires knowledge of what the existing dryland benefits are before irrigation development as well as what the expected benefits will be after the conversion to irrigated agriculture. It is the difference in net crop returns to the farmer which will be used to compare the economics of the various project alternatives in Chapter 5 of this report. As an initial step to this procedure, one must first determine what the on-farm or direct benefits of the existing dryland crops presently are, as well as what they could be by the end of the development period of the proposed irrigation project.

### 2.9.1 Dryland Crop Returns

The gross and net returns for both the existing and the potential dryland crop conditions were determined for each district, and are presented in Table 2-22 on page 70. The gross return for each major crop grown in the potential development was based on the average crop yield per cultivated hectare (Tables 2-12, 2-13) multiplied by the expected market value of that crop (Table 2-17). The net crop value was then determined by subtracting the crop input costs of Table 2-15. Based on the areal distribution of each crop within a district, a weighted net return was determined for each proposed development area. To illustrate the required calculations, the net crop value of wheat for site A1 under present conditions would be determined as follows:

```
NET CROP RETURN = (Yield in Kg/Ha)(.001 T/Kg)(Crop Price $/T)
                   -  (Crop Costs $/Ha)
                = (Table 2-12)(.001)(Table 2-17) - (Table 2-15)
                = (1313 Kg/Ha)(.001)(200 $/T) - (171 $/Ha)
                = 91.6 $/Ha
```

It should be noted in Table 2-22 that the crops of oats and canola produce extremely low and even slightly negative net returns in several districts under the present dryland cropping conditions. While it is possible that these negative benefits indicate minor errors in either the yield or crop input costs used for these districts, it is also quite possible that the crops are presently very marginal economically. Since these negative return crops are of very limited significance in each district, the assumption of a zero net return for the crop does not significantly alter the weighted net crop returns of each district.

### 2.9.2 Irrigated Crop Returns

To determine the total net return for each proposed district one must first determine the irrigated crops to be grown and their extent within each district.

### 2.9.3 Selection of Irrigated Crop Mix

The determination of the expected crop mix for an irrigation development is a complex problem due to the many factors which can influence and shape the crop pattern. These factors include the net return of each crop alternative, the marketability of the crop, the farmer's familiarity with the crop, the suitability of the farmer's existing machinery for the crop, the water requirements of the crop, and the crop rotations required to ensure long term productivity. An additional factor which further complicates the choice of a cropping pattern is that the "optimal" choice will vary with each farmer and his choice will not be a static pattern but will respond to crop market prices, input costs, and spring seeding conditions.

For the purposes of this study only one crop mix was assumed throughout a given proposed development. The cropping pattern chosen was based upon a qualitative analysis integrating the net return of each crop choice considered (Table 2-23), the existing prevalence of each crop within a district (Table 2-22), the forecast export potential for each crop choice (Table 2-18), the relative water requirement for each crop (Table 2-19), and previous studies [41,44,67]. While it can be argued that a more formal analysis should be used to determine the optimal cropping mix, the uncertainty of the factors affecting these choices make the validity of a more rigorous analysis exceedingly questionable. The cropping patterns for the proposed irrigation developments which were utilized in this study are presented in Table 2-23 on page 71, and consist primarily of cereal grain, oilseed, and alfalfa production. It should be noted that no specialty crops such as lentils, vegetables, or fababeans were selected due to the extremely limited market for these crops. Based on the cropping patterns selected for each area, the crop water demand patterns for each area were determined and are presented in Table 2-24 on page 72, while the effective consumptive use factor and the irrigation requirements for each area are presented in Table 2-20.

### 2.9.4 Irrigation Benefits to the Farmer

The irrigation benefit to the farmer is the difference in his net income between what his land could produce under the dryland conditions and what it would produce under irrigation. This increase in income is termed the direct benefits of the irrigation development, and can be used as an aid to determine the economic desirability of the irrigation project to the farmer. The direct irrigation benefits for each district were determined from the irrigated net crop return for the cropping pattern selected, the dryland net crop return, the on-farm costs of the irrigation system required to apply the water demands of each cropping pattern, and the costs of draining the land. The direct benefits for the various scenarios examined by the study are presented in Tables 2-25 to 2-32 on pages 73 to 76 for both the present and the potential crop conditions.

Two energy costs were utilized in determining the costs of the irrigation applications, with a $0.04 per kilowatt hour price representing the present farm cost, and $0.08 per kilowatt hour representing a possible future energy cost. While electrical energy costs are forecast to increase at or slightly greater than the general rate of inflation [41], the $0.08 rate was used to determine the sensitivity of the projects to changes in the cost of energy. The cost of electrical energy was utilized since it is generally the lowest cost energy source next to natural gas [25], and is more commonly available throughout the proposed irrigation districts. It must be noted that many farms in Alberta do use natural gas for pumping, for an energy cost saving of about 30 percent.

The fixed costs of each development's irrigation system were based on the costs of Table 2-8 for interest rates varying from 2 to 8 percent, however only the costs for an interest rate of 4 percent are presented in Tables 2-25 to 2-30. For comparative purposes Tables 2-31 and 2-32 present the net benefits under present conditions for interest rates of 2 percent and 8 percent respectively. This range in interest rates was identified in Chapter 5 as the appropriate range of rates to be examined in this study. It must be noted when reviewing Tables 2-25 to 2-32 that the on-farm irrigated benefits presented do not include the costs of the water supply and distribution works required to convey the water to the farms. These works and their associated costs will be examined in detail in Chapter 4 of the report.

TABLE 2-1 CROP AREAS ON THE PRAIRIES

| CROP | MANITOBA AREA IN $10^3$ Ha | | | | SASKATCHEWAN AREA IN $10^3$ Ha | | | | ALBERTA AREA IN $10^3$ Ha | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg | % | 1986 | % | Avg | % | 1986 | % | Avg | % | 1986 | % |
| H. WHEAT | 1410 | 30.3 | 1821 | 37.6 | 6139 | 34.3 | 6657 | 36.5 | 2147 | 21.1 | 2630 | 25.2 |
| D. WHEAT | 77 | 1.7 | 121 | 2.5 | 1141 | 6.4 | 1396 | 7.7 | 166 | 1.6 | 223 | 2.1 |
| OATS | 296 | 6.4 | 231 | 4.8 | 486 | 2.7 | 364 | 2.0 | 571 | 5.6 | 506 | 4.8 |
| BARLEY | 732 | 15.7 | 749 | 15.8 | 1307 | 7.3 | 1416 | 7.8 | 2200 | 21.6 | 2266 | 21.7 |
| RYE | 63 | 1.4 | 81 | 1.7 | 149 | 0.8 | 162 | 0.9 | 100 | 1.0 | 90 | 0.9 |
| FLAX | 333 | 7.2 | 425 | 8.8 | 188 | 1.1 | 283 | 1.6 | 53 | 0.5 | 32 | 0.3 |
| CANOLA | 336 | 7.2 | 405 | 8.4 | 828 | 4.6 | 1174 | 6.4 | 870 | 8.6 | 1133 | 10.8 |
| CORN | 49 | 1.1 | 45 | 0.9 | - | - | - | - | 2.4 | - | 6.5 | 0.1 |
| MXD GRAIN | 59 | 1.3 | 51 | 1.0 | 38 | 0.2 | 53 | 0.3 | 90 | 0.9 | 65 | 0.6 |
| TAME HAY | 537 | 11.6 | 546 | 11.3 | 784 | 4.4 | 728 | 4.0 | 1463 | 14.4 | 1578 | 15.1 |
| S.FALLOW | 757 | 16.3 | 364 | 7.5 | 6823 | 38.1 | 5666 | 31.1 | 2414 | 23.7 | 1760 | 16.8 |
| TOTAL | 4649 | | 4839 | | 17909 | | 18223 | | 10177 | | 10451 | |

NOTES: 1) Avg is average crop area in hectares for period 1974 - 1984
2) 1986 crop areas based on spring survey
3) All percentages are based on the total area for the period

SOURCE: 1985 Canadian Grains Industry Statistical Handbook [9]

TABLE 2-2 IRRIGATED CROPS AT OUTLOOK IN 1979

| CROP | AREA IN HECTARES | % AREA |
|---|---|---|
| Field Crops | 9570 | 78.4 |
| Hard Wheat | 3441 | 28.2 |
| Durum | 53 | .4 |
| Barley | 1069 | 8.8 |
| Oats | 154 | 1.3 |
| Utility Wheat | 48 | .4 |
| Soft Wheat | 344 | 2.8 |
| Corn | 77 | .6 |
| Flax | 1319 | 10.8 |
| Rapeseed | 891 | 7.3 |
| Oil Sunflower | 24 | .2 |
| Confection Sunflower | 190 | 1.6 |
| Canary Seed | 40 | .3 |
| Lentils | 12 | .1 |
| Faba Beans | 1526 | 12.5 |
| Field Peas | 129 | 1.1 |
| Potatoes | 194 | 1.6 |
| Vegetables | 53 | .4 |
| Rutabagas | 9 | .1 |
| Sweet Corn | 26 | .2 |
| Carrots | 5 | - |
| Cabbage | 4 | - |
| Other | 8 | .1 |
| Perennials | 2579 | 21.1 |

SOURCE: [55]

TABLE 2-3 PRESENT AND FORECAST LAND USES ON THE PRAIRIES

| Soil Zone | Present (1976) Fallow ha x $10^3$ | Cropped ha x $10^3$ | % Fallow | Forecast (1990) Fallow ha x $10^3$ | Cropped ha x $10^3$ | % Fallow |
|---|---|---|---|---|---|---|
| Brown | | | | | | |
| Sask. | 1949 | 2223 | 46.7 | 1949 | 2223 | 46.7 |
| Alberta | 737 | 1131 | 39.5 | 737 | 1131 | 39.5 |
| Sub Total | 2686 | 3354 | 44.5 | 2686 | 3354 | 44.5 |
| Dark Brown | | | | | | |
| Sask. | 2568 | 3264 | 44.0 | 1166 | 4665 | 20.0 |
| Alberta | 823 | 1572 | 34.4 | 479 | 1916 | 20.0 |
| Sub Total | 3391 | 4836 | 41.2 | 1645 | 6581 | 20.0 |
| Black & Grey | | | | | | |
| Manitoba | 934 | 3323 | 21.9 | 426 | 3832 | 10.0 |
| Sask. | 2689 | 4249 | 38.8 | 694 | 6243 | 10.0 |
| Alberta | 1071 | 3372 | 24.1 | 444 | 3999 | 10.0 |
| Sub Total | 4694 | 10944 | 30.0 | 1564 | 14074 | 10.0 |
| TOTAL | 10771 | 19134 | 36.0 | 5985 | 24009 | 20.0 |

NOTES:
1) Fallow = Area summerfallowed each year, in ha x $10^3$.
2) Cropped = Area seeded each year, in ha x $10^3$.
3) % Fallow = Fallow Area/(Fallow Area + Cropped Area) in percent

SOURCE: Adapted from R. A. Hedlin [16]

## TABLE 2-4 NUTRIENT REMOVAL BY PRAIRIE CROPS

| Crop | Yield kg/ha | Nutrient Removal Each Harvest in Kg/Ha Nitrogen (N) | Phosphorus ($P_2O_5$) | Potassium ($K_2O$) | Sulphur (S) |
|---|---|---|---|---|---|
| Grain | | | | | |
| Wheat | 2689 | 67 | 27 | 17 | 5 |
| Barley | 3226 | 67 | 25 | 22 | 5 |
| Oats | 3045 | 57 | 25 | 15 | 7 |
| Corn | 6380 | 89 | 44 | 27 | 5 |
| Oilseeds | | | | | |
| Canola | 1959 | 74 | 37 | 17 | 12 |
| Flax | 1252 | 45 | 20 | 17 | 5 |
| Sunflowers | 2240 | 57 | 20 | 15 | 5 |
| Pulses | | | | | |
| Peas | 2799 | 103 | 27 | 35 | 7 |
| Fababeans | 3360 | 151 | 37 | 45 | 7 |

NOTE: Nutrient Removal will vary with yield

SOURCE: [20]

## TABLE 2-5 AVERAGE FERTILIZER CONSUMPTION IN 1979

| Nutrient | Manitoba kg/ha | Saskatchewan kg/ha | Alberta kg/ha |
|---|---|---|---|
| Nitrogen (N) | 53.0 | 14.2 | 42.5 |
| Phosphorus ($P_2O_5$) | 28.5 | 12.9 | 23.2 |
| Potassium ($K_2O$) | 4.0 | 0.3 | 2.5 |

SOURCE: [21]

TABLE 2-6 RELATIVE DISTRIBUTION OF SNOW COVER WATER

| Topography | Accumulated Total Snowfall (Shielded Nipher Guage) | 1.0 |
|---|---|---|
| Level Plains | -Fallow | .55 |
| | -Stubble | .71 |
| | -Pasture | .59 |
| Hill Tops | -Fallow | .20 |
| | -Stubble | .48 |
| | -Pasture | .30 |
| Gradual Slopes | -Fallow | .66 |
| | -Stubble | .69 |
| | -Pasture & Brush | .83 |
| Small Draws | -Fallow | 1.32 |
| | -Stubble | 1.28 |
| | -Pasture & Brush | 1.28 |
| Steep Slopes | -Pasture & Brush | 2.53 |
| Farm Yards | | 1.50 |
| Mean of Entire Watershed | | .77 |

SOURCE: 1974, 1975 data for Creighton Watershed, Bad Lake Basin, from [17].

TABLE 2-7 COMPARISON OF IRRIGATION METHODS

| Irrigation Method | System Capital Cost $/Ha | Est. Life in Years | Annual O&M,% of Cap. % | Energy Use Kwh/Ha/m | Irrgn Effcny % | Labour Reqrmnt hrs/Ha/m |
|---|---|---|---|---|---|---|
| Center Pivot | | | | | | |
| -High Pres. | 1300 | 15 | 1.0 | 3810 | 85 | .321 |
| -Low Pres. | 1300 | 15 | 1.0 | 2675 | 85 | .321 |
| Linear Move | 1160 | 15 | 1.0 | 3243 | 90 | .486 |
| Side Roll | 935-1080 | 15 | 1.0 | 2756 | 75 | .972 |
| Travelling Gun | 1000 | 15 | 1.2 | 5270 | 75 | 1.167 |
| Furrow and Corrugation c/w Siphon | 850-1350 | 50 | 0.5 | 0 | 50 | 1.070 |
| To Add Autogated c/w Recycling | 800 | 15 | 1.0 | 486 | 85 | .486 |
| Border Dyke c/w Siphon | 850-1350 | 50 | 0.5 | 0 | 60 | .972 |
| To add Autogated c/w Recycling | 800 | 15 | 1.5 | 486 | 85 | .486 |

NOTES: 1) Cost to add autogated pipe is shown separately to allow life of 15 years to be included into economic analysis. The total capital cost is 1650-2150 $/ha for autogated pipe with either the Border Dyke or the Furrow/Corrugation methods.

2) Energy consumption assumes surface water adjacent to field. Figures are for water available for crop's consumptive use, in kwh's per metre of water supplied per hectare.

3) Irrgn Effcny is the ratio between the water available for consumptive use of the crop and the total water applied.

4) Labour Reqrmnt is in hours per hectare per metre of water applied.

SOURCES: Adapted from [25,27,29]

TABLE 2-8 ANNUAL FIXED AND ENERGY COSTS OF IRRIGATION FOR INTEREST RATES OF 2, 4, AND 8 PERCENT AND ENERGY RATES OF $.04/Kwh AND $.08/Kwh

| METHOD | CAPITAL $/Ha | INT % | O&M $/Ha | DPRC $/Ha | LABR $/Ha | FIXED $/Ha | ENERGY $/Ha/m $.04 | ENERGY $/Ha/m $.08 |
|---|---|---|---|---|---|---|---|---|
| CENTER PIVOT HIGH PRSSR | 1300 | 2 | 13 | 86.7 | 2.6 | 128 | 152 | 304 |
| | | 4 | 13 | 86.7 | 2.6 | 154 | 152 | 304 |
| | | 8 | 13 | 86.7 | 2.6 | 206 | 152 | 304 |
| CENTER PIVOT LOW PRSSR | 1300 | 2 | 13 | 86.7 | 2.6 | 128 | 107 | 214 |
| | | 4 | 13 | 86.7 | 2.6 | 154 | 107 | 214 |
| | | 8 | 13 | 86.7 | 2.6 | 206 | 107 | 214 |
| LINEAR MOVE | 1200 | 2 | 12 | 80.0 | 3.9 | 120 | 130 | 260 |
| | | 4 | 12 | 80.0 | 3.9 | 144 | 130 | 260 |
| | | 8 | 12 | 80.0 | 3.9 | 192 | 130 | 260 |
| BIG GUN | 1000 | 2 | 12 | 66.7 | 9.3 | 108 | 210 | 420 |
| | | 4 | 12 | 66.7 | 9.3 | 128 | 210 | 420 |
| | | 8 | 12 | 66.7 | 9.3 | 168 | 210 | 420 |
| SIDEROLL | 1000 | 2 | 10 | 67.3 | 7.8 | 105 | 110 | 210 |
| | | 4 | 10 | 67.3 | 7.8 | 125 | 110 | 210 |
| | | 8 | 10 | 67.3 | 7.8 | 166 | 110 | 210 |
| AUTOGATED PIPE | 800 | 2 | 8 | 53.3 | 3.9 | 81 | 19 | 38 |
| | | 4 | 8 | 53.3 | 3.9 | 97 | 19 | 38 |
| | | 8 | 8 | 53.3 | 3.9 | 129 | 19 | 38 |
| SURFACE WORK | 1100 | 2 | 5 | 22.0 | 8.6 | 58 | 0 | 0 |
| | | 4 | 5 | 22.0 | 8.6 | 71 | 0 | 0 |
| | | 8 | 5 | 22.0 | 8.6 | 115 | 0 | 0 |
| TOTAL PIPE & SURFACE | 1900 | 2 | 13 | 75.3 | 12.5 | 139 | 19 | 38 |
| | | 4 | 13 | 75.3 | 12.5 | 178 | 19 | 38 |
| | | 8 | 13 | 75.3 | 12.5 | 266 | 19 | 38 |

NOTES: 1) Total fixed costs = (Capital x Interest + O&M + Depreciation + Labour) in $/Ha

2) Energy cost = $/Ha/metre of water applied, at energy rates of $0.04 per Kwh and $0.08 per Kwh

SOURCE: [25,27,29]

TABLE 2-9 IRRIGATION SYSTEM SELECTION

| IRRIGATION SYSTEM | MAX. SLOPE % | SHAPE OF FIELD | FIELD SURFACE | MAX. CROP HEIGHT metres | SYSTEM SIZE Ha |
|---|---|---|---|---|---|
| Sprinkler Methods | | | | | |
| Center Pivot | 5-15 | Circular | No Obstructions, Path for towers | 2.4-3.0 | 15-260 |
| Linear Move | 5-15 | Rectangular | No Obstructions, Path for towers | 2.4-3.0 | 30-260 |
| Side Roll | 5-10 | Rectangular | No Obstructions, Path for wheels | 1.2-1.8 | 10-30 |
| Big Gun | 5 | Any Shape | Reasonably Smooth, Lane for hose | 2.4-3.0 | 10-15 |
| Surface Methods | | | | | |
| Border | Nearly Level | Rectangular | Constant Grade | N/A | 1 or more |
| Furrow | 3 | Rows should be of Equal Length | Constant Grade | N/A | 1 or more |
| Corrugation | 4-8 | Rows should be of Equal Length | Constant Grade | N/A | 1 or more |

SOURCE: [26]

TABLE 2-10 LAND CLASSIFICATION STANDARDS FOR IRRIGATION SUITABILITY

| Land Characteristics | Class 1 Very Good | Class 2 Good | Class 3 Fair | Class 4 Unsuitable |
|---|---|---|---|---|
| **Soils** | | | | |
| Texture | | | | |
| Very Coarse Textured<br>Very Fine Textured | Fine sandy loam to clay laoms | Loamy fine sand to light clay | Sand to permeable clay | Gravel to clay |
| Water Holding Capacity<br>Low Available Moisture Capacity | 40-60 saturation. 6" storage in 4'. 4"/hr hydraulic cond. | 35-65 sat. % 5" storage/4' 5"/hr hydraulic cond. | 25-75 sat. % 3" storage in 4' 7"/hr hydraulic cond. | 25 or 75 sat. % 3" storage in 4' 7"/hr hydr. cond. |
| Geological Deposit<br>Shallow Deposit Over Sand or Gravel | 36" or more of fine sandy loam or heavier | 24" or more of fine sandy loam or heavier or 30" plus of loamy fine sand or sandy loam | 18" or more of sandy loam or heavier, or 24" plus of loamy sand | 18" of sandy loam or heavier, or 24" of loamy sand or sand |
| Shallow Deposit Over Impervious Substrata | 10' of permeable material | 6' of permeable material | 3' of permeable material | 3' of permeable material |
| Salinity or Alkalinity | 4 mmhos in 0.2' 8 mmhos below 2' 6 SAR | 4 mmhos in 0.2' 12 mmhos below 2' 8 SAR | 8 mmhos in 0.2' 15 mmhos below 2' 12 SAR | 8 mmhos in 0.2' 15 mmhos below 2' 12 SAR |
| **External Features** | | | | |
| Topography<br>Slope<br>Excess Gradient | 1% and 0.1% in general gradient | 3% in general gradient | 5% in general gradient | 5% in general gradient |
| Irrigation Pattern<br>Deficient Field Size | 400' min. run 10 acres min. size if regular 20 acres min. size is irreg. | 300' min. run 5 acres min. size if regular 8 acres min. size is irreg. | 150' min. run 5 acres min. size | 150' run 5 acres size |
| Surface (Levelling Requirement) | light 0-200 $yd^3$ excavation per acre | medium 200-350 $yd^3$ excavation/acre | heavy 350-500 $yd^3$ excavation/acre | excessive more than 500 cu. yds excavation/acre |

TABLE 2-10 TYPICAL LAND CLASSIFICATION STANDARDS FOR IRRIGATION SUITABILITY (Cont'd)

| Land Characteristics | Class 1 Very Good | Class 2 Good | Class 3 Fair | Class 4 Unsuitable |
|---|---|---|---|---|
| Cover (Vegetation) | | | | |
| Tree and Brush Clearing | none to light clearing | none to medium clearing | none to heavy clearing | heavy bush |
| Stones - Rock Clearing | none to light clearing | none to medium clearing | none to heavy clearing | excessively stoney |
| Drainage | | | | |
| High Water Table | No problem anticipated | moderate drainage problem anticipated but may be improved at relatively low cost | moderate to severe drainage problem may be improved by expensive but feasible measures | drainage improvements not considered feasibile |

Source: PFRA, 1964 [36].

TABLE 2-11 IRRIGATED AREAS OF PROPOSED DEVELOPMENT

| Development | Area ha x $10^3$ Gross | Net | Development | Area ha x $10^3$ Gross | Net |
|---|---|---|---|---|---|
| M1 | 168 | 120 | S12 | 60 | 45 |
| M2 | 130 | 90 | S13 | 70 | 50 |
| TOTAL | | 210 | S14 | 60 | 45 |
| | | | S15 | 70 | 50 |
| | | | S16 | 100 | 70 |
| S1 | 280 | 200 | S17 | 80 | 55 |
| S2 | 200 | 140 | S18 | 180 | 130 |
| S3 | 190 | 135 | S19 | 75 | 55 |
| S4 | 410 | 290 | S20 | 25 | 20 |
| S5 | 130 | 95 | S21 | 60 | 45 |
| S6 | 65 | 45 | TOTAL | | 1,885 |
| S7 | 75 | 55 | | | |
| S8 | 160 | 115 | A1 | 750 | 535 |
| S9 | 180 | 130 | A2 | 1000 | 715 |
| S10 | 15 | 10 | A3 | 900 | 640 |
| S11 | 150 | 105 | TOTAL | | 1,890 |

NOTE: Net irrigable area is 70% of gross area.

SOURCE: [38 to 45]

## TABLE 2-12 PRESENT DRYLAND YIELDS ON PRAIRIE SOILS

| Crop | Province | Brown Soil | | | Dark Brown Soil | | | Black/Grey Soil | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Seed Kg/Ha | Cult Kg/Ha | %SF | Seed Kg/Ha | Cult Kg/Ha | %SF | Seed Kg/Ha | Cult Kg/Ha | %SF |
| Wheat | Sask. | 1673 | 890 | 88 | 1767 | 987 | 79 | 1945 | 1419 | 37 |
| | Alta./Man. | 1830 | 1040 | 76 | 2100 | 1313 | 60 | 2200 | 1693 | 30 |
| Oats | Sask. | 1714 | 1182 | 45 | 1766 | 1261 | 40 | 1930 | 1582 | 22 |
| | Alta./Man. | 1843 | 1345 | 37 | 2130 | 1651 | 29 | 2400 | 2086 | 15 |
| Barley | Sask. | 2013 | 1459 | 38 | 2102 | 1569 | 34 | 2234 | 1877 | 19 |
| | Alta./Man. | 2083 | 1693 | 23 | 2350 | 1992 | 18 | 2549 | 2339 | 9 |
| Flax | Sask. | 785 | 497 | 58 | 922 | 611 | 51 | 1060 | 828 | 28 |
| | Alta./Man. | 1200 | 705 | 70 | 1230 | 769 | 60 | 1402 | 1078 | 30 |
| Canola | Sask. | 870 | 453 | 92 | 1028 | 568 | 81 | 1285 | 892 | 44 |
| | Alta./Man. | 960 | 536 | 79 | 1100 | 675 | 63 | 1210 | 923 | 31 |
| Corn | Alta. | - | - | - | - | - | - | 6500 | 5417 | 20 |
| | Man. | - | - | - | - | - | - | 3678 | 3065 | 20 |
| Hay | All | | 1600 | | | 1060 | | | 2130 | |

NOTES:
1) All yields are 10 year averages adapted from [58, 59, 60]
2) Seed = Crop Yield in Kg per Ha seeded.
3) Cult = Crop Yield in Kg per Ha seeded and fallowed.
4) % SF = Percentage of crop grown on summerfallow estimated from [58, 59, 60, 16].

TABLE 2-13 POTENTIAL DRYLAND YIELDS ON PRAIRIE SOILS

| Crop | Province | Brown Soil Seed Kg/Ha | Brown Soil Cult Kg/Ha | Brown Soil %SF | Dark Brown Soil Seed Kg/Ha | Dark Brown Soil Cult Kg/Ha | Dark Brown Soil %SF | Black/Grey Soil Seed Kg/Ha | Black/Grey Soil Cult Kg/Ha | Black/Grey Soil %SF |
|---|---|---|---|---|---|---|---|---|---|---|
| Wheat | Sask. | 2175 | 1157 | 88 | 2297 | 1838 | 25 | 2529 | 2299 | 10 |
| | Alta./Man. | 2379 | 1352 | 76 | 2730 | 2184 | 25 | 2860 | 2600 | 10 |
| Oats | Sask. | 2228 | 1537 | 45 | 2296 | 2032 | 13 | 2509 | 2367 | 6 |
| | Alta./Man. | 2396 | 1749 | 37 | 2769 | 2472 | 12 | 3120 | 2971 | 5 |
| Barley | Sask. | 2617 | 1896 | 38 | 2733 | 2461 | 11 | 2904 | 2766 | 5 |
| | Alta./Man. | 2708 | 2202 | 23 | 3055 | 2829 | 8 | 3314 | 3217 | 3 |
| Flax | Sask. | 1021 | 646 | 58 | 1199 | 1033 | 16 | 1378 | 1276 | 8 |
| | Alta./Man. | 1560 | 886 | 76 | 1599 | 1279 | 25 | 1822 | 1657 | 10 |
| Canola | Sask. | 1131 | 589 | 92 | 1336 | 1061 | 26 | 1670 | 1491 | 12 |
| | Alta./Man. | 1248 | 697 | 79 | 1430 | 1735 | 26 | 1573 | 1417 | 11 |
| Corn | Alta. | - | - | - | - | - | - | 8450 | 7682 | 10 |
| | Man. | - | - | - | - | - | - | 4781 | 4347 | 10 |
| Hay | All | | 2080 | | | 2420 | | | 2770 | |

NOTES:
1) All yields are 10 year averages adapted from [58, 59, 60]
2) Seed = Crop Yield Kg per Ha seeded.
3) Cult = Crop Yield Kg per Ha seeded and cultivated
4) % SF = Percentage of crop grown on summerfallow estimated from [58, 59, 60, 16].

TABLE 2-14 IRRIGATED CROP YIELDS USED FOR THIS STUDY

| CROP | PRESENT YIELD kg/hectare | POTENTIAL YIELD kg/hectare |
|---|---|---|
| Soft Wheat | 4705 | 4940 |
| Hard Spring Wheat | 3435 | 3630 |
| Oats | 2705 | 2980 |
| Barley | 4267 | 4700 |
| Flax | 1951 | 2205 |
| Rapeseed | 1951 | 2205 |
| Field Corn | 5020 | 5522 |
| Silage Corn | 12000 | 13200 |
| Faba Beans | 2800 | 3080 |
| Sunflowers | 1900 | 2090 |
| Alfalfa | 3800 | 4180 |

NOTE: Potential irrigated crop yields are present crop yields increased by 5% to 13% due to expected genetic improvements, from [10].

SOURCE: [10,26,52,53].

TABLE 2-15 DRYLAND FARM INPUT COSTS

| CROP | CROP SERVICES | | MACHINERY | | LABOUR | | TOTAL COST | |
|---|---|---|---|---|---|---|---|---|
| | 1987 $/Ha | PTNL $/Ha | 1987 $/Ha | PTNL $/Ha | 1987 $/Ha | PTNL $/Ha | 1987 $/Ha | PTNL $/Ha |
| WHEAT | 85 | 100 | 68 | 88 | 18 | 18 | 171 | 206 |
| OATS | 67 | 80 | 71 | 92 | 15 | 15 | 153 | 187 |
| BARLEY | 77 | 93 | 71 | 92 | 18 | 18 | 166 | 203 |
| CORN | 96 | 115 | 85 | 108 | 21 | 21 | 202 | 244 |
| ALFALFA | 26 | 34 | 77 | 100 | 21 | 21 | 124 | 155 |
| CANOLA | 85 | 100 | 80 | 104 | 21 | 21 | 186 | 225 |
| FLAX | 77 | 86 | 74 | 96 | 18 | 18 | 169 | 200 |
| SMR FALLOW | 11 | 11 | 21 | 21 | 6 | 6 | 38 | 38 |

NOTES:
1) Crop Services = seed, chemical, fertlizer, insurance
2) Machinery = repairs, fuel, lubricants, depreciation
3) Labour = machine servicing and operation at $8.00 per hour
4) 1987 = present costs in $ per hectare
5) PTNL = costs for potential yields (see text for explanation)

SOURCE: Adapted from [30, 53, 54]

TABLE 2-16 IRRIGATED INPUT COSTS

| CROP | CROP SERVICES 1987 $/Ha | CROP SERVICES PTNL $/Ha | MACHINERY 1987 $/Ha | MACHINERY PTNL $/Ha | LABOUR 1987 $/Ha | LABOUR PTNL $/Ha | TOTAL COST 1987 $/Ha | TOTAL COST PTNL $/Ha |
|---|---|---|---|---|---|---|---|---|
| WHEAT | 173 | 183 | 68 | 71 | 29 | 29 | 270 | 283 |
| BARLEY | 175 | 185 | 68 | 74 | 29 | 29 | 272 | 288 |
| CORN | 247 | 260 | 81 | 90 | 42 | 46 | 370 | 396 |
| ALFALFA | 76 | 80 | 65 | 71 | 42 | 46 | 183 | 197 |
| CANOLA | 192 | 207 | 69 | 75 | 29 | 29 | 290 | 311 |
| FLAX | 177 | 190 | 76 | 85 | 29 | 29 | 282 | 304 |
| SUNFLOWERS | 234 | 246 | 73 | 82 | 29 | 29 | 336 | 357 |

NOTES:
1) Crop Service = seed, chemical, fertlizer, insurance
2) Machinery = repairs, fuel, lubricants, depreciation
3) Labour = machine servicing and operation at $8.00 per hour
4) 1987 = present costs in $ per hectare
5) PTNL = costs for potential yields (see text for explanation)

SOURCE: Adapted from [30, 53, 54]

Table 2-17 PRESENT AND PROJECTED CROP PRICES

| CROP | MARKET PRICE 5 YEAR AVERAGE $/TONNE | PROJECTED INCREASE OF 25% $/TONNE | POSSIBLE DECREASE OF 25% $/TONNE |
|---|---|---|---|
| Wheat | 200 | 250 | 150 |
| Oats | 118 | 148 | 89 |
| Barley | 152 | 190 | 114 |
| Corn | 70 | 88 | 53 |
| Alfalfa | 70 | 88 | 53 |
| Canola | 361 | 451 | 271 |
| Flax | 345 | 431 | 259 |

SOURCES: [1,9]

TABLE 2-18 PRESENT AND FORECAST CROP EXPORTS

| CROP | CROP EXPORTS IN MILLION TONNES IN YEAR | | |
|---|---|---|---|
| | 1984-1985 | 1990 | 2000 |
| Wheat | 19.750 | 20-25 | 22-29 |
| Hard | 17.400 | | |
| Durham | 2.350 | | |
| Course Grain | 5.420 | 7-10 | 8-13 |
| Barley | 4.400 | | |
| Corn | .490 | | |
| Oats | .810 | | |
| Rye | .450 | | |
| Oilseeds | 1.890 | 4-7 | 5-9 |
| Canola | 1.410 | | |
| Flax | .470 | | |
| TOTAL | 27.060 | 36 | 39-44 |

SOURCES: [1,2,9]

TABLE 2-19 CONSUMPTIVE CROP WATER USE FACTORS

| CROP | CONSUMPTIVE USE in mm, from reference [63] | [64] | [65] | [55] | MEAN | CROP USE FACTOR |
|---|---|---|---|---|---|---|
| Alfalfa | 660 | 610 | 648 | 610 | 639 | 1.00 |
| Wheat | 483-457 | 480 | 493-462 | 570-510 | 494 | .77 |
| Oats | 406 | 430 | 409 | | 415 | .65 |
| Barley | 406 | 430 | 409 | | 415 | .65 |
| Field Corn | 381 | | 373 | | 377 | .59 |
| Silage Corn | | 510 | | 660 | 585 | .91 |
| Flax | 381 | | 386 | 510 | 426 | .67 |
| Rapeseed | 420 | | | 560 | 590 | .77 |
| Sunflowers | | | | 610 | 610 | .95 |
| Faba Beans | | | | 610 | 610 | .95 |
| Sugar Beets | 559 | | | | 559 | .88 |
| Potatoes | 508 | 510 | | | 509 | .80 |
| Canning Peas | 330 | | | | 330 | .52 |
| Pasture | 610 | | | | 610 | .95 |

NOTES: 1) MEAN is average of consumptive uses presented for each crop

2) CROP USE FACTOR is consumptive use of crop divided by the consumptive use of alfalfa

SOURCES: [55,63,64,65]

TABLE 2-20 WATER REQUIREMENTS FOR EACH SITE

| SITE | Weighted Consumptive Use Factor | Moisture Deficit in mm Probability | | Annual Irrigation Requirement in mm | |
|---|---|---|---|---|---|
| | | P < 50% | P < 10% | P < 50% | P < 10% |
| A1 | .773 | 200 | 350 | 180 | 320 |
| A2 | .773 | 225 | 375 | 205 | 340 |
| A3 | .773 | 225 | 350 | 205 | 320 |
| S1 | .770 | 200 | 310 | 180 | 280 |
| S2 | .770 | 220 | 285 | 200 | 260 |
| S3 | .770 | 225 | 330 | 205 | 300 |
| S4 | .770 | 220 | 330 | 200 | 300 |
| S5 | .764 | 270 | 380 | 240 | 340 |
| S6 | .770 | 275 | 390 | 250 | 355 |
| S7 | .770 | 150 | 250 | 135 | 230 |
| S8 | .764 | 225 | 280 | 200 | 250 |
| S9 | .770 | 150 | 240 | 135 | 220 |
| S10 | .770 | 150 | 240 | 135 | 220 |
| S11 | .764 | 270 | 360 | 240 | 325 |
| S12 | .764 | 250 | 370 | 225 | 335 |
| S13 | .764 | 250 | 370 | 225 | 335 |
| S14 | .780 | 350 | 460 | 325 | 425 |
| S15 | .780 | 275 | 400 | 255 | 365 |
| S16 | .780 | 320 | 420 | 295 | 390 |
| S17 | .780 | 300 | 400 | 275 | 365 |
| S18 | .780 | 275 | 375 | 255 | 350 |
| S19 | .761 | 225 | 350 | 200 | 310 |
| S20 | .761 | 275 | 375 | 250 | 335 |
| S21 | .761 | 260 | 360 | 235 | 325 |
| M1 | .733 | 175 | 275 | 150 | 235 |
| M2 | .733 | 150 | 250 | 130 | 220 |

NOTES:
1) Weighted consumptive use factor based on crop mix selected for each site and crop requirements (i.e. Tables 2-19,2-23)
2) Moisture Deficit with probability of exceedance of 10% termed drought condition, average deficit has probability of exceedance of 50% (i.e. P<50%)
3) Irrigation requirement includes infield water losses of 15% (average irrigation system efficiency is 0.85), and weighted consumptive use factor
4) Assumes 4 inches of soil moisture storage

SOURCE: [45,66]

TABLE 2-21 SEASONAL VARIATION OF ANNUAL WATER REQUIREMENT FOR EACH CROP

| Crop | Percentage of Annual Water Requirement During Each Month | | | | |
|---|---|---|---|---|---|
| | May | June | July | August | September |
| Wheat | 7 | 32 | 47 | 14 | 0 |
| Barley | 9 | 48 | 43 | 0 | 0 |
| Alfalfa | 16 | 24 | 29 | 20 | 11 |
| Canola | 5 | 35 | 52 | 7 | 0 |
| Flax | 5 | 28 | 48 | 19 | 0 |
| Corn | 5 | 16 | 31 | 36 | 12 |

SOURCES: [63, 64, 65]

Table 2-22 NET RETURNS OF DRYLAND CROP PRODUCTION

| SITE | CROP | CRPLND % | PRESENT CONDITIONS YIELD Kg/Ha | GROSS $/Ha | NET $/HA | FUTURE CONDITIONS YIELD Kg/Ha | GROSS $/Ha | NET $/Ha |
|---|---|---|---|---|---|---|---|---|
| A1,A2, | WHEAT | 42.0 | 1313 | 262.6 | 91.6 | 2184 | 436.8 | 230.8 |
| A3 | BARLEY | 25.0 | 1992 | 302.8 | 136.8 | 2829 | 430.0 | 227.0 |
| | OATS | 6.2 | 1651 | 194.8 | 41.8 | 2472 | 291.7 | 104.7 |
| | CANOLA | 6.2 | 675 | 243.7 | 57.7 | 1135 | 409.7 | 184.7 |
| | FLAX | .4 | 769 | 265.3 | 96.3 | 1279 | 441.3 | 241.3 |
| | HAY | 16.0 | 1860 | 130.2 | 6.2 | 2420 | 169.4 | 14.4 |
| WEIGHTED | AVERAGE | | | | 80.2 | | | 174.9 |
| S1,S2 | WHEAT | 61.0 | 1419 | 283.8 | 112.8 | 2299 | 459.8 | 253.8 |
| | BARLEY | 14.0 | 1877 | 285.3 | 119.3 | 2766 | 420.4 | 217.4 |
| | OATS | 4.7 | 1582 | 186.7 | 33.7 | 2367 | 279.3 | 92.3 |
| | CANOLA | 5.7 | 892 | 322.0 | 136.0 | 1491 | 538.3 | 313.3 |
| | FLAX | 2.0 | 828 | 285.7 | 116.7 | 1276 | 440.2 | 240.2 |
| | HAY | 8.0 | 1860 | 130.2 | 6.2 | 2770 | 193.9 | 38.9 |
| WEIGHTED | AVERAGE | | | | 97.7 | | | 215.4 |
| S3,S4, | WHEAT | 61.0 | 987 | 197.4 | 26.4 | 1838 | 367.6 | 161.6 |
| S5 | BARLEY | 14.0 | 1569 | 238.5 | 72.5 | 2461 | 374.1 | 171.1 |
| | OATS | 4.7 | 1261 | 148.8 | -4.2 | 2032 | 239.8 | 52.8 |
| | CANOLA | 5.7 | 568 | 205.0 | 19.0 | 1061 | 383.0 | 158.0 |
| | FLAX | 2.0 | 611 | 210.8 | 41.8 | 1033 | 356.4 | 156.4 |
| | HAY | 8.0 | 1860 | 130.2 | 6.2 | 2420 | 169.4 | 14.4 |
| WEIGHTED | AVERAGE | | | | 28.5 | | | 138.3 |
| S7,S9, | WHEAT | 59.0 | 1419 | 283.8 | 112.8 | 2299 | 459.8 | 253.8 |
| S10 | BARLEY | 15.0 | 1877 | 285.3 | 119.3 | 2766 | 420.4 | 217.4 |
| | OATS | 5.0 | 1582 | 186.7 | 33.7 | 2367 | 279.3 | 92.3 |
| | CANOLA | 6.0 | 892 | 322.0 | 136.0 | 1491 | 538.3 | 313.3 |
| | FLAX | 2.1 | 828 | 285.7 | 116.7 | 1276 | 440.2 | 240.2 |
| | HAY | 10.3 | 2130 | 149.1 | 25.1 | 2770 | 193.9 | 38.9 |
| WEIGHTED | AVERAGE | | | | 99.3 | | | 214.8 |
| S8,S11, | WHEAT | 75.0 | 987 | 197.4 | 26.4 | 1838 | 367.6 | 161.6 |
| S12,S5 | BARLEY | 9.0 | 1569 | 238.5 | 72.5 | 2461 | 374.1 | 171.1 |
| | OATS | 2.7 | 1261 | 148.8 | -4.2 | 2032 | 239.8 | 52.8 |
| | CANOLA | 3.3 | 568 | 205.0 | 19.0 | 1061 | 383.0 | 158.0 |
| | FLAX | 1.2 | 611 | 210.8 | 41.8 | 1033 | 356.4 | 156.4 |
| | HAY | 6.0 | 1860 | 130.2 | 6.2 | 2420 | 169.4 | 14.4 |
| WEIGHTED | AVERAGE | | | | 27.8 | | | 146.0 |
| S14,S15, | WHEAT | 84.0 | 890 | 178.0 | 7.0 | 1157 | 231.4 | 25.4 |
| S16,S17, | BARLEY | 4.7 | 1459 | 221.8 | 55.8 | 1896 | 288.2 | 85.2 |
| S18 | OATS | 1.6 | 1182 | 139.5 | -13.5 | 1537 | 181.4 | -5.6 |
| | CANOLA | 2.0 | 453 | 163.5 | -22.5 | 589 | 212.6 | -12.4 |
| | FLAX | .7 | 497 | 171.5 | 2.5 | 646 | 222.9 | 22.9 |
| | HAY | 7.3 | 1600 | 112.0 | -12.0 | 2080 | 145.6 | -9.4 |
| WEIGHTED | AVERAGE | | | | 8.5 | | | 24.5 |
| S19,S20, | WHEAT | 71.0 | 1419 | 283.8 | 112.8 | 2299 | 459.8 | 253.8 |
| S21 | BARLEY | 9.6 | 1877 | 285.3 | 119.3 | 2766 | 420.4 | 217.4 |
| | OATS | 3.3 | 1582 | 186.7 | 33.7 | 2367 | 279.3 | 92.3 |
| | CANOLA | 4.0 | 892 | 322.0 | 136.0 | 1491 | 538.3 | 313.3 |
| | FLAX | 1.4 | 828 | 285.7 | 116.7 | 1276 | 440.2 | 240.2 |
| | HAY | 8.8 | 2130 | 149.1 | 25.1 | 2770 | 193.9 | 38.9 |
| WEIGHTED | AVERAGE | | | | 101.9 | | | 223.4 |
| M1,M2 | WHEAT | 45.0 | 1693 | 338.6 | 167.6 | 2600 | 520.0 | 314.0 |
| | BARLEY | 21.0 | 2339 | 355.5 | 189.5 | 3217 | 489.0 | 286.0 |
| | OATS | 5.7 | 2086 | 246.1 | 93.1 | 2971 | 350.6 | 163.6 |
| | CANOLA | 9.1 | 923 | 333.2 | 147.2 | 1417 | 511.5 | 286.5 |
| | FLAX | 13.1 | 1078 | 371.9 | 202.9 | 1657 | 571.7 | 371.7 |
| | HAY | 8.0 | 2130 | 149.1 | 25.1 | 2770 | 193.9 | 38.9 |
| WEIGHTED | AVERAGE | | | | 162.5 | | | 288.6 |

NOTES:
1) Crplnd % is the percentage of cropland that a given crop is currently grown on within the proposed development
2) Yield is the expected average crop yield in Kg/Ha
3) Net Return is the gross return minus the input costs in $/Ha
4) Future Conditions include changes in seed, fertilizer, and crop management. See Section 2.2 for full explanation

SOURCE: From Tables 2-12, 2-13, 2-15, 2-17, [58,59,60]

Table 2-23 NET RETURNS FOR IRRIGATED CROP PRODUCTION

| SITE | CROP | CRPLND % | PRESENT CONDITIONS YIELD Kg/Ha | PRESENT CONDITIONS GROSS $/Ha | PRESENT CONDITIONS NET $/HA | FUTURE CONDITIONS YIELD Kg/Ha | FUTURE CONDITIONS GROSS $/Ha | FUTURE CONDITIONS NET $/Ha |
|---|---|---|---|---|---|---|---|---|
| A1,A2, A3 | WHEAT | 50.0 | 3435 | 687.0 | 417.0 | 3630 | 726.0 | 443.0 |
| | BARLEY | 15.0 | 4267 | 648.6 | 376.6 | 4700 | 714.4 | 426.4 |
| | ALFALFA | 10.0 | 8000 | 560.0 | 377.0 | 8800 | 616.0 | 419.0 |
| | CANOLA | 15.0 | 1951 | 704.3 | 414.3 | 2205 | 796.0 | 485.0 |
| | FLAX | .0 | 1951 | 678.9 | 396.9 | 2205 | 767.3 | 463.3 |
| | CORN | 10.0 | 12000 | 840.0 | 470.0 | 13200 | 924.0 | 528.0 |
| WEIGHTED | AVERAGE | | | | 411.8 | | | 452.9 |
| S1,S2 | WHEAT | 55.0 | 3435 | 687.0 | 417.0 | 3630 | 726.0 | 443.0 |
| | BARLEY | 15.0 | 4267 | 648.6 | 376.6 | 4700 | 714.4 | 426.4 |
| | ALFALFA | 10.0 | 8000 | 560.0 | 377.0 | 8800 | 616.0 | 419.0 |
| | CANOLA | 15.0 | 1951 | 704.3 | 414.3 | 2205 | 796.0 | 485.0 |
| | FLAX | 5.0 | 1951 | 678.9 | 396.9 | 2205 | 767.3 | 463.3 |
| | CORN | .0 | 12000 | 840.0 | 470.0 | 13200 | 924.0 | 528.0 |
| WEIGHTED | AVERAGE | | | | 405.5 | | | 445.4 |
| S3,S4, S6 | WHEAT | 55.0 | 3435 | 687.0 | 417.0 | 3630 | 726.0 | 443.0 |
| | BARLEY | 15.0 | 4267 | 648.6 | 376.6 | 4700 | 714.4 | 426.4 |
| | ALFALFA | 10.0 | 8000 | 560.0 | 377.0 | 8800 | 616.0 | 419.0 |
| | CANOLA | 15.0 | 1951 | 704.3 | 414.3 | 2205 | 796.0 | 485.0 |
| | FLAX | 5.0 | 1951 | 678.9 | 396.9 | 2205 | 767.3 | 463.3 |
| | CORN | .0 | 12000 | 840.0 | 470.0 | 13200 | 924.0 | 528.0 |
| WEIGHTED | AVERAGE | | | | 405.5 | | | 445.4 |
| S7,S8, S10 | WHEAT | 55.0 | 3435 | 687.0 | 417.0 | 3630 | 726.0 | 443.0 |
| | BARLEY | 15.0 | 4267 | 648.6 | 376.6 | 4700 | 714.4 | 426.4 |
| | ALFALFA | 10.0 | 8000 | 560.0 | 377.0 | 8800 | 616.0 | 419.0 |
| | CANOLA | 15.0 | 1951 | 704.3 | 414.3 | 2205 | 796.0 | 485.0 |
| | FLAX | 5.0 | 1951 | 678.9 | 396.9 | 2205 | 767.3 | 463.3 |
| | CORN | .0 | 12000 | 840.0 | 470.0 | 13200 | 924.0 | 528.0 |
| WEIGHTED | AVERAGE | | | | 405.5 | | | 445.4 |
| S5,S8, S11,S12, S13 | WHEAT | 70.0 | 3435 | 687.0 | 417.0 | 3630 | 726.0 | 443.0 |
| | BARLEY | 10.0 | 4267 | 648.6 | 376.6 | 4700 | 714.4 | 426.4 |
| | ALFALFA | 5.0 | 8000 | 560.0 | 377.0 | 8800 | 616.0 | 419.0 |
| | CANOLA | 10.0 | 1951 | 704.3 | 414.3 | 2205 | 796.0 | 485.0 |
| | FLAX | 5.0 | 1951 | 678.9 | 396.9 | 2205 | 767.3 | 463.3 |
| | CORN | .0 | 12000 | 840.0 | 470.0 | 13200 | 924.0 | 528.0 |
| WEIGHTED | AVERAGE | | | | 409.7 | | | 445.4 |
| S14,S15, S16,S17, S18 | WHEAT | 80.0 | 3435 | 687.0 | 417.0 | 3630 | 726.0 | 443.0 |
| | BARLEY | 5.0 | 4267 | 648.6 | 376.6 | 4700 | 714.4 | 426.4 |
| | ALFALFA | 8.0 | 8000 | 560.0 | 377.0 | 8800 | 616.0 | 419.0 |
| | CANOLA | 5.0 | 1951 | 704.3 | 414.3 | 2205 | 796.0 | 485.0 |
| | FLAX | 2.0 | 1951 | 678.9 | 396.9 | 2205 | 767.3 | 463.3 |
| | CORN | .0 | 12000 | 840.0 | 470.0 | 13200 | 924.0 | 528.0 |
| WEIGHTED | AVERAGE | | | | 411.2 | | | 442.8 |
| S19,S20, S21 | WHEAT | 70.0 | 3435 | 687.0 | 417.0 | 3630 | 726.0 | 443.0 |
| | BARLEY | 5.0 | 4267 | 648.6 | 376.6 | 4700 | 714.4 | 426.4 |
| | ALFALFA | 5.0 | 8000 | 560.0 | 377.0 | 8800 | 616.0 | 419.0 |
| | CANOLA | 10.0 | 1951 | 704.3 | 414.3 | 2205 | 796.0 | 485.0 |
| | FLAX | 5.0 | 1951 | 678.9 | 396.9 | 2205 | 767.3 | 463.3 |
| | CORN | 5.0 | 12000 | 840.0 | 470.0 | 13200 | 924.0 | 528.0 |
| WEIGHTED | AVERAGE | | | | 414.4 | | | 450.4 |
| M1,M2 | WHEAT | 65.0 | 3435 | 687.0 | 417.0 | 3630 | 726.0 | 443.0 |
| | BARLEY | 2.0 | 4267 | 648.6 | 376.6 | 4700 | 714.4 | 426.4 |
| | ALFALFA | 3.0 | 8000 | 560.0 | 377.0 | 8800 | 616.0 | 419.0 |
| | CANOLA | 10.0 | 1951 | 704.3 | 414.3 | 2205 | 796.0 | 485.0 |
| | FLAX | 10.0 | 1951 | 678.9 | 396.9 | 2205 | 767.3 | 463.3 |
| | CORN | 10.0 | 12000 | 840.0 | 470.0 | 13200 | 924.0 | 528.0 |
| WEIGHTED | AVERAGE | | | | 418.0 | | | 456.7 |

NOTES:
1) Crplnd % is the percentage of cropland that a given crop will be grown on within the irrigation development
2) Yield is the expected average crop yield in Kg/Ha
3) Net Return is the gross return minus the input costs in $/Ha
4) Future Conditions include changes in seed, fertilizer, and crop management. See Section 2.2 for full explanation

SOURCE: From Tables 2-12, 2-13, 2-15, 2-17, [58,59,60]

TABLE 2-24 SEASONAL VARIATION OF ANNUAL WATER REQUIREMENT FOR EACH SITE

| SITE | Percentage of Annual Water Requirement During Each Month | | | | |
|---|---|---|---|---|---|
| | May | June | July | August | September |
| A1, A2, A3 | 8 | 33.5 | 45 | 12 | 1.5 |
| S1, S2, S3, S4, S6, S7, S9, S10 | 7.8 | 33.9 | 45.4 | 11.8 | 1.1 |
| S5, S8, S11, S12, S13 | 7.4 | 33.9 | 46.3 | 12.5 | .5 |
| S14, S15, S16, S17, S18 | 7.7 | 32.2 | 45.6 | 13.5 | 1.0 |
| S19, S20, S21 | 7.1 | 31.7 | 45.7 | 14.3 | 1.2 |
| M1, M2 | 6.0 | 30.4 | 45.4 | 15.9 | 1.5 |
| Weighted Avrg. | 7.6 | 33.2 | 45.6 | 12.3 | 1.3 |

SOURCE: Tables 2-21,2-23

Table 2-25 DIRECT BENEFITS OF IRRIGATION : PRESENT CONDITIONS

| SITE | AREA HAx1000 | IRF NT $/HA | WATER MM | IRR SYS $/HA | DRNGE $/HA | ENERGY $/HA | IRR NET $/HA | DRY NET $/HA | NET O-F BNFTS $/HA | NET BNFTS $/DAM3 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 200.0 | 405.5 | 180.0 | 155.0 | 34.8 | 19.0 | 196.7 | 97.7 | 99.0 | 55.0 |
| S2 | 140.0 | 405.5 | 200.0 | 155.0 | 34.8 | 21.1 | 194.6 | 97.7 | 96.9 | 48.4 |
| S3 | 135.0 | 405.5 | 205.0 | 155.0 | 34.8 | 21.6 | 194.1 | 28.7 | 165.4 | 80.7 |
| S4 | 290.0 | 405.5 | 200.0 | 155.0 | 34.8 | 21.1 | 194.6 | 28.7 | 165.9 | 82.9 |
| S5 | 95.0 | 409.7 | 240.0 | 155.0 | 34.8 | 25.3 | 194.6 | 27.8 | 166.8 | 69.5 |
| S6 | 45.0 | 405.5 | 250.0 | 155.0 | 34.8 | 26.4 | 189.3 | 28.7 | 160.6 | 64.2 |
| S7 | 55.0 | 405.5 | 135.0 | 155.0 | 34.8 | 14.3 | 201.5 | 99.3 | 102.2 | 75.7 |
| S8 | 115.0 | 409.7 | 200.0 | 155.0 | 34.8 | 21.1 | 198.8 | 27.8 | 171.0 | 85.5 |
| S9 | 130.0 | 405.5 | 135.0 | 155.0 | 34.8 | 14.3 | 201.5 | 99.3 | 102.2 | 75.7 |
| S10 | 10.0 | 405.5 | 135.0 | 155.0 | 34.8 | 14.3 | 201.5 | 99.3 | 102.2 | 75.7 |
| S11 | 105.0 | 409.7 | 240.0 | 155.0 | 34.8 | 25.3 | 194.6 | 27.8 | 166.8 | 69.5 |
| S12 | 45.0 | 409.7 | 225.0 | 155.0 | 34.8 | 23.8 | 196.2 | 27.8 | 168.4 | 74.8 |
| S13 | 50.0 | 409.7 | 225.0 | 155.0 | 34.8 | 23.8 | 196.2 | 27.8 | 168.4 | 74.8 |
| S14 | 45.0 | 411.2 | 325.0 | 155.0 | 34.8 | 34.3 | 187.1 | 8.5 | 178.6 | 55.0 |
| S15 | 750.0 | 411.2 | 255.0 | 155.0 | 34.8 | 26.9 | 194.5 | 8.5 | 186.0 | 72.9 |
| S16 | 70.0 | 411.2 | 295.0 | 155.0 | 34.8 | 31.1 | 190.3 | 8.5 | 181.8 | 61.6 |
| S17 | 55.0 | 411.2 | 275.0 | 155.0 | 34.8 | 29.0 | 192.4 | 8.5 | 183.9 | 66.9 |
| S18 | 130.0 | 411.2 | 255.0 | 155.0 | 34.8 | 26.9 | 194.5 | 8.5 | 186.0 | 72.9 |
| S19 | 55.0 | 414.4 | 200.0 | 155.0 | 34.8 | 21.1 | 203.5 | 101.9 | 101.6 | 50.8 |
| S20 | 20.0 | 414.4 | 250.0 | 155.0 | 34.8 | 26.4 | 198.2 | 101.9 | 96.3 | 38.5 |
| S21 | 45.0 | 414.4 | 235.0 | 155.0 | 34.8 | 24.8 | 199.8 | 101.9 | 97.9 | 41.7 |
| A1A | 134.0 | 411.8 | 180.0 | 155.0 | 34.8 | 19.0 | 203.0 | 80.2 | 122.8 | 68.2 |
| A1B | 321.0 | 411.8 | 180.0 | 155.0 | 34.8 | 19.0 | 203.0 | 80.2 | 122.8 | 68.2 |
| A1C | 80.0 | 411.8 | 180.0 | 155.0 | 34.8 | 19.0 | 203.0 | 80.2 | 122.8 | 68.2 |
| A2A | 286.0 | 411.8 | 205.0 | 155.0 | 34.8 | 21.6 | 200.4 | 80.2 | 120.2 | 58.6 |
| A2B | 286.0 | 411.8 | 205.0 | 155.0 | 34.8 | 21.6 | 200.4 | 80.2 | 120.2 | 58.6 |
| A2C | 143.0 | 411.8 | 205.0 | 155.0 | 34.8 | 21.6 | 200.4 | 80.2 | 120.2 | 58.6 |
| A3A | 384.0 | 411.8 | 205.0 | 155.0 | 34.8 | 21.6 | 200.4 | 80.2 | 120.2 | 58.6 |
| A3B | 256.0 | 411.8 | 205.0 | 155.0 | 34.8 | 21.6 | 200.4 | 80.2 | 120.2 | 58.6 |
| M1 | 120.0 | 418.0 | 150.0 | 155.0 | 34.8 | 15.8 | 212.4 | 162.5 | 49.9 | 33.2 |
| M2 | 90.0 | 418.0 | 130.0 | 155.0 | 34.8 | 13.7 | 214.5 | 162.5 | 52.0 | 40.0 |

Table 2-26 DIRECT BENEFITS OF IRRIGATION : FUTURE CONDITIONS

| SITE | AREA HAx1000 | IRF NT $/HA | WATER MM | IRR SYS $/HA | DRNGE $/HA | ENERGY $/HA | IRR NET $/HA | DRY NET $/HA | NET O-F BNFTS $/HA | NET BNFTS $/DAM3 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 200.0 | 445.4 | 180.0 | 155.0 | 34.8 | 18.9 | 236.7 | 215.4 | 21.3 | 11.8 |
| S2 | 140.0 | 445.4 | 200.0 | 155.0 | 34.8 | 21.0 | 234.6 | 215.4 | 19.2 | 9.6 |
| S3 | 135.0 | 445.4 | 205.0 | 155.0 | 34.8 | 21.6 | 234.0 | 138.3 | 95.7 | 46.7 |
| S4 | 290.0 | 445.4 | 200.0 | 155.0 | 34.8 | 21.0 | 234.6 | 138.3 | 96.3 | 48.1 |
| S5 | 95.0 | 445.4 | 240.0 | 155.0 | 34.8 | 25.3 | 230.3 | 146.0 | 84.3 | 35.1 |
| S6 | 45.0 | 445.4 | 250.0 | 155.0 | 34.8 | 26.3 | 229.3 | 138.3 | 91.0 | 36.4 |
| S7 | 55.0 | 445.4 | 135.0 | 155.0 | 34.8 | 14.2 | 241.4 | 214.8 | 26.6 | 19.7 |
| S8 | 115.0 | 445.4 | 200.0 | 155.0 | 34.8 | 21.0 | 234.6 | 146.0 | 88.6 | 44.3 |
| S9 | 130.0 | 445.4 | 135.0 | 155.0 | 34.8 | 14.2 | 241.4 | 214.8 | 26.6 | 19.7 |
| S10 | 10.0 | 445.4 | 135.0 | 155.0 | 34.8 | 14.2 | 241.4 | 214.8 | 26.6 | 19.7 |
| S11 | 105.0 | 445.4 | 240.0 | 155.0 | 34.8 | 25.3 | 230.3 | 146.0 | 84.3 | 35.1 |
| S12 | 45.0 | 445.4 | 225.0 | 155.0 | 34.8 | 23.7 | 231.9 | 146.0 | 85.9 | 38.2 |
| S13 | 50.0 | 445.4 | 225.0 | 155.0 | 34.8 | 23.7 | 231.9 | 146.0 | 85.9 | 38.2 |
| S14 | 45.0 | 442.8 | 325.0 | 155.0 | 34.8 | 34.2 | 218.8 | 24.5 | 194.3 | 59.8 |
| S15 | 750.0 | 442.8 | 255.0 | 155.0 | 34.8 | 26.8 | 226.2 | 24.5 | 201.7 | 79.1 |
| S16 | 70.0 | 442.8 | 295.0 | 155.0 | 34.8 | 31.0 | 222.0 | 24.5 | 197.5 | 66.9 |
| S17 | 55.0 | 442.8 | 275.0 | 155.0 | 34.8 | 28.9 | 224.1 | 24.5 | 199.6 | 72.6 |
| S18 | 130.0 | 442.8 | 255.0 | 155.0 | 34.8 | 26.8 | 226.2 | 24.5 | 201.7 | 79.1 |
| S19 | 55.0 | 450.4 | 200.0 | 155.0 | 34.8 | 21.0 | 239.6 | 223.4 | 16.2 | 8.1 |
| S20 | 20.0 | 450.4 | 250.0 | 155.0 | 34.8 | 26.3 | 234.3 | 223.4 | 10.9 | 4.4 |
| S21 | 45.0 | 450.4 | 235.0 | 155.0 | 34.8 | 24.7 | 235.9 | 223.4 | 12.5 | 5.3 |
| A1A | 134.0 | 452.9 | 180.0 | 155.0 | 34.8 | 18.9 | 244.2 | 174.9 | 69.3 | 38.5 |
| A1B | 321.0 | 452.9 | 180.0 | 155.0 | 34.8 | 18.9 | 244.2 | 174.9 | 69.3 | 38.5 |
| A1C | 80.0 | 452.9 | 180.0 | 155.0 | 34.8 | 18.9 | 244.2 | 174.9 | 69.3 | 38.5 |
| A2A | 286.0 | 452.9 | 205.0 | 155.0 | 34.8 | 21.6 | 241.5 | 174.9 | 66.6 | 32.5 |
| A2B | 286.0 | 452.9 | 205.0 | 155.0 | 34.8 | 21.6 | 241.5 | 174.9 | 66.6 | 32.5 |
| A2C | 143.0 | 452.9 | 205.0 | 155.0 | 34.8 | 21.6 | 241.5 | 174.9 | 66.6 | 32.5 |
| A3A | 384.0 | 452.9 | 205.0 | 155.0 | 34.8 | 21.6 | 241.5 | 174.9 | 66.6 | 32.5 |
| A3B | 256.0 | 452.9 | 205.0 | 155.0 | 34.8 | 21.6 | 241.5 | 174.9 | 66.6 | 32.5 |
| M1 | 120.0 | 456.7 | 150.0 | 155.0 | 34.8 | 15.8 | 251.1 | 288.6 | -37.5 | -25.0 |
| M2 | 90.0 | 456.7 | 130.0 | 155.0 | 34.8 | 13.7 | 253.2 | 288.6 | -35.4 | -27.2 |

NOTES:
1) IRF NT is irrigated crop return (i.e. Table 2-23) in $/Ha
2) IRR SYS is the annual cost of the irrigation system in $/Ha
3) DRNGE is the annual cost of the drainage works in $/Ha
4) ENERGY is annual on-farm energy costs of irrigation in $/Ha
5) IRR NET is net irrigated crop return in $/Ha
6) DRY NET is dryland crop return (i.e. Table 2-22) in $/Ha
7) NET O-F BNFTS are the on-farm benefits of irrigation (i.e. IRR NET - DRY NET ) in $/Ha

Table 2-27 DIRECT BENEFITS OF IRRIGATION : PRESENT CONDITIONS
CROP PRICE INCREASE OF 25%

| SITE | AREA HAx1000 | IRF NT $/HA | WATER MM | IRR SYS $/HA | DRNGE $/HA | ENERGY $/HA | IRR NET $/HA | DRY NET $/HA | NET O-F BNFTS $/HA | NET BNFTS $/DAM3 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 200.0 | 573.2 | 180.0 | 155.0 | 34.8 | 18.9 | 364.5 | 161.8 | 202.7 | 112.59 |
| S2 | 140.0 | 573.2 | 200.0 | 155.0 | 34.8 | 21.0 | 362.4 | 161.8 | 200.6 | 100.28 |
| S3 | 135.0 | 573.2 | 205.0 | 155.0 | 34.8 | 21.6 | 361.8 | 75.3 | 286.5 | 139.77 |
| S4 | 290.0 | 573.2 | 200.0 | 155.0 | 34.8 | 21.0 | 362.4 | 75.3 | 287.1 | 143.53 |
| S5 | 95.0 | 579.2 | 240.0 | 155.0 | 34.8 | 25.3 | 364.1 | 75.4 | 288.7 | 120.31 |
| S6 | 45.0 | 573.2 | 250.0 | 155.0 | 34.8 | 26.3 | 357.1 | 75.3 | 281.8 | 112.72 |
| S7 | 55.0 | 573.2 | 135.0 | 155.0 | 34.8 | 14.2 | 369.2 | 164.4 | 204.8 | 151.70 |
| S8 | 115.0 | 579.2 | 200.0 | 155.0 | 34.8 | 21.0 | 368.4 | 75.4 | 293.0 | 146.48 |
| S9 | 130.0 | 573.2 | 135.0 | 155.0 | 34.8 | 14.2 | 369.2 | 164.4 | 204.8 | 151.70 |
| S10 | 10.0 | 573.2 | 135.0 | 155.0 | 34.8 | 14.2 | 369.2 | 164.4 | 204.8 | 151.70 |
| S11 | 105.0 | 579.2 | 240.0 | 155.0 | 34.8 | 25.3 | 364.1 | 75.4 | 288.7 | 120.31 |
| S12 | 45.0 | 579.2 | 225.0 | 155.0 | 34.8 | 23.7 | 365.7 | 75.4 | 290.3 | 129.03 |
| S13 | 50.0 | 579.2 | 225.0 | 155.0 | 34.8 | 23.7 | 365.7 | 75.4 | 290.3 | 129.03 |
| S14 | 45.0 | 580.1 | 325.0 | 155.0 | 34.8 | 34.2 | 356.1 | 50.7 | 305.4 | 93.97 |
| S15 | 750.0 | 580.1 | 255.0 | 155.0 | 34.8 | 26.8 | 363.5 | 50.7 | 312.8 | 122.65 |
| S16 | 70.0 | 580.1 | 295.0 | 155.0 | 34.8 | 31.0 | 359.3 | 50.7 | 308.6 | 104.60 |
| S17 | 55.0 | 580.1 | 275.0 | 155.0 | 34.8 | 28.9 | 361.4 | 50.7 | 310.7 | 112.97 |
| S18 | 130.0 | 580.1 | 255.0 | 155.0 | 34.8 | 26.8 | 363.5 | 50.7 | 312.8 | 122.65 |
| S19 | 55.0 | 586.3 | 200.0 | 155.0 | 34.8 | 21.0 | 375.5 | 168.2 | 207.3 | 103.63 |
| S20 | 20.0 | 586.3 | 250.0 | 155.0 | 34.8 | 26.3 | 370.2 | 168.2 | 202.0 | 80.80 |
| S21 | 45.0 | 586.3 | 235.0 | 155.0 | 34.8 | 24.7 | 371.8 | 168.2 | 203.6 | 86.63 |
| A1A | 134.0 | 583.4 | 180.0 | 155.0 | 34.8 | 18.9 | 374.7 | 139.0 | 235.7 | 130.92 |
| A1B | 321.0 | 583.4 | 180.0 | 155.0 | 34.8 | 18.9 | 374.7 | 139.0 | 235.7 | 130.92 |
| A1C | 80.0 | 583.4 | 180.0 | 155.0 | 34.8 | 18.9 | 374.7 | 139.0 | 235.7 | 130.92 |
| A2A | 286.0 | 583.4 | 205.0 | 155.0 | 34.8 | 21.6 | 372.0 | 139.0 | 233.0 | 113.67 |
| A2B | 286.0 | 583.4 | 205.0 | 155.0 | 34.8 | 21.6 | 372.0 | 139.0 | 233.0 | 113.67 |
| A2C | 143.0 | 583.4 | 205.0 | 155.0 | 34.8 | 21.6 | 372.0 | 139.0 | 233.0 | 113.67 |
| A3A | 384.0 | 583.4 | 205.0 | 155.0 | 34.8 | 21.6 | 372.0 | 139.0 | 233.0 | 113.67 |
| A3B | 256.0 | 583.4 | 205.0 | 155.0 | 34.8 | 21.6 | 372.0 | 139.0 | 233.0 | 113.67 |
| M1 | 120.0 | 592.7 | 150.0 | 155.0 | 34.8 | 15.8 | 387.1 | 245.5 | 141.6 | 94.41 |
| M2 | 90.0 | 592.7 | 130.0 | 155.0 | 34.8 | 13.7 | 389.2 | 245.5 | 143.7 | 110.55 |

Table 2-28 DIRECT BENEFITS OF IRRIGATION : PRESENT CONDITION
CROP PRICE DECREASE OF 25%

| SITE | AREA HAx1000 | IRF NT $/HA | WATER MM | IRR SYS $/HA | DRNGE $/HA | ENERGY $/HA | IRR NET $/HA | DRY NET $/HA | NET O-F BNFTS $/HA | NET BNFTS $/DAM3 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 200.0 | 237.8 | 180.0 | 155.0 | 34.8 | 18.9 | 29.1 | 36.3 | -7.2 | -4.0 |
| S2 | 140.0 | 237.8 | 200.0 | 155.0 | 34.8 | 21.0 | 27.0 | 36.3 | -9.3 | -4.7 |
| S3 | 135.0 | 237.8 | 205.0 | 155.0 | 34.8 | 21.6 | 26.4 | 1.8 | 24.6 | 12.0 |
| S4 | 290.0 | 237.8 | 200.0 | 155.0 | 34.8 | 21.0 | 27.0 | 1.8 | 25.2 | 12.6 |
| S5 | 95.0 | 240.2 | 240.0 | 155.0 | 34.8 | 25.3 | 25.1 | 1.2 | 23.9 | 10.0 |
| S6 | 45.0 | 237.8 | 250.0 | 155.0 | 34.8 | 26.3 | 21.7 | 1.8 | 19.9 | 8.0 |
| S7 | 55.0 | 237.8 | 135.0 | 155.0 | 34.8 | 14.2 | 33.8 | 36.2 | -2.4 | -1.8 |
| S8 | 115.0 | 240.2 | 200.0 | 155.0 | 34.8 | 21.0 | 29.4 | 1.2 | 28.2 | 14.1 |
| S9 | 130.0 | 237.8 | 135.0 | 155.0 | 34.8 | 14.2 | 33.8 | 36.2 | -2.4 | -1.8 |
| S10 | 10.0 | 237.8 | 135.0 | 155.0 | 34.8 | 14.2 | 33.8 | 36.2 | -2.4 | -1.8 |
| S11 | 105.0 | 240.2 | 240.0 | 155.0 | 34.8 | 25.3 | 25.1 | 1.2 | 23.9 | 10.0 |
| S12 | 45.0 | 240.2 | 225.0 | 155.0 | 34.8 | 23.7 | 26.7 | 1.2 | 25.5 | 11.3 |
| S13 | 50.0 | 240.2 | 225.0 | 155.0 | 34.8 | 23.7 | 26.7 | 1.2 | 25.5 | 11.3 |
| S14 | 45.0 | 242.3 | 325.0 | 155.0 | 34.8 | 34.2 | 18.3 | .0 | 18.3 | 5.6 |
| S15 | 750.0 | 242.3 | 255.0 | 155.0 | 34.8 | 26.8 | 25.7 | .0 | 25.7 | 10.1 |
| S16 | 70.0 | 242.3 | 295.0 | 155.0 | 34.8 | 31.0 | 21.5 | .0 | 21.5 | 7.3 |
| S17 | 55.0 | 242.3 | 275.0 | 155.0 | 34.8 | 28.9 | 23.6 | .0 | 23.6 | 8.6 |
| S18 | 130.0 | 242.3 | 255.0 | 155.0 | 34.8 | 26.8 | 25.7 | .0 | 25.7 | 10.1 |
| S19 | 55.0 | 242.4 | 200.0 | 155.0 | 34.8 | 21.0 | 31.6 | 37.2 | -5.6 | -2.8 |
| S20 | 20.0 | 242.4 | 250.0 | 155.0 | 34.8 | 26.3 | 26.3 | 37.2 | -10.9 | -4.4 |
| S21 | 45.0 | 242.4 | 235.0 | 155.0 | 34.8 | 24.7 | 27.9 | 37.2 | -9.3 | -4.0 |
| A1A | 134.0 | 240.2 | 180.0 | 155.0 | 34.8 | 18.9 | 31.5 | 26.3 | 5.2 | 2.9 |
| A1B | 321.0 | 240.2 | 180.0 | 155.0 | 34.8 | 18.9 | 31.5 | 26.3 | 5.2 | 2.9 |
| A1C | 80.0 | 240.2 | 180.0 | 155.0 | 34.8 | 18.9 | 31.5 | 26.3 | 5.2 | 2.9 |
| A2A | 286.0 | 240.2 | 205.0 | 155.0 | 34.8 | 21.6 | 28.8 | 26.3 | 2.5 | 1.2 |
| A2B | 286.0 | 240.2 | 205.0 | 155.0 | 34.8 | 21.6 | 28.8 | 26.3 | 2.5 | 1.2 |
| A2C | 143.0 | 240.2 | 205.0 | 155.0 | 34.8 | 21.6 | 28.8 | 26.3 | 2.5 | 1.2 |
| A3A | 384.0 | 240.2 | 205.0 | 155.0 | 34.8 | 21.6 | 28.8 | 26.3 | 2.5 | 1.2 |
| A3B | 256.0 | 240.2 | 205.0 | 155.0 | 34.8 | 21.6 | 28.8 | 26.3 | 2.5 | 1.2 |
| M1 | 120.0 | 243.4 | 150.0 | 155.0 | 34.8 | 15.8 | 37.8 | 80.5 | -42.7 | -28.5 |
| M2 | 90.0 | 243.4 | 130.0 | 155.0 | 34.8 | 13.7 | 39.9 | 80.5 | -40.6 | -31.2 |

NOTES:
1) IRF NT is irrigated crop return (i.e. Table 2-23) in $/Ha
2) IRR SYS is the annual cost of the irrigation system in $/Ha
3) DRNGE is the annual cost of the drainage works im $/Ha
4) ENERGY is annual on-farm energy costs of irrigation in $/Ha
5) IRR NET is net irrigated crop return in $/Ha
6) DRY NET is dryland crop return (i.e. Table 2-22) in $/Ha
7) NET O-F BNFTS are the on-farm benefits of irrigation (i.e. IRR NET - DRY NET ) in $/Ha

Table 2-29 DIRECT BENEFITS OF IRRIGATION : PRESENT CONDITIONS
ALTERNATE DRAINAGE SCHEME

| SITE | AREA HAx1000 | IRF NT $/HA | WATER MM | IRR SYS $/HA | DRNGE $/HA | ENERGY $/HA | IRR NET $/HA | DRY NET $/HA | NET O-F BNFTS $/HA | NET BNFTS $/DAM3 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 200.0 | 405.5 | 180.0 | 155.0 | 47.1 | 19.0 | 184.4 | 97.7 | 86.7 | 48.2 |
| S2 | 140.0 | 405.5 | 200.0 | 155.0 | 47.1 | 21.1 | 182.3 | 97.7 | 84.6 | 42.3 |
| S3 | 135.0 | 405.5 | 205.0 | 155.0 | 47.1 | 21.6 | 181.8 | 28.7 | 153.1 | 74.7 |
| S4 | 290.0 | 405.5 | 200.0 | 155.0 | 47.1 | 21.1 | 182.3 | 28.7 | 153.6 | 76.8 |
| S5 | 95.0 | 409.7 | 240.0 | 155.0 | 47.1 | 25.3 | 182.3 | 27.8 | 154.5 | 64.4 |
| S6 | 45.0 | 405.5 | 250.0 | 155.0 | 47.1 | 26.4 | 177.0 | 28.7 | 148.3 | 59.3 |
| S7 | 55.0 | 405.5 | 135.0 | 155.0 | 47.1 | 14.3 | 189.2 | 99.3 | 89.9 | 66.6 |
| S8 | 115.0 | 409.7 | 200.0 | 155.0 | 47.1 | 21.1 | 186.5 | 27.8 | 158.7 | 79.3 |
| S9 | 130.0 | 405.5 | 135.0 | 155.0 | 47.1 | 14.3 | 189.2 | 99.3 | 89.9 | 66.6 |
| S10 | 10.0 | 405.5 | 135.0 | 155.0 | 47.1 | 14.3 | 189.2 | 99.3 | 89.9 | 66.6 |
| S11 | 105.0 | 409.7 | 240.0 | 155.0 | 47.1 | 25.3 | 182.3 | 27.8 | 154.5 | 64.4 |
| S12 | 45.0 | 409.7 | 225.0 | 155.0 | 47.1 | 23.8 | 183.9 | 27.8 | 156.1 | 69.4 |
| S13 | 50.0 | 409.7 | 225.0 | 155.0 | 47.1 | 23.8 | 183.9 | 27.8 | 156.1 | 69.4 |
| S14 | 45.0 | 411.2 | 325.0 | 155.0 | 47.1 | 34.3 | 174.8 | 8.5 | 166.3 | 51.2 |
| S15 | 750.0 | 411.2 | 255.0 | 155.0 | 47.1 | 26.9 | 182.2 | 8.5 | 173.7 | 68.1 |
| S16 | 70.0 | 411.2 | 295.0 | 155.0 | 47.1 | 31.1 | 178.0 | 8.5 | 169.5 | 57.4 |
| S17 | 55.0 | 411.2 | 275.0 | 155.0 | 47.1 | 29.0 | 180.1 | 8.5 | 171.6 | 62.4 |
| S18 | 130.0 | 411.2 | 255.0 | 155.0 | 47.1 | 26.9 | 182.2 | 8.5 | 173.7 | 68.1 |
| S19 | 55.0 | 414.4 | 200.0 | 155.0 | 47.1 | 21.1 | 191.2 | 101.9 | 89.3 | 44.6 |
| S20 | 20.0 | 414.4 | 250.0 | 155.0 | 47.1 | 26.4 | 185.9 | 101.9 | 84.0 | 33.6 |
| S21 | 45.0 | 414.4 | 235.0 | 155.0 | 47.1 | 24.8 | 187.5 | 101.9 | 85.6 | 36.4 |
| A1A | 134.0 | 411.8 | 180.0 | 155.0 | 47.1 | 19.0 | 190.7 | 80.2 | 110.5 | 61.4 |
| A1B | 321.0 | 411.8 | 180.0 | 155.0 | 47.1 | 19.0 | 190.7 | 80.2 | 110.5 | 61.4 |
| A1C | 80.0 | 411.8 | 180.0 | 155.0 | 47.1 | 19.0 | 190.7 | 80.2 | 110.5 | 61.4 |
| A2A | 286.0 | 411.8 | 205.0 | 155.0 | 47.1 | 21.6 | 188.1 | 80.2 | 107.9 | 52.6 |
| A2B | 286.0 | 411.8 | 205.0 | 155.0 | 47.1 | 21.6 | 188.1 | 80.2 | 107.9 | 52.6 |
| A2C | 143.0 | 411.8 | 205.0 | 155.0 | 47.1 | 21.6 | 188.1 | 80.2 | 107.9 | 52.6 |
| A3A | 384.0 | 411.8 | 205.0 | 155.0 | 47.1 | 21.6 | 188.1 | 80.2 | 107.9 | 52.6 |
| A3B | 256.0 | 411.8 | 205.0 | 155.0 | 47.1 | 21.6 | 188.1 | 80.2 | 107.9 | 52.6 |
| M1 | 120.0 | 418.0 | 150.0 | 155.0 | 47.1 | 15.8 | 200.1 | 162.5 | 37.6 | 25.0 |
| M2 | 90.0 | 418.0 | 130.0 | 155.0 | 47.1 | 13.7 | 202.2 | 162.5 | 39.7 | 30.5 |

Table 2-30 DIRECT BENEFITS OF IRRIGATION : PRESENT CONDITIONS
ENERGY COST INCREASE OF 50%

| SITE | AREA HAx1000 | IRF NT $/HA | WATER MM | IRR SYS $/HA | DRNGE $/HA | ENERGY $/HA | IRR NET $/HA | DRY NET $/HA | NET O-F BNFTS $/HA | NET BNFTS $/DAM3 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 200.0 | 405.5 | 180.0 | 155.0 | 34.8 | 37.9 | 177.8 | 97.7 | 80.1 | 44.5 |
| S2 | 140.0 | 405.5 | 200.0 | 155.0 | 34.8 | 42.1 | 173.6 | 97.7 | 75.9 | 38.0 |
| S3 | 135.0 | 405.5 | 205.0 | 155.0 | 34.8 | 43.1 | 172.6 | 28.7 | 143.9 | 70.2 |
| S4 | 290.0 | 405.5 | 200.0 | 155.0 | 34.8 | 42.1 | 173.6 | 28.7 | 144.9 | 72.5 |
| S5 | 95.0 | 409.7 | 240.0 | 155.0 | 34.8 | 50.5 | 169.4 | 27.8 | 141.6 | 59.0 |
| S6 | 45.0 | 405.5 | 250.0 | 155.0 | 34.8 | 52.6 | 163.1 | 28.7 | 134.4 | 53.8 |
| S7 | 55.0 | 405.5 | 135.0 | 155.0 | 34.8 | 28.4 | 187.3 | 99.3 | 88.0 | 65.2 |
| S8 | 115.0 | 409.7 | 200.0 | 155.0 | 34.8 | 42.1 | 177.8 | 27.8 | 150.0 | 75.0 |
| S9 | 130.0 | 405.5 | 135.0 | 155.0 | 34.8 | 28.4 | 187.3 | 99.3 | 88.0 | 65.2 |
| S10 | 10.0 | 405.5 | 135.0 | 155.0 | 34.8 | 28.4 | 187.3 | 99.3 | 88.0 | 65.2 |
| S11 | 105.0 | 409.7 | 240.0 | 155.0 | 34.8 | 50.5 | 169.4 | 27.8 | 141.6 | 59.0 |
| S12 | 45.0 | 409.7 | 225.0 | 155.0 | 34.8 | 47.4 | 172.5 | 27.8 | 144.7 | 64.3 |
| S13 | 50.0 | 409.7 | 225.0 | 155.0 | 34.8 | 47.4 | 172.5 | 27.8 | 144.7 | 64.3 |
| S14 | 45.0 | 411.2 | 325.0 | 155.0 | 34.8 | 68.4 | 153.0 | 8.5 | 144.5 | 44.5 |
| S15 | 750.0 | 411.2 | 255.0 | 155.0 | 34.8 | 53.7 | 167.7 | 8.5 | 159.2 | 62.4 |
| S16 | 70.0 | 411.2 | 295.0 | 155.0 | 34.8 | 62.1 | 159.3 | 8.5 | 150.8 | 51.1 |
| S17 | 55.0 | 411.2 | 275.0 | 155.0 | 34.8 | 57.9 | 163.5 | 8.5 | 155.0 | 56.4 |
| S18 | 130.0 | 411.2 | 255.0 | 155.0 | 34.8 | 53.7 | 167.7 | 8.5 | 159.2 | 62.4 |
| S19 | 55.0 | 414.4 | 200.0 | 155.0 | 34.8 | 42.1 | 182.5 | 101.9 | 80.6 | 40.3 |
| S20 | 20.0 | 414.4 | 250.0 | 155.0 | 34.8 | 52.6 | 172.0 | 101.9 | 70.1 | 28.0 |
| S21 | 45.0 | 414.4 | 235.0 | 155.0 | 34.8 | 49.5 | 175.1 | 101.9 | 73.2 | 31.2 |
| A1A | 134.0 | 411.8 | 180.0 | 155.0 | 34.8 | 37.9 | 184.1 | 80.2 | 103.9 | 57.7 |
| A1B | 321.0 | 411.8 | 180.0 | 155.0 | 34.8 | 37.9 | 184.1 | 80.2 | 103.9 | 57.7 |
| A1C | 80.0 | 411.8 | 180.0 | 155.0 | 34.8 | 37.9 | 184.1 | 80.2 | 103.9 | 57.7 |
| A2A | 286.0 | 411.8 | 205.0 | 155.0 | 34.8 | 43.1 | 178.9 | 80.2 | 98.7 | 48.1 |
| A2B | 286.0 | 411.8 | 205.0 | 155.0 | 34.8 | 43.1 | 178.9 | 80.2 | 98.7 | 48.1 |
| A2C | 143.0 | 411.8 | 205.0 | 155.0 | 34.8 | 43.1 | 178.9 | 80.2 | 98.7 | 48.1 |
| A3A | 384.0 | 411.8 | 205.0 | 155.0 | 34.8 | 43.1 | 178.9 | 80.2 | 98.7 | 48.1 |
| A3B | 256.0 | 411.8 | 205.0 | 155.0 | 34.8 | 43.1 | 178.9 | 80.2 | 98.7 | 48.1 |
| M1 | 120.0 | 418.0 | 150.0 | 155.0 | 34.8 | 31.6 | 196.6 | 162.5 | 34.1 | 22.8 |
| M2 | 90.0 | 418.0 | 130.0 | 155.0 | 34.8 | 27.4 | 200.8 | 162.5 | 38.3 | 29.5 |

NOTES:
1) IRF NT is irrigated crop return (i.e. Table 2-23) in $/Ha
2) IRR SYS is the annual cost of the irrigation system in $/Ha
3) DRNGE is the annual cost of the drainage works im $/Ha
4) ENERGY is annual on-farm energy costs of irrigation in $/Ha
5) IRR NET is net irrigated crop return in $/Ha
6) DRY NET is dryland crop return (i.e. Table 2-22) in $/Ha
7) NET O-F BNFTS are the on-farm benefits of irrigation (i.e. IRR NET - DRY NET ) in $/Ha

Table 2-31 DIRECT BENEFITS OF IRRIGATION : PRESENT CONDITIONS
INTEREST RATE OF 2%

| SITE | AREA HAx1000 | IRF NT $/HA | WATER MM | IRR SYS $/HA | DRNGE $/HA | ENERGY $/HA | IRR NET $/HA | DRY NET $/HA | NET O-F BNFTS $/HA | NET BNFTS $/DAM3 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 200.0 | 405.5 | 180.0 | 127.4 | 30.0 | 19.0 | 229.1 | 97.7 | 131.4 | 73.0 |
| S2 | 140.0 | 405.5 | 200.0 | 127.4 | 30.0 | 21.1 | 227.0 | 97.7 | 129.3 | 64.6 |
| S3 | 135.0 | 405.5 | 205.0 | 127.4 | 30.0 | 21.6 | 226.5 | 28.7 | 197.8 | 96.5 |
| S4 | 290.0 | 405.5 | 200.0 | 127.4 | 30.0 | 21.1 | 227.0 | 28.7 | 198.3 | 99.1 |
| S5 | 95.0 | 409.7 | 240.0 | 127.4 | 30.0 | 25.3 | 227.0 | 27.8 | 199.2 | 83.0 |
| S6 | 45.0 | 405.5 | 250.0 | 127.4 | 30.0 | 26.4 | 221.7 | 28.7 | 193.0 | 77.2 |
| S7 | 55.0 | 405.5 | 135.0 | 127.4 | 30.0 | 14.3 | 233.9 | 99.3 | 134.6 | 99.7 |
| S8 | 115.0 | 409.7 | 200.0 | 127.4 | 30.0 | 21.1 | 231.2 | 27.8 | 203.4 | 101.7 |
| S9 | 130.0 | 405.5 | 135.0 | 127.4 | 30.0 | 14.3 | 233.9 | 99.3 | 134.6 | 99.7 |
| S10 | 10.0 | 405.5 | 135.0 | 127.4 | 30.0 | 14.3 | 233.9 | 99.3 | 134.6 | 99.7 |
| S11 | 105.0 | 409.7 | 240.0 | 127.4 | 30.0 | 25.3 | 227.0 | 27.8 | 199.2 | 83.0 |
| S12 | 45.0 | 409.7 | 225.0 | 127.4 | 30.0 | 23.8 | 228.6 | 27.8 | 200.8 | 89.2 |
| S13 | 50.0 | 409.7 | 225.0 | 127.4 | 30.0 | 23.8 | 228.6 | 27.8 | 200.8 | 89.2 |
| S14 | 45.0 | 411.2 | 325.0 | 127.4 | 30.0 | 34.3 | 219.5 | 8.5 | 211.0 | 64.9 |
| S15 | 750.0 | 411.2 | 255.0 | 127.4 | 30.0 | 26.9 | 226.9 | 8.5 | 218.4 | 85.6 |
| S16 | 70.0 | 411.2 | 295.0 | 127.4 | 30.0 | 31.1 | 222.7 | 8.5 | 214.2 | 72.6 |
| S17 | 55.0 | 411.2 | 275.0 | 127.4 | 30.0 | 29.0 | 224.8 | 8.5 | 216.3 | 78.6 |
| S18 | 130.0 | 411.2 | 255.0 | 127.4 | 30.0 | 26.9 | 226.9 | 8.5 | 218.4 | 85.6 |
| S19 | 55.0 | 414.4 | 200.0 | 127.4 | 30.0 | 21.1 | 235.9 | 101.9 | 134.0 | 67.0 |
| S20 | 20.0 | 414.4 | 250.0 | 127.4 | 30.0 | 26.4 | 230.6 | 101.9 | 128.7 | 51.5 |
| S21 | 45.0 | 414.4 | 235.0 | 127.4 | 30.0 | 24.8 | 232.2 | 101.9 | 130.3 | 55.4 |
| A1A | 134.0 | 411.8 | 180.0 | 127.4 | 30.0 | 19.0 | 235.4 | 80.2 | 155.2 | 86.2 |
| A1B | 321.0 | 411.8 | 180.0 | 127.4 | 30.0 | 19.0 | 235.4 | 80.2 | 155.2 | 86.2 |
| A1C | 80.0 | 411.8 | 180.0 | 127.4 | 30.0 | 19.0 | 235.4 | 80.2 | 155.2 | 86.2 |
| A2A | 286.0 | 411.8 | 205.0 | 127.4 | 30.0 | 21.6 | 232.8 | 80.2 | 152.6 | 74.4 |
| A2B | 286.0 | 411.8 | 205.0 | 127.4 | 30.0 | 21.6 | 232.8 | 80.2 | 152.6 | 74.4 |
| A2C | 143.0 | 411.8 | 205.0 | 127.4 | 30.0 | 21.6 | 232.8 | 80.2 | 152.6 | 74.4 |
| A3A | 384.0 | 411.8 | 205.0 | 127.4 | 30.0 | 21.6 | 232.8 | 80.2 | 152.6 | 74.4 |
| A3B | 256.0 | 411.8 | 205.0 | 127.4 | 30.0 | 21.6 | 232.8 | 80.2 | 152.6 | 74.4 |
| M1 | 120.0 | 418.0 | 150.0 | 127.4 | 30.0 | 15.8 | 244.8 | 162.5 | 82.3 | 54.8 |
| M2 | 90.0 | 418.0 | 130.0 | 127.4 | 30.0 | 13.7 | 246.9 | 162.5 | 84.4 | 64.9 |

Table 2-32 DIRECT BENEFITS OF IRRIGATION : PRESENT CONDITIONS
INTEREST RATE OF 8%

| SITE | AREA HAx1000 | IRF NT $/HA | WATER MM | IRR SYS $/HA | DRNGE $/HA | ENERGY $/HA | IRR NET $/HA | DRY NET $/HA | NET O-F BNFTS $/HA | NET BNFTS $/DAM3 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 200.0 | 405.5 | 180.0 | 210.2 | 45.5 | 19.0 | 130.8 | 97.7 | 33.1 | 18.4 |
| S2 | 140.0 | 405.5 | 200.0 | 210.2 | 45.5 | 21.1 | 128.7 | 97.7 | 31.0 | 15.5 |
| S3 | 135.0 | 405.5 | 205.0 | 210.2 | 45.5 | 21.6 | 128.2 | 28.7 | 99.5 | 48.5 |
| S4 | 290.0 | 405.5 | 200.0 | 210.2 | 45.5 | 21.1 | 128.7 | 28.7 | 100.0 | 50.0 |
| S5 | 95.0 | 409.7 | 240.0 | 210.2 | 45.5 | 25.3 | 128.7 | 27.8 | 100.9 | 42.0 |
| S6 | 45.0 | 405.5 | 250.0 | 210.2 | 45.5 | 26.4 | 123.4 | 28.7 | 94.7 | 37.9 |
| S7 | 55.0 | 405.5 | 135.0 | 210.2 | 45.5 | 14.3 | 135.6 | 99.3 | 36.3 | 26.9 |
| S8 | 115.0 | 409.7 | 200.0 | 210.2 | 45.5 | 21.1 | 132.9 | 27.8 | 105.1 | 52.5 |
| S9 | 130.0 | 405.5 | 135.0 | 210.2 | 45.5 | 14.3 | 135.6 | 99.3 | 36.3 | 26.9 |
| S10 | 10.0 | 405.5 | 135.0 | 210.2 | 45.5 | 14.3 | 135.6 | 99.3 | 36.3 | 26.9 |
| S11 | 105.0 | 409.7 | 240.0 | 210.2 | 45.5 | 25.3 | 128.7 | 27.8 | 100.9 | 42.0 |
| S12 | 45.0 | 409.7 | 225.0 | 210.2 | 45.5 | 23.8 | 130.3 | 27.8 | 102.5 | 45.5 |
| S13 | 50.0 | 409.7 | 225.0 | 210.2 | 45.5 | 23.8 | 130.3 | 27.8 | 102.5 | 45.5 |
| S14 | 45.0 | 411.2 | 325.0 | 210.2 | 45.5 | 34.3 | 121.2 | 8.5 | 112.7 | 34.7 |
| S15 | 750.0 | 411.2 | 255.0 | 210.2 | 45.5 | 26.9 | 128.6 | 8.5 | 120.1 | 47.1 |
| S16 | 70.0 | 411.2 | 295.0 | 210.2 | 45.5 | 31.1 | 124.4 | 8.5 | 115.9 | 39.3 |
| S17 | 55.0 | 411.2 | 275.0 | 210.2 | 45.5 | 29.0 | 126.5 | 8.5 | 118.0 | 42.9 |
| S18 | 130.0 | 411.2 | 255.0 | 210.2 | 45.5 | 26.9 | 128.6 | 8.5 | 120.1 | 47.1 |
| S19 | 55.0 | 414.4 | 200.0 | 210.2 | 45.5 | 21.1 | 137.6 | 101.9 | 35.7 | 17.8 |
| S20 | 20.0 | 414.4 | 250.0 | 210.2 | 45.5 | 26.4 | 132.3 | 101.9 | 30.4 | 12.2 |
| S21 | 45.0 | 414.4 | 235.0 | 210.2 | 45.5 | 24.8 | 133.9 | 101.9 | 32.0 | 13.6 |
| A1A | 134.0 | 411.8 | 180.0 | 210.2 | 45.5 | 19.0 | 137.1 | 80.2 | 56.9 | 31.6 |
| A1B | 321.0 | 411.8 | 180.0 | 210.2 | 45.5 | 19.0 | 137.1 | 80.2 | 56.9 | 31.6 |
| A1C | 80.0 | 411.8 | 180.0 | 210.2 | 45.5 | 19.0 | 137.1 | 80.2 | 56.9 | 31.6 |
| A2A | 286.0 | 411.8 | 205.0 | 210.2 | 45.5 | 21.6 | 134.5 | 80.2 | 54.3 | 26.5 |
| A2B | 286.0 | 411.8 | 205.0 | 210.2 | 45.5 | 21.6 | 134.5 | 80.2 | 54.3 | 26.5 |
| A2C | 143.0 | 411.8 | 205.0 | 210.2 | 45.5 | 21.6 | 134.5 | 80.2 | 54.3 | 26.5 |
| A3A | 384.0 | 411.8 | 205.0 | 210.2 | 45.5 | 21.6 | 134.5 | 80.2 | 54.3 | 26.5 |
| A3B | 256.0 | 411.8 | 205.0 | 210.2 | 45.5 | 21.6 | 134.5 | 80.2 | 54.3 | 26.5 |
| M1 | 120.0 | 418.0 | 150.0 | 210.2 | 45.5 | 15.8 | 146.5 | 162.5 | -16.0 | -10.7 |
| M2 | 90.0 | 418.0 | 130.0 | 210.2 | 45.5 | 13.7 | 148.6 | 162.5 | -13.9 | -10.7 |

NOTES:
1) IRF NT is irrigated crop return (i.e. Table 2-23) in $/Ha
2) IRR SYS is the annual cost of the irrigation system in $/Ha
3) DRNGE is the annual cost of the drainage works im $/Ha
4) ENERGY is annual on-farm energy costs of irrigation in $/Ha
5) IRR NET is net irrigated crop return in $/Ha
6) DRY NET is dryland crop return (i.e. Table 2-22) in $/Ha
7) NET O-F BNFTS are the on-farm benefits of irrigation

# CHAPTER 3 WATER RESOURCES OF THE PRAIRIES

## 3.1 INTRODUCTION

It is apparent that development of the irrigable areas identified in Chapter 2 is dependent upon an adequate supply of good quality water throughout the growing season. To determine the amount of water available to each of the proposed developments, the study examined the existing water sources, the quantity of water available, and the existing and potential water uses on the prairies.

## 3.2 GROUNDWATER RESOURCES

The utilization of groundwater sources to supply the demands of the proposed irrigation developments was not really considered by this study, since previous groundwater studies have indicated that the majority of prairie groundwater aquifers are unsuitable for large scale irrigation because of their chemical composition and limited yield [68]. It is quite possible that groundwater could be blended with suitable surface water for irrigation, or could be used to supplement surface water sources for other water users such as industry or municipal waste dilution, thus increasing the amount of good quality water available for irrigation. The potential of the prairie groundwater resources should be examined in greater detail in a more rigorous study of the available water resources of the prairies, but was deemed to be unjustifiable for a study of this nature, and thus all of the water uses examined in this study were assumed to be satisfied by surface water flows.

## 3.3 SURFACE WATER RESOURCES

As was briefly discussed in Chapter 1 of the report, the prairies contribute very little runoff to the flows of the Saskatchewan-Nelson river basin, with the great majority of the flow originating in the Rocky Mountains and conveyed east through the prairie provinces in deep glacial outwash valleys. The maximum, minimum, and average annual natural flow volumes for various points throughout the prairies are presented in Table 3-1 on page 90, while Figure 6 on page 79 shows the relative locations of the various points of interest across the prairies. The average natural flow volumes for the periods of October through April, May and June, July, and August and September are also presented in Table 3-1.

## 3.4 WATER USE ON THE PRAIRIES

To determine the volume of water available for irrigation on the prairies, one must first determine the existing water uses as well as predict the future or potential water uses. This study utilized the current water uses and demands catalogued in the "Historical and Current Water Uses" study by the Prairie Provinces Water Board (PPWB) [70]. The current municipal, industrial, and agricultural water demands (including existing irrigation) upon the various river basins are presented in Table 3-2 on page 91, and were based on the data presented in the PPWB report. It must be noted that the water demands presented in the table represent the <u>net</u> water demands rather than than the total diversion requirements of the various users.

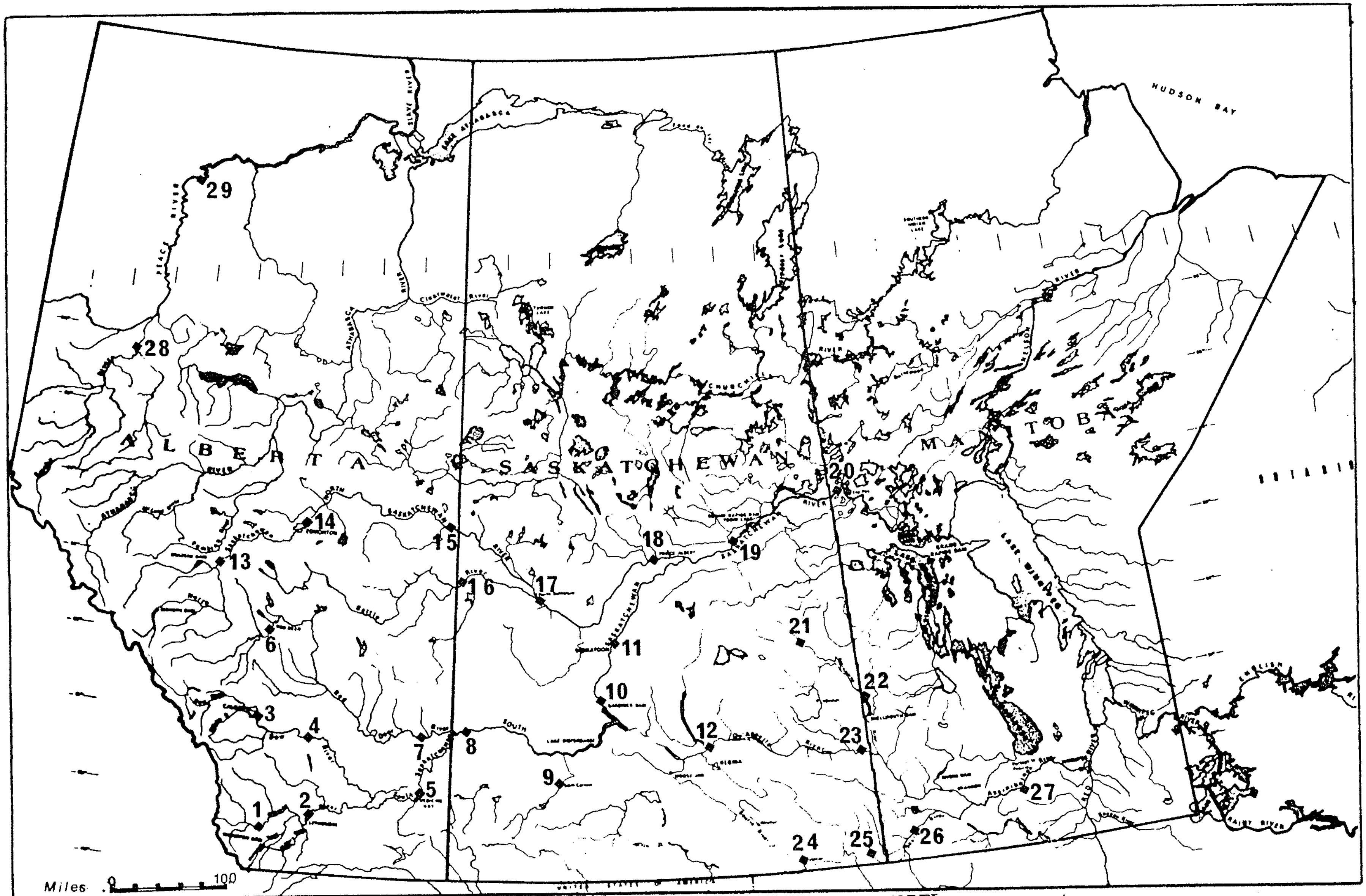


Figure 6 NODES OF THE WATER BALANCE MODEL

The evaporation losses from the prairie river network are implicit to the natural flow values for the various nodes, but do not include the losses which occur when the flows are impounded. For the purposes of this analysis, the evaporation losses for Lake Deifenbaker were incorporated into the water balance model by designating the loss as a industrial demand which must be satisfied throughout the year.

Given the 15 year period of development forecast for the proposed irrigated areas, this study based its water availability calculations on the present water uses of Table 3-2, as well using a future water use scenario which assumes that the the present municipal and industrial water uses are quadrupled [71]. These increases are expected to be due to continued population and economic growth of the prairie provinces, and were assumed to include the water requirements of any heavy oil/tarsands energy developments which may occur.

One important water use not included in Table 3-2 is the hydroelectric generation plants located throughout the prairies, since they do not consume water (barring some small evaporation losses from their forebay) but merely extract the available potential energy and convert it into electrical energy. Manitoba has a hydroelectric generating capacity of about 3750 MW (including the soon to be completed Limestone Generating Station), Alberta has 800 MW, and Saskatchewan has 855 MW of hydroelectric generating capacity [71]. Since water diverted for irrigation use is entirely consumptive except for the resulting return flow, any increase in irrigation demand will subsequently reduce the amount of energy produced at the existing and potential hydroelectric generating sites downstream of the flow withdrawal for irrigation. The economic penalty associated with these energy losses can be quite significant, however it may be argued that it may be easier to produce energy without water than it is to grow food without water. The costs of these energy losses are discussed in greater detail in Chapter 5 of the report. It should be stressed that the irrigation developments examined in this study would not eliminate this hydroelectric production but merely reduce it, since the environmental and political constraints upon the prairie water resource system would not permit such unlimited growth of water consumption for irrigation.

## 3.5 ENVIRONMENTAL CONSTRAINTS

In addition to the water demands identified in Section 3.4, there are also the water demands inherent to the prairie water resource system such as the minimum releases required to ensure the long term health and viability of the flora and fauna which inhabit the prairie river system, as well as the releases required for waste dilution and assimilation. To assess the impact that the flow withdrawals for the proposed irrigation developments would have on these other instream water users, the Montana method of evaluating the environmental impact of a flow diversion was applied to the basins. This empirical method assesses the relative impact of flow alterations on the river environment by examining the percentage of the average annual natural flow which flows during several defined time periods, thus simplifying what in reality is a tremendously complex evaluation process [72]. The desirability and suitability of the flow regime for fish, wildlife, recreation, and related resources increases as the percentage of the average annual natural flow volume which occurs in that time period increases. The flow regime relationships for the Montana method are summarized in Table 3-3 on page 92, from which we can observe that for good flow regime the October to March flows should comprise 20 percent or more of the average annual flow, and the April to September flows should comprise 40 percent or more of the annual flow volume. This implies that consuming more than 40 percent of the average annual flow will result in a fair to degrading flow regime. As will be discussed in the subsequent section, the present water apportionment agreement between the prairie provinces could see the river flows from the west into Manitoba be reduced to approximately 25 percent of the average annual natural flow volume, with Alberta and Saskatchewan consuming 75 percent of the natural flows. This implies that full apportionment of the water resources of the prairies will have a great impact on the environmental suitability and desirability of the river flows from Saskatchewan into Manitoba, and a lesser but still significant impact on the river flows from Alberta to Saskatchewan.

It must be noted that in reality the minimum acceptable flow for a given site will be dependent upon the site's hydrology as well as the aquatic community affected, however the Montana method was deemed to be adequate for assessing the impact of the flow withdrawals for this study.

## 3.6 POLITICAL CONSTRAINTS

Since the majority of the surface water flow volumes of the prairies originate in the Rocky Mountains and then proceed east through the three prairie provinces to Hudson's Bay, it is inevitable that the water resources of the prairies are closely controlled by agreements between the three prairie provinces of Alberta, Saskatchewan, and Manitoba. The terms and provisions of the Prairie Provinces Master Apportionment Agreement provides for the allocation of stream flows among the three prairie provinces [70]. The basic tenet of this agreement is that 50 percent of all flow entering or arising in a province must be released to the province downstream, thus Alberta may retain for its use 50 percent of the water that originates within its boundaries. Saskatchewan receives 50 percent of the flow arising in Alberta, but must pass on 50 percent of its share of the Alberta flow to Manitoba, in addition to sharing equally any flow arising in Saskatchewan. Although this agreement legally applies only to the Saskatchewan River, for the purposes of this study the principles of the agreement were applied to all of the interprovincial rivers to determine the flow volume available for irrigation development. In addition to the apportionment agreement, certain reaches have defined minimum releases to satisfy municipal intake and waste dilution requirements [70]. These reaches along with their respective minimum flow releases are presented in Table 3-2.

It should be noted that the present apportionment agreement does not define the time period within which the flows are to be apportioned. Currently the water flows are to be balanced on an annual basis, rather than monthly or even daily.

## 3.7 WATER BALANCE MODEL FOR THE PRAIRIES

To determine the water volumes available for irrigation of the areas identified in Chapter 2 of the report, a water balance model of the prairie river system was formulated. The model was composed of a number of points or nodes throughout the prairie river system (see Figure 6 on page 79), and was structured to examine the prairie river network for a duration of an average year, with the year being divided into four time periods of varying length. The first time period consisted of the "winter" months of October through April, during which time there are no irrigation demands upon the system. The remaining time periods were roughly based on the monthly irrigation crop water requirements during the growing season (i.e. Table 2-24), with the second time period being the moderate demand months of May and June, the third being the peak demand month of July, and the fourth period being the low demand months of August and September. While there is no theoretical difficulty to increasing either the total duration or the number of time periods examined each year, it would require substantially more input time as well as hydrologic data, with possibly little or no gain in veracity. For the purposes of this study the time frame and the time discretization presented was considered to be adequate , but a more rigorous analysis of this problem would require simulation of the prairie river network for an extended period of record while examining more time periods within each year.

The model begins with the average natural flow volumes for each node during each of the four time periods, and then determines the total net lateral inflow between each node and the node or nodes immediately upstream from it in the prairie river network. This flow data was obtained from the SNBB hydrology appendix "H file" [69], which lists the natural mean monthly discharges at numerous sites throughout the Saskatchewan-Nelson watershed. Natural flow values were used throughout the study, since the operating policies of the various reservoirs and projects which currently influence the recorded flows on the prairie river network may be altered at any time, and because use of the natural flows greatly simplified the analysis for this study. For the purposes of this study the use of the natural flow values was deemed acceptable, but a more detailed and rigorous analysis of the proposed irrigation developments would require simulation of all of the present and proposed reservoirs and water uses on the prairie river network. Given the uncertainty as to the future operation of any existing or proposed reservoir, such a model was deemed to be unjustified for a study of this nature.

The flow at a node is determined by adding the calculated lateral inflow at that node to the flows at the upstream nodes and subtracting the existing water requirements at the node of interest. The same procedure is then followed for each and every node throughout the model network, moving from the most upstream nodes in the Rocky Mountains to the most downstream nodes in Manitoba. For a given node, this procedure can be stated mathematically as :

$$QR_{jt} = QR_{kt} + LI_{jt} - (QMI_j)(KMI_t) - (QEI_j)(KIR_t)$$

where $QR_{jt}$ = river flow at node j during time t in $dam^3$

$QR_{kt}$ = river flow at nodes k immediately upstream from node j during time t in $dam^3$

$LI_{jt}$ = lateral inflow at node j during time t

= natural $QR_{jt}$ - $QR_{kt}$ (SNBB "H" file)

$QMI_j$ = existing annual net demand for municipal and industrial water use at node j

$KMI_t$ = (number of months in time period t) / (12)

$QEI_j$ = annual <u>net</u> water consumption of existing irrigation supplied from node j. (i.e. diversion - return flow)

$KIR_t$ = proportion of annual crop water requirement supplied during time t

It should be noted that implicit to this flow algorithm is the assumption that the flow volumes are able to travel instantaneously throughout the model network. Given that the duration of the time periods examined with the model range from 1 to 7 months, this assumption was deemed acceptable for a study of this nature, but the effects of routing the flows through the river network may be required for a more rigorous study on the subject.

At each point the model determines the difference between the calculated flows and the minimum release required to maintain acceptable flow regime in the channel for the other instream water users. The original intent was to use 20 percent of the average annual natural flow during the winter (October to March) months, and 40 percent during the summer months (April to September), but these values would preclude the terms of the provincial apportionment agreement, so the model used a value of only 10 percent during both the summer and winter months, which corresponds to a minimum to fair flow regime from the Montana method (see Table 3-3). At a node where the minimum release has been previously defined in Table 3-2, then the defined release was used in place of the release required to maintain a suitable flow regime. The model also determined the flow difference between the flow provided and the flow required to satisfy the provisions of the Master Apportionment agreement at those nodes adjacent to a provincial boundary.

By examining the flow surpluses (i.e. positive differences) and flow deficits throughout the system one can readily observe where additional withdrawals for irrigation of the proposed areas can be made.

The calculations for the flow volumes of the network proceed very rapidly with the aid of "spreadsheet" computer programs such as "Visicalc", "Supercalc", or "Multiplan", which solve the entire prairie network with its 29 nodes and 4 time periods in less than 2 seconds.

## 3.8 FLOW VOLUMES AVAILABLE FOR IRRIGATION

To determine the average annual volume of water surplus available for irrigation development or any other supplemental water use at each node of the network, the model was first solved using only the existing water uses and the defined minimum flow requirements. The average annual surplus flow volume indicates the maximum volume of surplus flow available for irrigation development at each node on average each year, and can only be provided by storing the surplus flows throughout the entire year. To obtain the minimum volume of water available throughout the entire irrigation period, the flow surpluses in each of time periods 2 to 4 were divided by the average irrigation requirement for each time period (see Table 2-24), with the smallest of the three volumes being the average annual draft of the node. This volume would correspond to the water volume available at the node each year on average for diverting water directly from the river, while meeting the varying irrigation demands throughout the irrigation period.

The flow surpluses at the various nodes for both the present and future water use conditions are presented in Table 3-4 on page 93, with the future conditions assuming that the present municipal and industrial water uses are quadrupled. It should be noted that the surplus flow volumes presented are cumulative throughout the network, and any upstream consumption will reduce the actual flow surplus throughout the network downstream of the consumption. The actual solutions for the water balance model are presented in Appendix A.

Based on the surplus flow volumes presented in Table 3-4, the majority of the areas identified as potential irrigation developments in Chapter 2 appear to have access to one or even two adequate sources of water. The only site which does not appear to have access to an adequate source of water is site S18, which was expected to be supplied from Swift Current Creek or the Frenchman River, which is not included in the water balance model since it drains into the Missouri - Mississippi river basin in the United States. The model indicates that the existing and potential future water use demands on Swift Current Creek do not allow any additional flow withdrawals for irrigation, while the Frenchman Creek is already fully apportioned to its existing water uses [90], and thus an adequate supply of water for S18 was not located.

Having identified the water volumes available for irrigation, and their geographic distribution throughout the prairie river network, the study examined the engineering works required to convey the water from its source to the irrigation developments. Once the relative economic desirability of the various developments are determined in Chapter 5, we shall return to the water balance model described herein and the model shall be enhanced and used to allocate flows to the various projects, as will be fully described in Chapter 6.

TABLE 3-1 NATURAL FLOW VOLUMES FOR PRAIRIE RIVERS

| SITE | NODE | NATURAL FLOW VOLUMES in $10^3$ $DAM^3$ OCT-APR FLOW | MAY&JUN FLOW | JULY FLOW | AUG&SEP FLOW | AVG. FLOW | MIN. FLOW | MAX. FLOW |
|---|---|---|---|---|---|---|---|---|
| Ft. MacLeod | 1 | 322.64 | 777.85 | 167.09 | 114.64 | 1382 | 415 | 2279 |
| Lethbridge | 2 | 837.98 | 1893.49 | 488.95 | 352.20 | 3572 | 1438 | 6661 |
| Calgary | 3 | 642.14 | 1061.49 | 626.47 | 633.19 | 2963 | 1909 | 4611 |
| Bassano | 4 | 958.18 | 1532.47 | 798.67 | 791.81 | 4081 | 2429 | 7346 |
| Medcn Hat | 5 | 1840.69 | 3343.60 | 1305.04 | 1105.02 | 7594 | 3769 | 13855 |
| Red Deer | 6 | 418.81 | 591.50 | 269.05 | 313.94 | 1593 | 658 | 3945 |
| Bindloss | 7 | 639.83 | 639.45 | 333.85 | 380.98 | 1994 | 750 | 5664 |
| Lemsford | 8 | 2511.57 | 3807.60 | 1711.04 | 1419.87 | 9450 | 4952 | 16236 |
| Swift Crnt | 9 | 65.90 | 9.98 | 1.86 | 1.34 | 79 | 0 | 114 |
| L.Diefnbkr | 10 | 2587.09 | 3811.70 | 1907.17 | 1687.51 | 9993 | 5419 | 17438 |
| Saskatoon | 11 | 2593.33 | 3675.20 | 1864.44 | 1624.66 | 9757 | 5242 | 18418 |
| Lumsden | 12 | 49.30 | 29.64 | 6.48 | 4.62 | 90 | 4 | 432 |
| Rocky Mtn | 13 | 771.48 | 959.22 | 1008.14 | 1242.42 | 3981 | 2787 | 6426 |
| Edmonton | 14 | 1335.65 | 2282.21 | 1494.42 | 1806.81 | 6919 | 4495 | 11454 |
| Deer Crk | 15 | 1451.00 | 2301.35 | 1537.83 | 1980.47 | 7270 | 4330 | 11963 |
| Battle Rvr | 16 | 65.31 | 92.56 | 18.54 | 21.22 | 197 | 48 | 949 |
| N.Battlfrd | 17 | 1622.35 | 2313.56 | 1626.60 | 2048.53 | 7611 | 4304 | 12953 |
| Prnc Albrt | 18 | 1622.35 | 2313.56 | 1626.60 | 2048.53 | 7611 | 4304 | 12953 |
| Nipawin | 19 | 4529.79 | 5884.06 | 3724.50 | 3865.32 | 18003 | 9365 | 30503 |
| The Pas | 20 | 5738.55 | 6589.12 | 4186.64 | 5530.71 | 22045 | 10762 | 37179 |
| Kamsack | 21 | 122.50 | 105.55 | 18.10 | 28.30 | 274 | 6 | 1413 |
| Russell | 22 | 169.34 | 200.84 | 47.29 | 37.38 | 454 | 60 | 1819 |
| Tantallon | 23 | 67.02 | 65.83 | 19.88 | 16.16 | 168 | 4 | 1182 |
| Estevan | 24 | 42.52 | 17.95 | 2.16 | 0.52 | 63 | 0 | 588 |
| Oxbow | 25 | 0.00 | 7.37 | 1.27 | 0.67 | 9 | 0 | 86 |
| Melita | 26 | 13.03 | 9.23 | 1.94 | 0.67 | 25 | 0 | 171 |
| Holland | 27 | 518.59 | 614.21 | 172.47 | 144.47 | 1450 | 227 | 4265 |
| Smokey Rvr | 28 | 2487.52 | 5428.17 | 1885.22 | 1947.99 | 11748 | 6064 | 25691 |
| Peace Rvr | 29 | 12187.7 | 27331.9 | 10309.0 | 8599.89 | 58428 | 40522 | 107253 |

NOTES:
1) All flow volumes are in $Dam^3 \times 10^3$ ($1\ Dam^3 = 1000\ m^3$)
2) AVG, MIN, and MAX are average, minimum. and maximum annual natural flow volumes in period of record
3) Due to a lack of information, data for node 17 duplicates that of node 18

SOURCE: SNBB Report [69]

TABLE 3-2 PRESENT WATER USES ON THE PRAIRIES

| SITE | NODE | PRESENT WATER USE IN DAM³ X 10³ MUNICIPAL | INDUSTRIAL | EXISTING IRRIGATION | MIN FLOW PER MONTH DAM³ X 10³ |
|---|---|---|---|---|---|
| FT MACLEOD | 1 | 0.00 | 0.00 | 100.00 | |
| LETHBRIDGE | 2 | 4.42 | 2.38 | 375.00 | |
| CALGARY | 3 | 29.75 | 16.91 | 0.00 | |
| BASSANO | 4 | 0.00 | 0.00 | 352.00 | |
| MEDCN HAT | 5 | 2.75 | 3.98 | 225.75 | |
| RED DEER | 6 | 2.25 | 2.74 | 330.00 | 42.10 |
| BINDLOSS | 7 | 0.00 | 0.00 | 0.00 | |
| LEMSFORD | 8 | 0.00 | 0.00 | 0.00 | |
| SWIFT CRNT | 9 | 0.17 | 1.50 | 49.05 | |
| L.DIEFBKR | 10 | 0.00 | 179.00 | 132.00 | |
| SASKATOON | 11 | 7.56 | 1.50 | 0.00 | 112.00 |
| LUMSDEN | 12 | 6.62 | 1.19 | 40.75 | |
| ROCKY MTN | 13 | 0.00 | 0.00 | 0.00 | |
| EDMONTON | 14 | 19.72 | 34.85 | 48.50 | 262.98 |
| DEER CRK | 15 | 0.00 | 0.00 | 0.00 | |
| BATTLE RVR | 16 | 0.00 | 0.00 | 0.00 | |
| N.BATTLFRD | 17 | 0.00 | 0.00 | 0.00 | |
| PRNC ALBRT | 18 | 2.04 | 1.93 | 26.80 | |
| NIPAWIN | 19 | 0.00 | 0.00 | 0.00 | 394.50 |
| THE PAS | 20 | 0.69 | 0.59 | 0.00 | 736.30 |
| KAMSACK | 21 | 0.78 | 0.01 | 5.15 | |
| RUSSEL | 22 | 0.00 | 0.00 | 0.00 | |
| TANTALLON | 23 | 0.00 | 0.00 | 0.00 | |
| ESTEVAN | 24 | 0.68 | 0.01 | 15.24 | |
| OXBOW | 25 | 0.00 | 0.00 | 0.00 | |
| MELITA | 26 | 0.12 | 0.01 | 5.15 | |
| HOLLAND | 27 | 1.91 | 0.39 | 21.42 | |
| SMOKEY RVR | 28 | 0.00 | 0.00 | 0.00 | |
| PEACE RVR | 29 | 0.00 | 0.00 | 0.00 | |
| ATHBSCA RVR | 30 | 0.00 | 0.00 | 0.00 | |

<u>NOTES:</u>
1) All flow volumes are in dam³ x 10³ (1 Dam³ = 1000 m³)
2) Min Flow are government agency defined minimum flow volumes per month.
3) Evaporation from Lake Diefenbaker termed industrial use for purposes of modeling.

<u>SOURCE:</u> PPWB [70]

TABLE 3-3 MONTANA METHOD OF FLOW EVALUATION

| Flow Description | Percentage of Average Annual Natural Flow October to March % | April to September % |
|---|---|---|
| Flushing or Maximum | 200 | 200 |
| Optimal Range | 60-100 | 60-100 |
| Outstanding | 40 | 60 |
| Excellent | 30 | 50 |
| Good | 20 | 40 |
| Fair or Degrading | 10 | 30 |
| Poor or Minimum | 10 | 10 |
| Severe Degradation | <10 | <10 |

SOURCE: [72]

TABLE 3-4 WATER VOLUME SURPLUSES: PRESENT AND FUTURE WATER USES

| SITE | NODE | PRESENT USE FL>MIN $DAM^3 10^3$ | PRESENT USE IRR FLOW $DAM^3 10^3$ | FUTURE USE FL>MIN $DAM^3 10^3$ | FUTURE USE IRR FLOW $DAM^3 10^3$ |
|---|---|---|---|---|---|
| FT MACLEOD | 1 | 867.58 | 67.83 | 867.58 | 67.83 |
| LETHBRIDGE | 2 | 2020.99 | 335.54 | 2006.47 | 333.84 |
| CALGARY | 3 | 2041.08 | 1153.33 | 1941.40 | 1141.67 |
| BASSANO | 4 | 2471.57 | 1097.25 | 2371.89 | 1085.59 |
| MEDCN HAT | 5 | 4220.44 | 1249.03 | 4091.86 | 1233.98 |
| RED DEER | 6 | 754.54 | 167.28 | 743.88 | 166.04 |
| BINDLOSS | 7 | 1276.24 | 854.87 | 1265.58 | 852.37 |
| LEMSFORD | 8 | 3295.98 | 487.96 | 3156.64 | 471.66 |
| SWIFT CRNT | 9 | 5.12 | 0.00 | 1.55 | 0.00 |
| L.DIEFBKR | 10 | 5302.89 | 1908.99 | 5176.77 | 1894.23 |
| SASKATOON | 11 | 6714.64 | 2299.43 | 6569.17 | 2282.40 |
| LUMSDEN | 12 | 16.71 | 0.00 | 0.03 | 0.00 |
| ROCKY MTN | 13 | 2786.88 | 1692.20 | 2786.88 | 1692.20 |
| EDMONTON | 14 | 3675.97 | 2647.47 | 3559.41 | 2633.83 |
| DEER CRK | 15 | 3547.97 | 1633.17 | 3431.41 | 1619.53 |
| BATTLE RVR | 16 | 138.34 | 26.22 | 138.84 | 26.22 |
| N.BATTLFRD | 17 | 5240.37 | 2957.70 | 5123.81 | 2944.05 |
| PRNC ALBRT | 18 | 5210.74 | 2930.55 | 5085.70 | 2915.92 |
| NIPAWIN | 19 | 11453.69 | 5678.80 | 11183.18 | 5647.14 |
| THE PAS | 20 | 11392.54 | 5942.61 | 11119.29 | 5910.63 |
| KAMSACK | 21 | 186.40 | 14.41 | 184.72 | 14.21 |
| RUSSEL | 22 | 312.68 | 47.40 | 311.00 | 47.01 |
| TANTALLON | 23 | 71.91 | 0.00 | 55.23 | 0.00 |
| ESTEVAN | 24 | 28.48 | 0.00 | 27.00 | 0.00 |
| OXBOW | 25 | 6.51 | 0.37 | 6.51 | 0.37 |
| MELITA | 26 | 0.00 | 0.00 | 0.00 | 0.00 |
| HOLLAND | 27 | 963.07 | 224.95 | 956.73 | 223.98 |
| SMOKEY RVR | 28 | 8224.23 | 3275.42 | 8224.23 | 3275.42 |
| PEACE RVR | 29 | 40900.03 | 18336.51 | 40900.30 | 18336.51 |

<u>NOTES:</u>
1) All flow volumes are in $Dam^3 \times 10^3$ ($1\ Dam^3 = 1000\ m^3$)
2) Present uses are total current water uses of Table 3-2.
3) Fl>MIN is flow volume greater than defined minimum
4) Future uses are present municipal and industrial water uses multiplied by factor of 4.0.
5) IRR FLOW is the maximum flow volume available for irrigation throughout the irrigation season, with the irrigation demands for each time period (ie Table 2-24) being fully satisfied.

<u>SOURCE:</u> Water Balance Model Solutions: Appendix A

# CHAPTER 4 ENGINEERING WORKS

## 4.1 INTRODUCTION

Development of the potentially irrigable areas identified in Chapter 2 is dependent upon an adequate supply of water throughout the growing season, and a satisfactory system of conveying the required water from its source to the farmers' fields. Having identified the water sources and available volumes in Chapter 3, the study determined the conveyance systems required to supply the proposed developments with water, and the expected costs of these systems.

## 4.2 DESIGN CAPACITY OF THE CONVEYANCE SYSTEM

The required capacity of a conveyance system for irrigation is determined primarily by three factors, these being the conveyance losses of the system, the crop water requirements, and the schedule for conveying the water to the farmers.

### 4.2.1 Conveyance Losses

As the water moves through the conveyance system, the loss of water through seepage and evaporation can become very significant when the areal extent of the distribution system and the length of main canals are quite large, as they are for most of the potentially irrigable areas examined in this study. Conveyance losses as great as 60 percent of the diverted water have been observed on existing projects [28], and such losses greatly increase the required capacity and cost of the conveyance system. To reduce these losses, and the potential for any salinization problems, all of the main canals and distribution systems for the proposed developments were assumed to be membrane lined throughout 75 percent of their extent, while the remaining 25 percent were assumed to be constructed in relatively impermeable clays and heavy soils.

The conveyance losses from evaporation and seepage were estimated using the empirical "Moritz" formula for clay type soils [74], from which

$$\text{Losses } (m^3/sec/km) = .0047 \left(\frac{\text{Discharge}}{\text{Flow velocity}}\right)^{0.5}$$

For the main canals and distribution laterals examined in this study, these seepage losses ranged from 0.15 percent to 0.05 percent of the total flow per kilometre of main canal, and 0.3 percent to 0.1 percent per kilometre for the smaller flows in the distribution laterals. The "Moritz" formula has been found to be reasonably accurate at the start of the irrigation season, but becomes quite conservative as the soil becomes saturated over the course of the irrigation season [74]. Since all the canals of this study were assumed to be membrane lined for 75 percent of their length, the actual losses were expected to approach the lower limit of that predicted by the "Moritz" formula. Consequently, the main canals were expected to lose about 0.05 percent of their total flow per kilometre of length, while the distribution system was expected to lose about 0.1 percent of its total flow per kilometre of lateral. Based on a rough relationship of about 1 kilometre of distribution lateral per 100 hectares of field [75], the losses for a 10,000 hectares block would be about 10 percent of the total flow delivered to that block from the main canal.

The ratio between the water diverted and the water actually supplied to the on-farm irrigation system is termed the conveyance efficiency. For the purposes of this study the conveyance efficiency for each of the supply systems was calculated from the following expression:

Conveyance Efficiency = 1 - .0005 (LMC) - DSL

where LMC = Length of main canal in km

DSL = Distribution system loss = 10%

The actual conveyance losses calculated for each of the conveyance systems discussed in Section 4.3 are presented in Table 4-1 on page 123.

### 4.2.2 Crop Water Requirements

To ensure an adequate supply of water throughout the majority of the project life, the conveyance systems were designed to supply the crop water requirements for the drought condition water deficit, which has a probability of excedance of 10 percent, as defined in Section 2.6.

### 4.2.3 Irrigation Schedule

For irrigation to be successful, the peak daily crop water requirements must be continuously met throughout the growing season, otherwise the plant growth becomes stressed and yields greatly decrease. These peak crop water requirements generally occur during the month of July, during which time the crop must be supplied with roughly 46 percent of its total annual water requirement, as was previously discussed in Section 2.8 of this report. The majority of the sprinkler irrigation systems in use today apply water at a maximum rate of about 7 mm per day, which provides the crop with about 5.9 mm per day for an irrigation system with an application efficiency of 85 percent. This rate of application is sufficient to prevent stressing of the crops during their peak daily cropwater requirements in July [76]. The sprinkler system delivers the water at a relatively constant rate, with the varying daily and monthly water requirements being met by varying the frequency and duration of the application.

To account for the unlikelihood of all of the irrigation systems of a district operating simultaneously, the peak conveyance capacity is reduced by the irrigation factor, which is defined to be the ratio between the maximum area that can be irrigated simultaneously during periods of peak daily crop water demands, and the total net irrigable area of the project. Based on previous studies, small irrigation projects of 4000 hectares or less should use an irrigation factor of 1.00, whereas large projects of 40,000 hectares or more should utilize an irrigation factor ranging from 0.8 to 0.85 to avoid oversizing the conveyance system [74]. Due to the size of the developments examined in this study, which range from 20,000 hectares to 460,000 hectares, an irrigation factor of 0.75 was used for the majority of the proposed developments.

Using the conveyance capacity required for an irrigation factor of 0.75, the time required to apply the drought requirements for the month of July was examined, and resulted in several projects with relatively low drought water requirements having their irrigation factors reduced, while those areas with large drought water requirements had their irrigation factors increased to ensure that all of the water required in July could be readily applied within the time available. The irrigation factors for each of the projects is presented in Table 4-1, along with the number of days the conveyance systems would require to supply the crop water requirements for the average and the drought conditions during the peak water use month of July.

It should be noted that to allow for some mechanical breakdown and/or maintenance time of the pumping plants and canal works, all of the conveyance systems were required to have sufficient capacity to supply the drought water requirements for July in only 94 percent of the month, thus allowing two days of flexibility in the water delivery schedule.

### 4.2.4 Design Discharge Capacity

The required discharge capacity for each conveyance system was determined by the following expression:

$$Q = \frac{(PCWA)(IRR\ AREA)(10{,}000)(IRR\ FACTOR)}{(SEC)(CONV\ EFF)}$$

where Q = Design Discharge Capacity in $m^3$/sec

PCWA = Peak crop water application of 7mm per day

IRR AREA = Irrigated Area of project in hectares

IRR FACTOR = Irrigation Factor for project

SEC = Number of seconds in one day

CONV EFF = Conveyance Efficiency (from Table 4-1)

The calculated design capacity for each of the conveyance systems examined is presented in Table 4-1. It must be noted that in reality the choice of the design discharge capacity should be based on a form of risk analysis, since there is generally a substantial economic penalty associated with designing the conveyance system for the drought rather than the average water requirement. The increased costs of the delivery system should theoretically be balanced by the increased reliability of crop production and its subsequent benefits, but determining the optimal balance between risk and system cost is exceedingly complex since any analysis should incorporate the social as well as economic consequences of an insufficient design capacity. For the purposes of this study, the conveyance systems were designed to be capable of supplying the crop water requirements for a drought with a probability of excedance of 10 percent, and thus on average the systems would have adequate capacity 9 out of every 10 years, while rationing or scheduling of irrigation would be required once every 10 years on average.

## 4.3 WATER SUPPLY SYSTEMS FOR IRRIGATION

The reservoirs, canals, and pumping plants required to supply each district with water were determined on the basis of the topography, the potential water sources, and the relative economics of supplying that district with water. Given the high annual energy and fixed costs of pumping plants, an effort was made to minimize pumping wherever possible. The difficulty with the prairie topography is that generally the river valleys from which the required water is to be obtained are considerably below the elevation of the surrounding fields. This invariably results in either large pumping heads or large dams, which reduce the required pumping head and energy costs but are expensive to build due to the large height and width required for most dams on the prairies. The potential dam sites and inter-basin transfers considered in this study were based entirely on those presented in the Saskatchewan-Nelson Basin Board's Project Catalogue [73].

It should be noted that while it is probable that the water supply systems identified and utilized for each proposed development may not be the economically optimal supply system, the actual costs of such a system are not expected to vary significantly from those examined in this study. For the purposes of this study the supply systems identified for each development were assumed to be the best supply alternative possible. At several sites two or more supply alternatives were identified due to either uncertainty as to which of the alternatives was less costly, or concerns regarding water availability.

The supply system choices for each proposed irrigation district are briefly described below, and their geographic layouts are shown in Figures 8, 9, and 10. When examining the components of the supply systems it should be realized that the length of main canal specified is only the length required to convey the water from the point of diversion to a point from which a gravity canal distribution system can supply the various farms without requiring significant amounts of supplemental pumping. The main canal, pipelines, and pumping plants required for each district are summarized in Table 4-2 on page 125, while a schematic diagram of a typical project is presented in Figure 7 below.

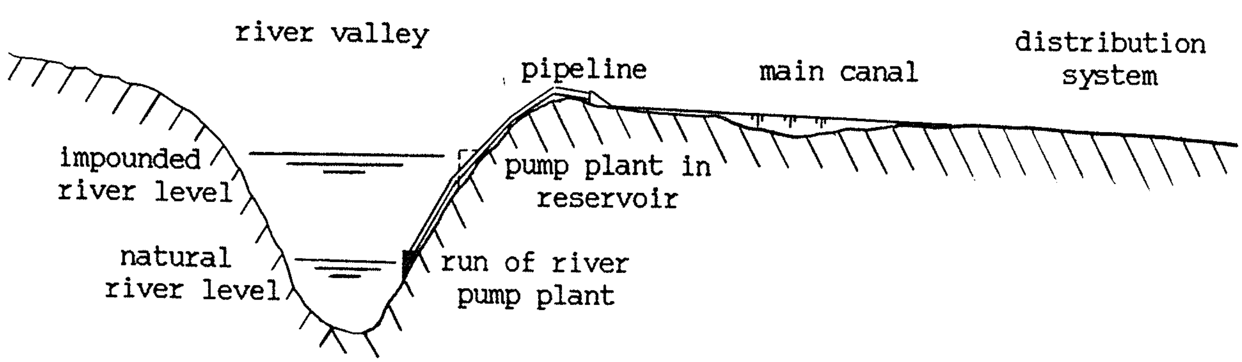


Figure 7 Schematic Diagram Of Typical Irrigation Project

Supply Systems

a) S1 is supplied with water from the North Saskatchewan River either by pumping from a river elevation of 491 m (designated as S1 in Table 4-2) or from the full supply level of 515.1 m created by the construction of the Highgate Dam (designated S1R). The water is pumped up a steep abutment to an elevation of 609 m through a pipeline 1000 metres long. From the outlet of the pipeline on the abutment, the diverted water flows to the irrigation district through a 75 kilometre main canal and is then distributed to the farms in the district.

b) S2 is supplied with water from the North Saskatchewan River either by pumping from a river elevation of 448 m or by pumping from the full supply level of 466.3 m created by the construction of Callaghan Dam (designated S2R). The water is pumped up through 3500 metres of pipeline to an elevation of 579 m, from where if flows 70 kilometres through the main canal and then is distributed to the farms.

c) S3 is supplied with water from the North Saskatchewan River which is pumped from a river elevation of 457 m up to an elevation of 610 m through 1800 metres of pipeline discharging into a canal. The water flows through 5 kilometres of canal to another pump plant which lifts the water up to an elevation of 671 m through 1000 metres of pipeline to the main canal, through which the water flows 40 kilometres to the district.

If Highgate Dam were constructed the water could be pumped from the full supply level of 515.1 m rather than the 457 m river elevation (designated as S3R in Table 4-2).

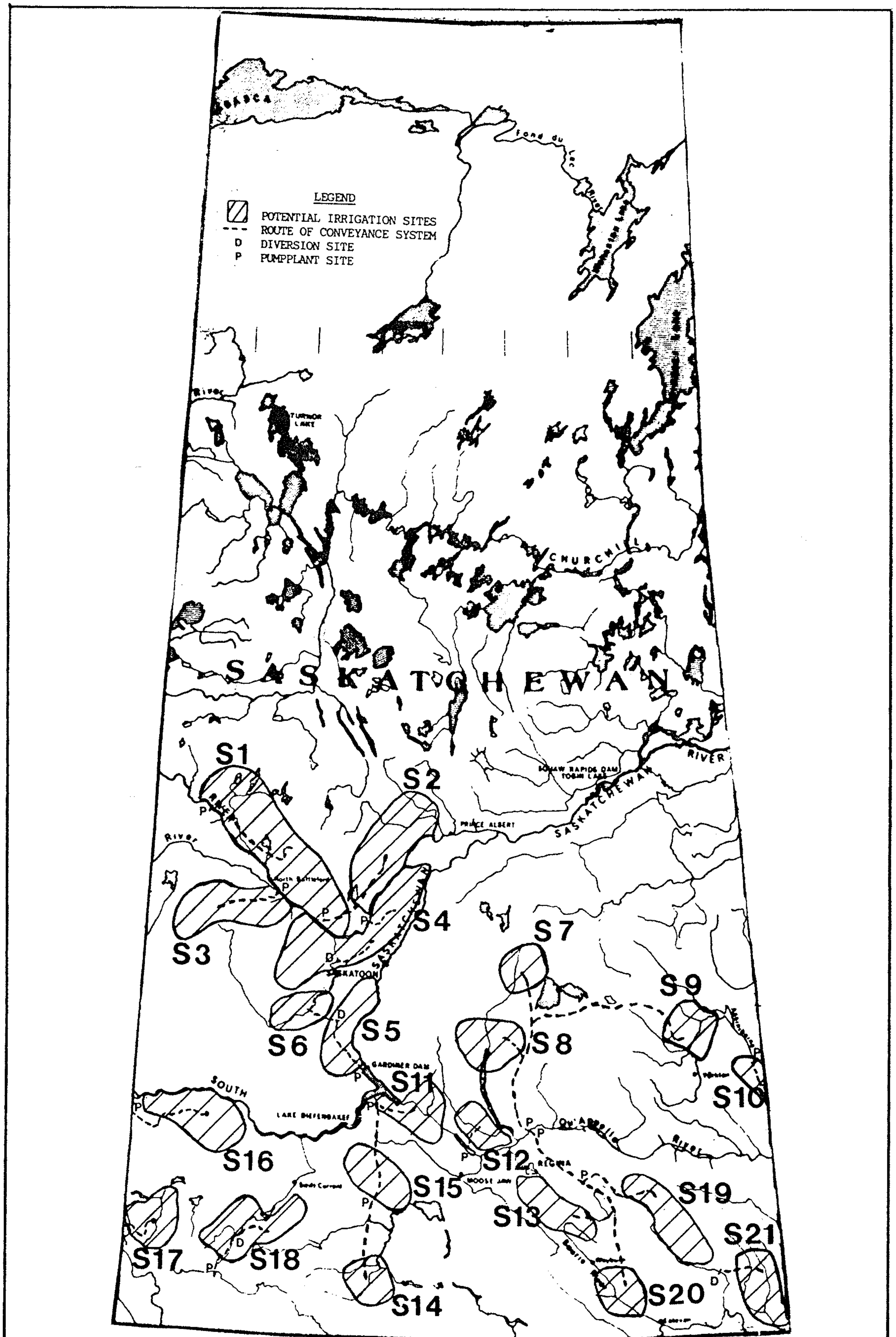


Figure 8 IRRIGATION SUPPLY SYSTEMS FOR SASKATCHEWAN SITES

d) S4 can be supplied from the North Saskatchewan River by pumping water from a river elevation of 448 m up to an elevation of 524 m through 1100 metres of pipeline. If the Callaghan Dam is constructed the water can be pumped up from the full supply elevation of 466.3 m (designated S4R). The diverted water flows through a main canal for 15 kilometres to the distribution system.

An alternate water source (designated S4R2) for supplying S4 could be to pump water from Lake Diefenbaker (full supply level of 556.9 m) up to an elevation of 564 m through a 200 metre pipeline. The water is conveyed in a canal 35 kilometres to the proposed McDonald Creek Reservoir, from which the water flows a further 40 kilometres to Eagle Creek. The water flows down Eagle Creek for about 35 kilometres, whereupon the water is diverted into a canal at elevation 524 m. Only 40 percent of the irrigable area can be supplied directly from the diversion through a 35 kilometre canal. The remainder of S4 will require the water to be conveyed 60 kilometres through a canal to a pump plant which lifts the water from elevation 500 m up to 524 m through a pipeline 150 metres long. The water then flows another 15 kilometres to the district.

e) S5 is supplied with water from Lake Diefenbaker by lifting the water up to an elevation of 564 m through a 200 metre pipeline, similar to S4R2. The water for S5 is conveyed 45 kilometres north through a main canal to the distribution system.

f) S6 is supplied with water from Lake Diefenbaker in a fashion similar to district S4 and S5. The water is pumped up out of Lake Diefenbaker and is then conveyed into the proposed McDonald Creek reservoir, from which the water flows another 40 kilometres to Eagle Creek whereupon the water is distributed to the development.

g) S7, S8 and S9 are all supplied by releases from Lake Diefenbaker into the Qu'appelle River channel, from which the water is lifted from a river elevation of 491 m up the abutment to an elevation 556 m through a 500 metre pipeline. The water is then conveyed to each district through a branched canal, with the canal to S7 being 210 kilometres from the pump to the district, S8 being 140 kilometres, and S9 being 360 kilometres from the pump. In each case, the first 120 kilometres of each canal would be common to all three districts.

h) S10 is supplied with water from the Assiniboine River pumped from the Shellmouth Reservoir (full supply level of 429.3 m) up to an elevation of 521 m through a 300 metre pipeline. The water then flows through a 15 kilometre main canal to the irrigation district.

i) S11 is supplied with water from Lake Diefenbaker (full supply level of 556.9 m) which is pumped up to an elevation of 640 m through a pipeline 600 metres in length. The water is then conveyed to Thunder Creek through a main canal 33 kilometres long, from which the distribution system will deliver the required water volumes to the farmers.

j) S12 is supplied with water released from Lake Diefenbaker which is pumped out of Buffalo Pound Lake (full supply level of 509 m) up to an elevation of 582 m through a 1000 metre pipeline. The water is then conveyed to the district through a main canal 10 kilometres long.

k) S14 and S15 are supplied with water pumped from Lake Diefenbaker (full supply level of 556.9 m) up to an elevation of 762 m through a 5000 metre long pipeline. The water then flows through the main canal for 30 kilometres, where the water for S15 is turned out. The canal supplying S14 continues another 65 kilometres to a second pump plant which lifts the water from an elevation of 733 m up to an elevation of 762 m through a 1000 metre long pipeline. The pipeline discharges into a 35 kilometre long main canal to the district.

l) S16 is supplied with water pumped from the South Saskatchewan River at an elevation of 582 m up to an elevation of 716 m through a 1000 metre pipeline. If the Meridan Dam is constructed the water could be pumped up from its full supply elevation of 646.2 m, thus saving about 64 metres of head (designated as S16R in Table 4-2). The pipeline would discharge into a 45 kilometre canal leading to the irrigation district.

m) S17 is supplied with water pumped from the South Saskatchewan River at an elevation of 637 m up to an elevation of 747 m through a 700 metre pipeline. The water then flows through a 10 kilometre canal to a second pump plant which lifts the water from elevation 745 m up to elevation 762 m through a 500 metre pipeline, whereupon the water is conveyed 80 kilometres to the irrigation district through a canal.

If Meridan Dam were constructed, the initial pump plant could pump from the full supply level of 646.2 up to the required elevation of 747 m (designated S17R in Table 4-2).

n) S18 was to be supplied with water from the Frenchman River and/or the Swift Current Creek, however in Chapter 3 it was determined that both the Swift Current Creek and the Frenchman River are already fully apportioned for their existing water users and are unable to provide significant water volumes for any additional irrigation. A factor which further reduces the desirability of using water from the Frenchman River is that it is an international waterway, and any increase in water demands would probably have to be preceded by a formal water apportionment agreement with the United States. Due to the lack of an adequate supply of water for the irrigation of site S18, the site was effectively dropped from the analysis. This is not to imply that smaller, local irrigation developments are not feasible, but rather for the purposes of this study, the development of large portions of the area identified as S18 does not appear feasible at this time.

o) S19, S20, S21 and S13 are supplied with water released from Lake Diefenbaker into the Qu`Appelle River which is pumped from a river elevation of 486 m up to an elevation of 613 m through a pipeline 1500 metres long. The water for each district initially flows south in a common canal for 60 kilometres, whereupon the required flows for S19 and S21 must be lifted from an elevation of 597 m up to an elevation of 646 m through a pipeline 1300 metres long. The pipeline discharges into a main canal which conveys the water 60 kilometres to the S19 district, while the flow for S21 continues on another 35 kilometres whereupon it enters into Moose Mountain Creek. Further downstream, the water for S21 is diverted out of Moose Mountain Creek at an elevation of 584 m and flows through a 65 kilometre long main canal to the S21 district. This district's diverted water use could be reduced by using the natural Moose Mountain, Antler, Lightning and Gainsborough Creek flows, but these are extremely variable and are insufficient for any major irrigation development.

The canal conveying water to S20 and S13 proceeds south for 40 kilometres after the flow withdrawals for the S19/S21 pump plant, whereupon the required flow for S13 is diverted into a canal which conveys the water the 20 kilometres to the district. The water required by S20 continues on for another 80 kilometres after the turnout for the S13 diversion.

p) A1 can be supplied with water from the North Saskatchewan River as well as the Red Deer River (see Figure 9 on page 108). Water from the North Saskatchewan River can be diverted into the Red Deer River by constructing the Horseguard Dam. Water from the Red Deer River, along with any water from the North Saskatchewan, is diverted into a canal by constructing the Raven Dam on the Red Deer River. The main canal splits into three separate canals, with 25 percent of the A1 district (termed A1-A) being supplied by a canal 75 kilometres long, 60 percent (A1-B) being supplied by a 45 kilometre long canal into Spruce Creek which then feeds into Kneehills Creek from which the water is distributed, and 15 percent (A1-C) being supplied by a 135 kilometre canal to Rosebud Creek. Water can also be diverted into the Bow River if it is warranted.

q) A2 was divided into three major sections, each of which was supplied by water from the Bow River. District A2-A encompassed 40 percent of the total area of District A2, and comprised the western portion of the development. This area is supplied by a canal which conveys water

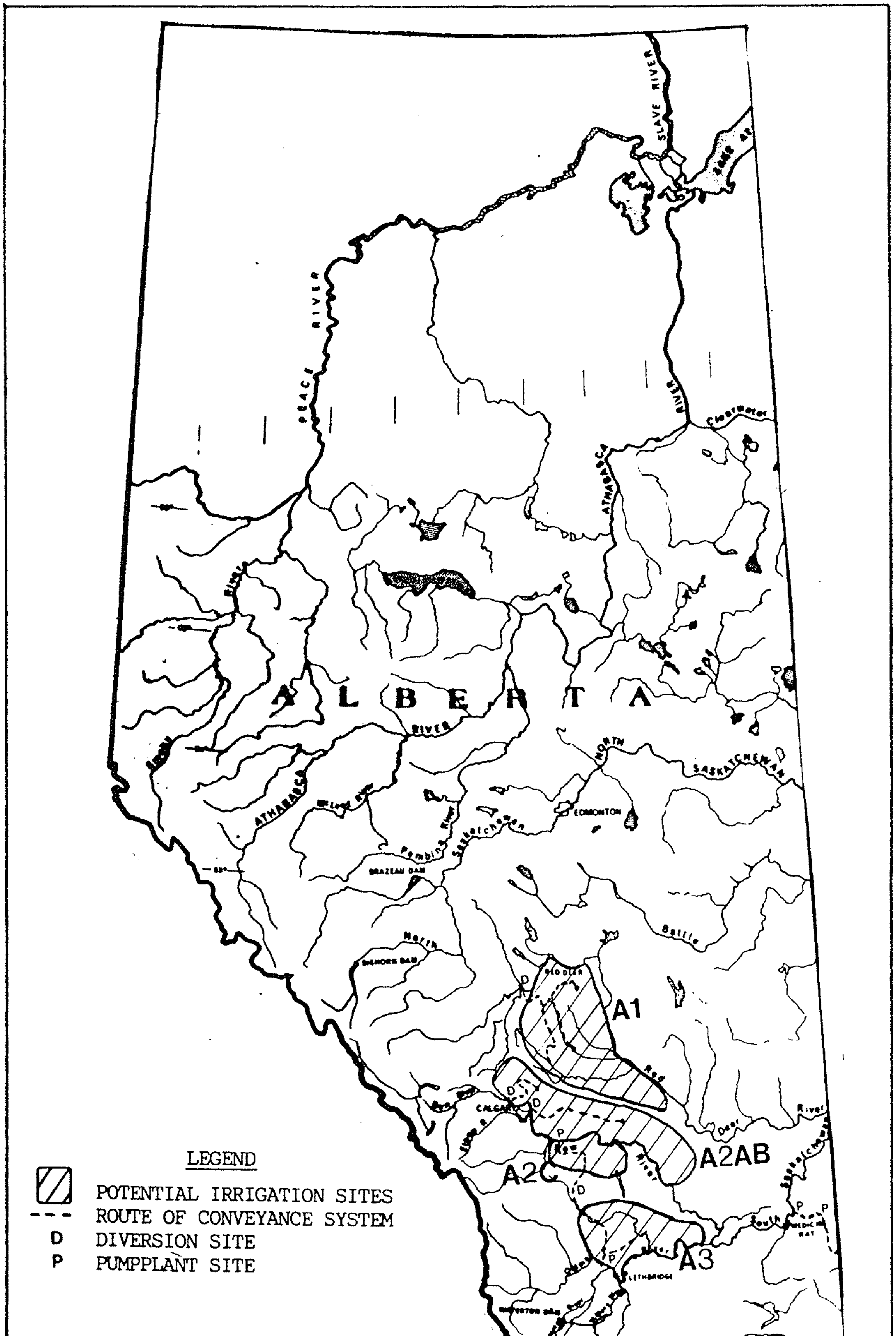


Figure 9 IRRIGATION SUPPLY SYSTEMS FOR ALBERTA SITES

diverted at Calgary (at elevation 1204 m) the 50 kilometre distance to the site.

District A2-B is the north-eastern portion of the A2 district, and comprises 40 percent of the total irrigable area of the district. The development is supplied with water diverted at Calgary which is conveyed to the site through 60 kilometres of upgraded existing canals and 10 kilometres of new canals.

The remaining 20 percent of the irrigable area in the A2 district is located on the southern bank of the Bow River, and can only be supplied by pumping water from the Bow at an elevation of 933 m up to elevation 1009 m through a 600 metre long pipeline. The water is then conveyed 25 kilometres to the A2-C district through a canal.

An alternative method of supplying the A2-C district (designated as A2-CR in Table 4-2) would be a 10 kilometre canal which is pumped out of the Bow River to the Oldman River diversion channel. If Dalemead Dam were constructed to facilitate this diversion the water for A2-C could be pumped from the full supply level of 998.2 m, thus reducing the required lift to 7.5 metres. The actual Bow to Oldman diversion would require no pumping so long as the full supply level of Dalemead is greater than 995.2 m, but a pump plant is included in the design to allow diversions down to the minimum supply level of 983 m.

r) A3 was subdivided into two major sections, with the northern section (A3-A) consisting of 60 percent of the district's irrigable area, while the more southerly A3-B section encompasses the remaining area. The A3-A section is supplied by water diverted from the Bow River through a

130 kilometre long canal which is supplied either by pumping water out of the Bow from an elevation of 932 m up to an elevation of 995 m (designated A3-A), or by constructing Dalemead Dam which would allow water to be diverted without pumping at its full supply elevation of 998.2 m (designated A3-AR). To divert water directly into the Oldman River basin requires this canal be extended only 20 kilometres, whereupon it enters a chute spillway dropping the water 30.5 metres down into the Oldman River.

The A3-B project is supplied with water either through pumping out of the Oldman River at El. 905 m up to El. 935 m through a 250 m long pipeline, or by diverting water from the Bow River through the proposed Bow-Oldman diversion. In either case, the water would be supplied to the site by upgrading 60 kilometres of existing canals and constructing 20 kilometres of new canals.

s) M1 is supplied with water pumped directly out of the Assiniboine River from an elevation of 338 m through a 2000 metre long pipeline up to an elevation of 390 m (see Figure 10 on page 111). The pipeline discharges into a canal which conveys the water 40 kilometres to the irrigation district.

t) M2 is supplied with water pumped out of the Assiniboine River, from an elevation of 295 m up to an elevation of 344 m through a pipeline 3000 metres long. The water is then conveyed 30 kilometres to the irrigation district through a lined main canal.

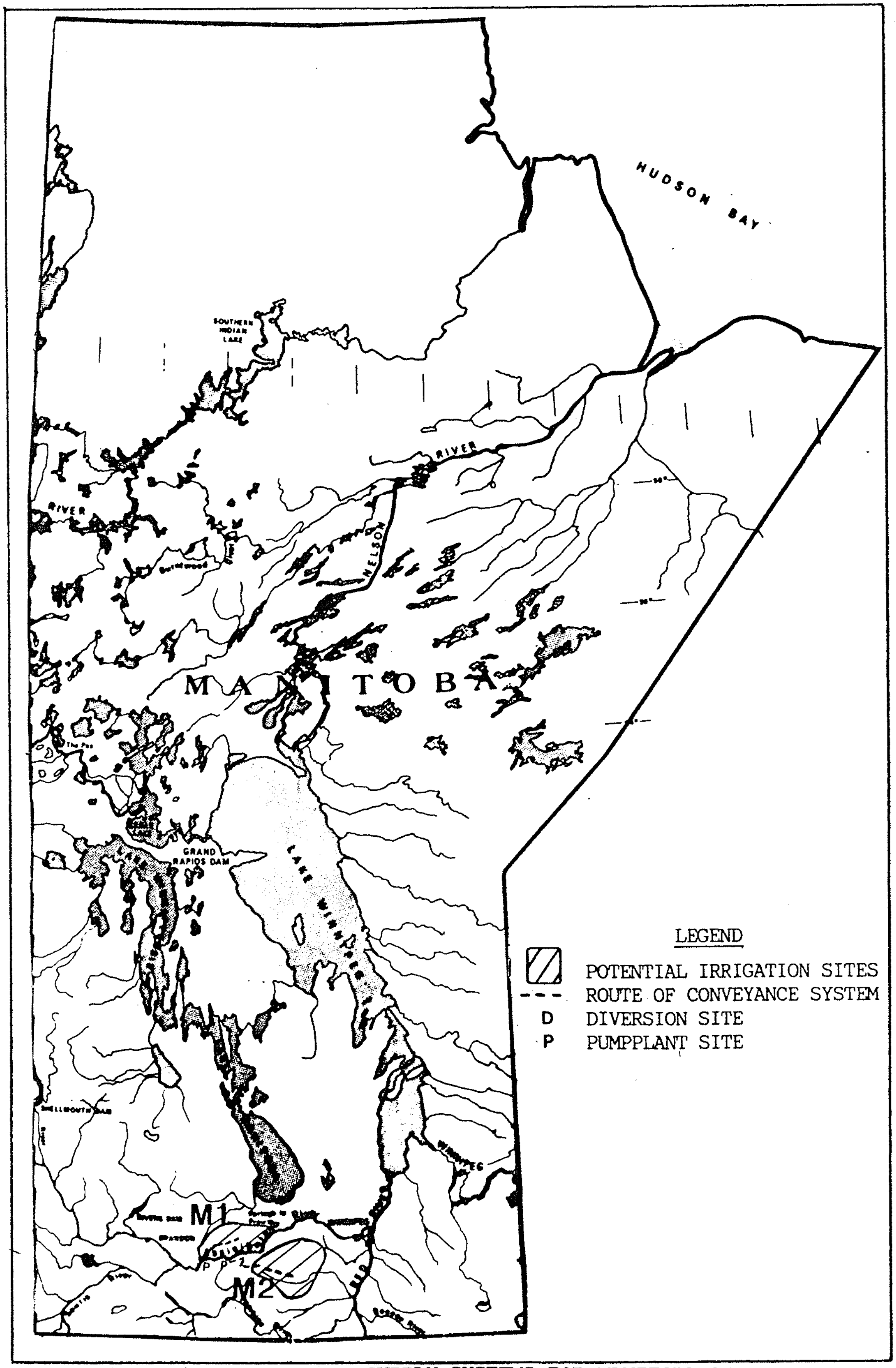


Figure 10 IRRIGATION SUPPLY SYSTEMS FOR MANITOBA SITES

## 4.4 COSTS OF THE IRRIGATION WORKS

The cost estimates for the various irrigation works were separated into seven main components, these being: the main canal, the pumping plant, the pipeline or pipelines, the distribution system, the energy cost of pumping, any reservoirs required to supply the water, and any diversion works required to transfer water from one basin to another. The capital costs of each component of the system were estimated separately, and these capital costs were then converted into annual costs to account for the differing lives of the various components over the assumed design life of the development, which was taken as 50 years. All of the required components were designed for the capacities identified in Section 4.2 of the report. The methodology for estimating the capital cost of each component of the conveyance system for a development was dependent on the component, and are briefly described below. The capital costs for the components of the various developments are presented in Tables 4-3 to 4-8 on pages 127 to 133.

### 4.4.1 Main Canals

The length of the main canals was based on the distance from the pipeline outlet (or the water supply source for a diversion) to the approximate center of gravity of the proposed irrigation district. The canal routes were laid out using 1:250,000 scale topographic maps of the region, which had a contour interval of 7.6 m (25 ft). Due to the large number of canals to be examined, a relationship between capital cost and the canal capacity was developed from preliminary hydraulic and cost calculations, and is presented in Figure 11 on page 129. All of the canals were designed as cut and fill structures with quite low slopes ranging from .0002 to .0004, so as to reduce the loss in elevation between the outlet of the pipeline and the distribution system of the districts. The canals were assumed to be membrane lined over 75 percent of their length so as to reduce conveyance losses and the subsequent salinization problems commonly associated with these losses. The unit costs and the values used to determine Figure 11 are presented in Tables 4-3 and 4-4.

The canals were sized using relationships between width, depth and discharge which are suitable only for preliminary design [74,77], but were entirely satisfactory for a study of this nature. The canal design utilized a 3:1 interior slope and a 2.5:1 exterior slope with the top of fill being 4 metres wide to facilitate a maintenance and inspection roadway, the cost of which is included in the canal costs presented. The maximum allowable flow velocity in the canals was restricted to 0.80 metres per second (2.6 feet per second) to avoid displacing the membrane cover material and to prevent any erosion in the remaining 25 percent of the canal which was to be unlined.

It should be noted that the costs shown in Figure 11 include contingencies of 15 percent, engineering design and survey costs of 10 percent, and an additional 10 percent to cover the costs of the numerous road and creek crossings.

Because of the extensive existing irrigation development in the Alberta districts A2 and A3, some of the proposed developments utilize existing canals which are to be increased in capacity. The costs of these renovations were conservatively assumed to be equal to 75 percent of the cost of constructing a new canal of the required additional capacity.

The annual costs of the canal systems were calculated assuming a design life of 50 years, with annual maintenance and operation costs equal to 1.0 percent of the capital costs, and sinking fund depreciation. For an effective interest rate of 4.0 percent, the annual cost of a canal would be calculated as follows:

Annual Cost = Capital Cost x (Interest Rate + O&M + (SFF,4%,50))

= Capital Cost x ( 0.04 + .01 + 0.00655 )

= Capital Cost x ( 0.05655 )

### 4.4.2 Pipelines

The capital costs of the pipelines running from the pumping plants to the entrance to the main canal were determined by first designing several steel pipelines satisfying the applicable hydraulic and structural criteria [78]. The sizes of the pipelines examined were standard, factory available 1.829 m (72 inch) and 1.981 m (78 inch) diameter pipes along with custom fabricated 2.44 m (96 inch) and 3.00 m (118 inch) diameter steel pipes.

The majority of the pipeline sections were designed for a static head of 100 m, which exceeds the static head of 75 percent of the pump plants examined in this study, with the water hammer surge pressure determined using fundamental surge wave relationships and assuming instantaneous closure of the flow. To determine the sensitivity of the pipeline design to increased static head, the 3.00 m diameter pipeline was also designed for several static heads ranging up to 205 m. The sections required to withstand these pressures, along with their unit weights in kilograms per metre of pipeline, are presented in Table 4-5 on page 130. As the water hammer pressure wave is approximately double the total pump head of 100 m for all of the pipe sections examined, the potential savings associated with providing surge release valves or slow closure valves was examined. As can be observed from Table 4-5, reducing the proportion of the maximum potential water hammer that the 2.44 m and 3.00 m pipe sections were required to withstand by 50 percent (i.e. from 100% to 50%), produced a 25 percent decrease in the weight of the section required.

The project capital costs of the pipelines were determined using a supply price of about $1.32 per kilogram ($0.60 per pound) for steel pipe, and a cost for installation and backfill over the pipeline approximately equal to the supply price, for a total installed cost of about $2.65 per kilogram of pipeline. These costs were then increased by 20 percent for contingencies, and 5 percent for engineering and surveys for a total project capital cost of $3.35 per kilogram of pipeline. Based on these capital costs, the unit discharge costs in $\$/(m^3/s)/(\text{m of pipeline})$ for each of the pipeline sections is presented in Table 4-5.

As can be observed in Table 4-5, requiring the pipelines to withstand the entire maximum potential water pressure hammer has a considerable cost in comparison to the sections designed to resist only 50 percent of this maximum value, and it is entirely probable that pressure release valves, surge tanks, or slow closure valves would more economically dissipate any such pressure wave. To incorporate these probable economies into this study, the pipeline costs for all of the conveyance systems were based on the average of the unit discharge costs for the pipe section designed to withstand full water hammer and the section designed for only 50 percent of the water hammer. For the 3.00 m diameter pipeline, the averaged cost was 162 $/(m^3/s)/(m of pipe). By using the average of the two costs some allowance was made for the costs of the release valves, surge tanks, or the slow closure valves required to mitigate these water hammer pressure waves. The costs for the 3.00 m diameter pipeline are only slightly less than the average cost for the 2.44 m diameter pipeline which was 165 $/(m^3/s)/(m of pipe), thus the cost of the pipeline appeared to be relatively insensitive to the pipeline size selected.

The capital costs of the majority of the pipelines required for the various conveyance systems examined in this study were obtained by multiplying the unit cost of 162 $/(m^3/s)/(m of pipe) by the required discharge and by the required length of pipeline. This assumes that all of the flows will produce exact increments of 21.5 m^3/s, which is the maximum capacity of the 3.00 m diameter pipeline. In reality this is only correct if the project needs a large number of pipelines to supply the required capacity, which the majority of the projects do. For the purposes of this study, the pipeline costs for those projects which had flows smaller than the capacity of a 3.00 m pipeline were assumed to be identical to that for the 3.00 m pipe, since the unit costs of the smaller pipelines are comparable to the unit cost of the 3.00 m diameter pipeline.

It should be noted in Table 4-5 that the unit costs for the pipelines substantially increase as the static head on the pipelines increases. This was incorporated in the analysis by multiplying the basic unit cost of 162 $/dam^3/(m of head) by a "Head Cost Factor" based on the costs of

Table 4-5, which increase linearly with the design static head. This factor was determined from the following expression:

$$\text{Head Cost Factor} = 1 + (\text{CSSH} - 100) \times \text{LNF}$$
$$> 1.0$$

where CSSH = Conveyance system static head in m

LNF = Linear factor of 0.0038977

The project costs of all of the pipelines examined in this study are presented in Table 4-6. The annual costs for the pipelines for each project were calculated assuming a design life of 50 years, annual operation and maintenance costs equal to 0.5 percent of the capital cost, and sinking fund depreciation.

### 4.4.3 Pump Plants

The capital costs of the pumping plants for the conveyance systems described in Section 4.3 are based on information presented in the SNBB Project Investigations report [79], in which the capital costs of pump plants are related to two variables, the first being the product of the design discharge and the total head, and the second being simply the total head. The total pumping head was the sum of the static head and the friction losses of the pipelines, as determined in the previous section. These capital costs were escalated from 1968 to 1987 dollars using an escalation factor of 3.76, as determined from the U.S.B.R. index for pump plants [80]. These costs were increased by 20 percent for contingencies, and a further 15 percent for engineering design costs. A comparison with several recent estimates of proposed pump plants [67,81] found this methodology to be quite accurate, and thus was deemed of acceptable veracity for this study. The total capital costs of the various pumping plants required are presented in Table 4-6 on page 131, and include the intake, substructure, superstructure, and outlet. The electrical capacity of the pump plants are also presented in Table 4-6.

The annual fixed costs for the pumping plants was calculated assuming a design life of 30 years, annual operation and maintenance costs equaling 1.5 percent of the capital costs, and sinking fund depreciation.

### 4.4.4 Distribution System

The distribution system costs for this study were based on information derived by the Irrigation Branch of Alberta Agriculture from studies of proposed and existing irrigation developments [75]. This relationship was converted to metric units and then escalated to 1987 dollars. The costs shown in Table 4-6 represent the total expected capital costs per hectare of irrigated land developed, and are based on lined distribution canals so as to reduce the potential for seepage and salinization problems. These costs include 10 percent for engineering, and 10 percent for contingencies. Recent irrigation developments in Saskatchewan have utilized pressurized pipe distribution systems, however their cost can become prohibitive for large flows and districts of large areal extent, so only lined canals and laterals were utilized for this study.

The annual costs for the distribution system were calculated assuming a design life of 50 years, annual operating and maintenance costs equaling 1.0 percent of the capital costs, and sinking fund depreciation.

### 4.4.5 Reservoir Costs

The capital costs of the reservoirs examined in this study were entirely based on the costs and information provided in the SNBB project catalogue [73]. As these costs were in 1968$, the project costs were escalated to 1987 costs using an escalation factor of 3.21, which was based on the USBR cost index for dams [80]. The escalated project costs for the various dams and reservoirs are presented in Table 4-7 on page 131. The annual costs of the dams and reservoirs were calculated assuming a design life of 50 years, annual operating and maintenance costs equal to 1.0 percent of the capital costs, and sinking fund depreciation.

It must be noted that none of the proposed conveyance systems utilize balancing or off-stream storage reservoirs. While the inclusion of these reservoirs would probably allow the design discharge capacities and their associated costs to be reduced, for the purposes of this study the potential cost savings were not deemed to justify the large increase in design work required to include them into the proposed systems, nor did the available data facilitate such an analysis.

### 4.4.6 Energy Costs of Pumping

The energy costs were calculated using an assumed "wire to water" pump efficiency of 0.7 and two energy rates, with $.04 per Kwh representing the present energy costs and $.08 per Kwh representing a possible future price should electrical energy costs increase at a rate in excess of the overall economy. Recent forecasts have indicated [43] that no such differential increase in energy costs is expected, but the increased rate was included to examine the sensitivity of the projects to such an increase.

Based on the defined efficiency and energy values, one can determine that it costs \$0.156/dam$^3$/(m of head) to pump water at an energy cost of \$0.04 per Kwh, and \$0.312/dam$^3$/(m of head) at an energy cost of \$0.08 per Kwh. It should be noted that the annual energy costs were based on the average annual water requirements rather than the drought year requirements, since it is the average annual costs of operation for each pump plant that are required.

### 4.4.7 Diversion Works

Based on the flow volume surpluses presented in Table 3-4, the full development of the potential sites which draw water from the Bow and the Red Deer rivers requires additional flow volumes be diverted into the respective basins. Since the present and the possible future water demands upon the Alberta portion of the North Saskatchewan River appear to result in considerably more flow being released to Saskatchewan than is required under the apportionment agreement, the study examined the works required to divert flow from the North Saskatchewan River into the Red Deer and Bow rivers. All of the proposed diversion works and their associated costs are based on information presented in the SNBB project catalogue [73].

The flow from the North Saskatchewan River would be diverted into the Red Deer river by constructing the Rocky Mountain and Horseguard dams, which raise the water level of the North Saskatchewan sufficiently to divert flow through a 30 km long canal to the Red Deer River. Flow could also be diverted from the Red Deer to the Bow River by constructing the Raven and Torrington dams, which would divert flow through a canal 220 kilometres long to the Bow. To overcome a plateau, the final portion of the diversion includes a pump plant to lift the water 54 m, which is followed by a 45 m drop down into the Bow River. To reduce the energy requirements of the diversion, a hydroelectric generating plant was added at the base of the 45 m drop into the Bow River to supply power to the diversion pumpworks.

The total capital costs for the diversion works, along with the average annual energy requirements for the various discharge capacities, are presented in Table 4-8 on page 132. These costs were determined by escalating the costs presented in the SNBB report [73] by a factor of 3.21, which corresponds to the USBR escalation index for dams from 1968 to 1987 [80]. Since the SNBB report on the Red Deer to Bow river diversion does not include any hydroelectric generation at the 46 m drop down to the Bow River, the cost of incorporating generating units into the diversion works was added to the project costs presented in their report. A cost of $650 per kilowatt of installed capacity was used to determine the incremental cost of the hydroelectric generation, the cost of which was based on information presented in the SNBB Project Investigations [79].

The annual costs for the diversions were calculated assuming a design life of 50 years, annual operating and maintenance costs equal to 1.0 percent of the capital costs, and sinking fund depreciation.

Having determined the expected costs of the various engineering works required for development of the irrigable sites identified in this study, the overall social and economic worth of the proposed projects could be examined.

TABLE 4-1 DESIGN CAPACITY AND WATER REQUIREMENTS

| SITE | NET AREA $10^3$ha | CONV. LOSS % | ANNUAL DIVERSION $10^3$ $DAM^3$ | | IRRGTN FACTOR | Q $M^3/S$ | DAYS IN JULY REQUIRED | |
|---|---|---|---|---|---|---|---|---|
| | | | AVERAGE | DROUGHT | | | AVERAGE | DROUGHT |
| S1 | 200 | 13.6 | 419.39 | 650.05 | .700 | 131.3 | 16.9 | 26.1 |
| S1R | 200 | 13.6 | 419.39 | 650.05 | .700 | 131.3 | 16.9 | 26.1 |
| S2 | 140 | 13.5 | 322.56 | 417.86 | .650 | 85.2 | 20.0 | 25.9 |
| S2R | 140 | 13.5 | 322.56 | 417.86 | .650 | 85.2 | 20.0 | 25.9 |
| S3 | 135 | 12.3 | 313.75 | 460.17 | .750 | 93.5 | 17.7 | 26.0 |
| S3R | 135 | 12.3 | 313.75 | 460.17 | .750 | 93.5 | 17.7 | 26.0 |
| S4 | 290 | 10.8 | 647.93 | 1001.35 | .750 | 197.6 | 17.3 | 26.8 |
| S4R | 290 | 10.8 | 647.93 | 1001.35 | .750 | 197.6 | 17.3 | 26.8 |
| S4R2 | 290 | 16.7 | 693.82 | 1072.27 | .750 | 211.5 | 17.3 | 26.8 |
| S5 | 95 | 12.3 | 262.88 | 369.98 | .766 | 67.2 | 20.6 | 29.0 |
| S6 | 45 | 13.8 | 130.05 | 184.43 | .793 | 33.5 | 20.5 | 29.0 |
| S4R2,5,6 | 430 | | 1086.75 | 1626.69 | | 312.3 | 18.4 | 27.5 |
| S7 | 55 | 20.5 | 94.01 | 156.68 | .600 | 33.6 | 14.8 | 24.6 |
| S8 | 115 | 17.0 | 280.21 | 348.70 | .600 | 67.4 | 22.0 | 27.3 |
| S9 | 130 | 28.0 | 245.34 | 392.55 | .600 | 87.8 | 14.8 | 23.6 |
| S10 | 10 | 10.8 | 15.23 | 24.37 | .600 | 5.4 | 14.8 | 23.6 |
| S11 | 105 | 11.7 | 288.58 | 384.77 | .750 | 72.3 | 21.1 | 28.1 |
| S12 | 45 | 10.5 | 112.98 | 167.21 | .750 | 30.6 | 19.5 | 28.9 |
| S13 | 50 | 16.0 | 133.75 | 197.96 | .750 | 36.2 | 19.5 | 28.9 |
| S14 | 45 | 16.5 | 173.09 | 227.49 | .947 | 41.3 | 22.1 | 29.0 |
| S15 | 50 | 11.5 | 142.57 | 207.38 | .825 | 37.8 | 19.9 | 29.0 |
| S14,15 | 95 | | 315.66 | 434.87 | | 79.1 | 21.1 | 29.0 |
| S16 | 70 | 12.3 | 234.38 | 307.63 | .865 | 55.9 | 22.1 | 29.0 |
| S16R | 70 | 12.3 | 234.38 | 307.63 | .865 | 55.9 | 22.1 | 29.0 |
| S17 | 55 | 14.5 | 177.09 | 236.12 | .825 | 43.0 | 21.7 | 29.0 |
| S17R | 55 | 14.5 | 177.09 | 236.12 | .825 | 43.0 | 21.7 | 29.0 |
| S18 | 130 | 13.4 | 378.82 | 516.57 | .773 | 94.0 | 21.3 | 29.0 |
| S19 | 55 | 19.0 | 131.90 | 205.17 | .750 | 39.8 | 17.5 | 27.2 |
| S20 | 20 | 16.0 | 60.79 | 82.90 | .755 | 15.1 | 21.2 | 29.0 |
| S21 | 45 | 22.0 | 134.29 | 185.95 | .750 | 35.1 | 20.2 | 28.0 |

<u>NOTES</u>:
1) 1.0 $Dam^3$ = 1000 $m^3$
2) Conv Loss is the total conveyance losses of the diverted water expressed in percent.
3) Irrgtn Factor is the ratio between the total area of the project and the maximum area that can be irrigated with the peak water requirement at any given time.
4) Q is the discharge capacity of the conveyance system.
5) Days in July is the number of days the conveyance system must operate at its design capacity to provide the monthly water requirements during July for that site

TABLE 4-1 DESIGN CAPACITY AND WATER REQUIREMENTS cont'd

| SITE | NET AREA $10^3$ha | CONV. LOSS % | ANNUAL DIVERSION 1000 DAM$^3$ | | IRRGTN FACTOR | Q M$^3$/S | DAYS IN JULY REQUIRED | |
|---|---|---|---|---|---|---|---|---|
| | | | AVERAGE | DROUGHT | | | AVERAGE | DROUGHT |
| A1A | 134 | 13.7 | 282.41 | 493.65 | .750 | 94.3 | 15.8 | 27.6 |
| A1B | 321 | 12.3 | 665.73 | 1165.02 | .750 | 222.4 | 15.8 | 27.6 |
| A1C | 80 | 16.8 | 174.89 | 306.05 | .750 | 58.4 | 15.8 | 27.6 |
| A1AB | 456 | 13.0 | 953.31 | 1668.30 | .750 | 318.5 | 15.8 | 27.6 |
| A2A | 286 | 12.5 | 668.81 | 1114.68 | .765 | 202.6 | 17.4 | 29.0 |
| A2B | 286 | 13.0 | 672.65 | 1121.09 | .765 | 203.7 | 17.4 | 29.0 |
| A2C | 143 | 11.3 | 329.88 | 549.80 | .765 | 99.9 | 17.4 | 29.0 |
| A2CR | 143 | 11.3 | 329.88 | 549.80 | .765 | 99.9 | 17.4 | 29.0 |
| A3A | 384 | 16.5 | 941.00 | 1463.77 | .750 | 279.4 | 17.8 | 27.6 |
| A3B | 256 | 16.5 | 627.33 | 975.85 | .750 | 186.3 | 17.8 | 27.6 |
| A3AR | 384 | 16.5 | 941.00 | 1463.77 | .750 | 279.4 | 17.8 | 27.6 |
| A3BR | 256 | 16.5 | 627.33 | 975.85 | .750 | 186.3 | 17.8 | 27.6 |
| M1 | 120 | 12.0 | 205.79 | 323.38 | .600 | 66.3 | 16.4 | 25.7 |
| M2 | 90 | 11.5 | 131.55 | 219.24 | .600 | 49.4 | 14.0 | 23.4 |

<u>NOTES</u>:
1) 1.0 Dam$^3$ = 1000 m$^3$
2) Conv Loss is the total conveyance losses of the diverted water expressed in percent.
3) Irrgtn Factor is the ratio between the total area of the project and the maximum area that can be irrigated with the peak water requirement at any given time.
4) Q is the discharge capacity of the conveyance system.
5) Days in July is the number of days the conveyance system must operate at its design capacity to provide the monthly water requirements during July for that site

TABLE 4-2 IRRIGATION WATER SUPPLY SYSTEM COMPONENTS

| SITE | CANALS NEW KM | CANALS OLD KM | PUMP PLANT HEAD M | PUMP PLANT PIPELINE LENGTH M | DROUGHT Q $M^3/S$ | NEW RESERVOIRS REQUIRED |
|---|---|---|---|---|---|---|
| S1 | 75 | 0 | 118.0 | 1000 | 131.3 | |
| S1R | 75 | 0 | 93.9 | 950 | 131.3 | HIGHGATE |
| S2 | 70 | 0 | 131.1 | 3500 | 85.2 | |
| S2R | 70 | 0 | 112.8 | 3400 | 85.2 | CALLAGHAN |
| S3 | 5 | 0 | 152.5 | 1800 | 93.5 | |
| | 40 | 0 | 62.3 | 1000 | 93.5 | |
| S3R | 5 | 0 | 94.4 | 1700 | 93.5 | HIGHGATE |
| | 40 | 0 | 62.3 | 1000 | 93.5 | |
| S4 | 15 | 0 | 76.2 | 1100 | 197.6 | |
| S4R | 15 | 0 | 58.0 | 1050 | 197.6 | CALLAGHAN |
| S4R2 | 75 | 35 | 7.1 | 200 | 211.5 | McDONALD CR. |
| A | 35 | 0 | 0.0 | 0 | 84.6 | |
| B | 60 | 0 | 24.3 | 150 | 126.9 | |
| B | 15 | 0 | 0.0 | 0 | 126.9 | |
| S5 | 45 | 0 | 7.1 | 200 | 67.2 | |
| S6 | 75 | 0 | 7.1 | 200 | 33.5 | McDONALD CR. |
| S7 | 210 | 0 | 65.6 | 500 | 33.6 | |
| S8 | 140 | 0 | 65.6 | 500 | 67.4 | |
| S9 | 360 | 0 | 65.6 | 500 | 87.8 | |
| S10 | 15 | 0 | 91.9 | 300 | 5.4 | |
| S11 | 33 | 0 | 83.2 | 600 | 72.3 | |
| S12 | 10 | 0 | 91.9 | 300 | 30.6 | |
| S13 | 100 | 0 | 126.4 | 1500 | 36.2 | |
| | 20 | 0 | 0.0 | 0 | 36.2 | |
| S14 | 30 | 0 | 205.1 | 5000 | 41.3 | |
| | 65 | 0 | 29.0 | 1000 | 41.3 | |
| | 35 | 0 | 0.0 | 0 | 41.3 | |
| S15 | 30 | 0 | 205.1 | 5000 | 37.8 | |
| S16 | 45 | 0 | 134.3 | 1000 | 55.9 | |
| S16R | 45 | 0 | 70.1 | 800 | 55.9 | MERIDIAN |
| S17 | 10 | 0 | 109.8 | 700 | 43.0 | |
| | 80 | 0 | 17.4 | 500 | 43.0 | |
| S17R | 10 | 0 | 100.6 | 680 | 43.0 | MERIDIAN |
| | 80 | 0 | 17.4 | 500 | 43.0 | |
| S19 | 60 | 0 | 126.4 | 1500 | 39.8 | |
| | 60 | 0 | 49.6 | 1300 | 39.8 | |
| S20 | 100 | 0 | 126.4 | 1500 | 15.1 | |
| | 80 | 0 | 0.0 | 0 | 15.1 | |
| S21 | 60 | 0 | 126.4 | 1500 | 35.1 | |
| | 95 | 0 | 49.6 | 1300 | 35.1 | |
| | 65 | 0 | 0.0 | 0 | 35.1 | |

<u>NOTES</u>: 1) Old canal is existing canal or river whose capacity is to be increased.
2) Dalemead & Dvrn is the Oldman diversion from Dalemead Dam

TABLE 4-2 IRRIGATION WATER SUPPLY SYSTEM COMPONENTS cont'd

| SITE | CANALS | | PUMP PLANT | | DROUGHT | NEW RESERVOIRS REQUIRED |
|---|---|---|---|---|---|---|
| | NEW KM | OLD KM | HEAD M | PIPELINE LENGTH M | Q $M^3/S$ | |
| A1 A | 75 | 0 | 0.0 | 0 | 94.2 | |
| B | 45 | 0 | 0.0 | 0 | 225.8 | |
| C | 135 | 0 | 0.0 | 0 | 56.3 | |
| A2 A | 50 | 0 | 0.0 | 0 | 203.0 | |
| B | 10 | 60 | 0.0 | 0 | 203.0 | |
| C | 25 | 0 | 73.1 | 600 | 101.5 | |
| A2RC | 10 | 0 | 7.5 | 100 | 101.5 | DALEMEAD |
| A3 A | 130 | 0 | 62.5 | 500 | 277.1 | |
| B | 20 | 60 | 0.0 | 0 | 184.7 | |
| A3RA | 130 | 0 | 0.0 | 0 | 277.1 | DALEMEAD |
| A3RB | 20 | 60 | 0.0 | 0 | 184.7 | DALEMEAD & DVRN |
| M1 | 40 | 0 | 72.0 | 2000 | 66.3 | |
| M1R | 40 | 0 | 72.0 | 2000 | 66.3 | HOLLAND |
| M2 | 30 | 0 | 49.0 | 3000 | 49.4 | |

NOTES: 1) Old canal is existing canal or river whose capacity is to be increased.
2) Dalemead & Dvrn is the Oldman diversion from Dalemead Dam

TABLE 4-3 UNIT COSTS FOR CANALS

| Item | Costs |
|---|---|
| Excavation | 2.10 $\$/m^3$ |
| Compact Fill | 2.95 $\$/m^3$ |
| Soil Stripping | 2.10 $\$/m^3$ |
| Land | 1500 \$/ha Right-of-Way<br>1500 \$/ha Clearing |
| Fencing | 5000 \$/km of Canal |
| Roadway | 2850 \$/km of Gravel Road |
| Grassing | 3000 \$/ha |
| Lining | 9 $\$/m^2$ of Perimeter |
| Additional Costs | 15% Contingencies |
| | 10% Engineering, Survey |
| | 10% Crossings, Care of Water |

NOTE: Assumes 20% shrinkage of excavated volume.

TABLE 4-4 CAPITAL COSTS OF MAIN CANALS

| Q Dsgn $m^3/s$ | Earth Work $/km | Land $/km | Fence &Road $/km | Grass $/km | Canal Lining $/km | Total Estimate $/km | Addtnl Costs $/km | Project Cost $/km |
|---|---|---|---|---|---|---|---|---|
| 5 | 80,630 | 9,210 | 7,850 | 5,000 | 98,175 | 200,865 | 70,300 | 271,165 |
| 15 | 151,320 | 13,220 | 7,850 | 6,600 | 153,825 | 332,815 | 116,485 | 449,300 |
| 30 | 211,640 | 16,240 | 7,850 | 7,400 | 196,625 | 439,755 | 153,915 | 593,670 |
| 50 | 273,475 | 19,050 | 7,850 | 7,710 | 236,580 | 544,665 | 190,630 | 735,297 |
| 75 | 341,685 | 21,860 | 7,850 | 8,800 | 276,000 | 656,875 | 229,905 | 886,780 |
| 100 | 399,610 | 24,100 | 7,850 | 9,250 | 308,930 | 749,740 | 262,410 | 1,012,150 |
| 140 | 485,715 | 27,180 | 7,850 | 10,000 | 353,325 | 884,670 | 309,425 | 1,193,495 |
| 180 | 562,680 | 29,780 | 7,850 | 10,600 | 390,870 | 1,001,780 | 350,625 | 1,352,405 |
| 240 | 660,495 | 32,980 | 7,850 | 11,240 | 437,850 | 1,150,415 | 402,645 | 1,553,060 |
| 300 | 752,625 | 35,820 | 7,850 | 11,830 | 479,325 | 1,287,450 | 450,608 | 1,738,058 |
| 350 | 825,100 | 37,930 | 7,850 | 12,210 | 510,300 | 1,393,390 | 487,685 | 1,881,075 |

<u>NOTES</u>: 1) Based on canal with 3:1 interior slope, 2.5:1 exterior, 4 m bank crest on either side.
2) Unit costs presented in Table 4-2.
3) Canal lining costs assume only 75% of canal is lined.
4) Addtnl Costs include Contingencies, Engineering, and Care of Water.

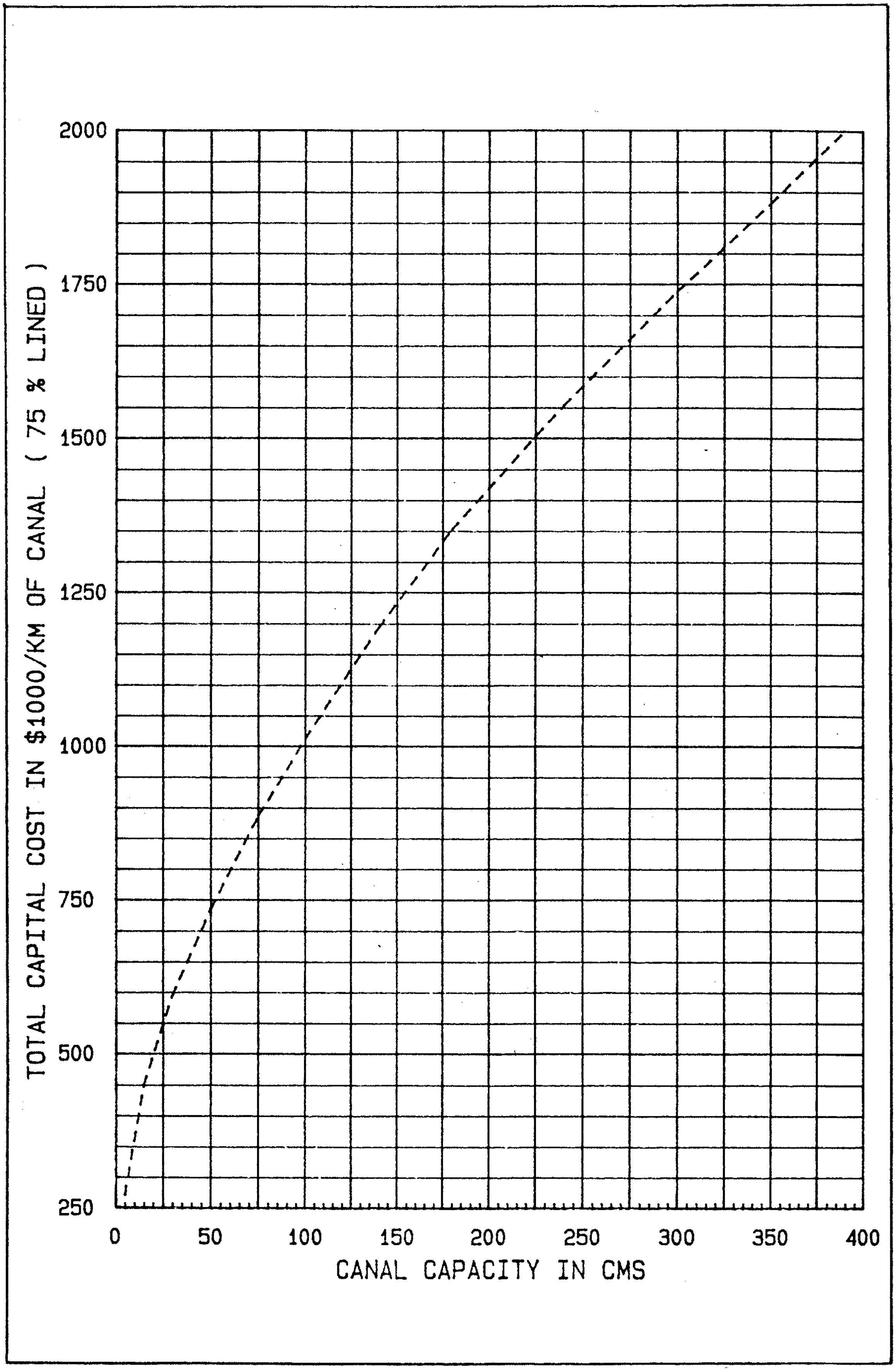


Figure 11 CANAL COSTS VERSUS CANAL CAPACITY

TABLE 4-5 PIPELINE COSTS

| Pipe Diam. mm | Max. Q $m^3/s$ | Stc. Head m | Frtn Loss m/km | Max. W.H. m | Min t mm | Sect. Mass Kg/m | Cap. Cost $/m | Unit Cost $/cms/m | Avgd Price $/cms/m |
|---|---|---|---|---|---|---|---|---|---|
| 1829 | 8.0 | 80 | 3.3 | 277 | 11.9 | 537 | 1800 | 225 | 225 |
| 1981 | 9.40 | 80 | 2.9 | 281 | 13.5 | 660 | 2210 | 235 | 235 |
| 2440 | 14.23 | 100 | 2.3 | 267 | 14.1 | 848 | 2841 | 200 | 165 |
| | | 100 | 2.3 | 133 | 9.1 | 548 | 1834 | 129 | |
| 3000 | 21.50 | 100 | 1.8 | 266 | 17.1 | 1265 | 4238 | 197 | 162 |
| | | | | 133 | 11.1 | 818 | 2739 | 127 | |
| | | 125 | 1.8 | 273 | 18.5 | 1372 | 4596 | 214 | 178 |
| | | | | 136 | 12.3 | 911 | 3052 | 142 | |
| | | 150 | 1.8 | 279 | 19.9 | 1475 | 4942 | 230 | 194 |
| | | | | 139 | 13.6 | 1005 | 3368 | 157 | |
| | | 175 | 1.8 | 284 | 21.3 | 1579 | 5288 | 246 | 209 |
| | | | | 142 | 14.9 | 1100 | 3685 | 171 | |
| | | 205 | 1.8 | 290 | 22.9 | 1697 | 5685 | 264 | 227 |
| | | | | 145 | 16.4 | 1211 | 4056 | 189 | |

NOTES:
1) Max Q = discharge for 3.05 m/s (10 fps) flow velocity.
2) Stc Head = static head for pumping.
3) Frtn Loss = friction losses in m/Km of pipeline.
4) Max W.H. = maximum water hammer for design of pipeline.
5) Min t = minimum thickness of steel required.
6) Sectn Mass is mass of design section in kg/m of pipeline.
7) Unit costs are in $ per $m^3/s$ per m of pipeline.
8) Avgd Price is averaged cost of section designed for full Water Hammer and section designed for 50% Water Hammer.

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TABLE 4-6 CAPITAL COSTS OF CONVEYANCE SYSTEM COMPONENTS cont'd

| SITE | Q | HEAD | PUMPPLANT | | PIPELINE | CANAL | CANAL | DISTR | SYSTEM |
|---|---|---|---|---|---|---|---|---|---|
| | $M^3/S$ | M | $\$x10^3$ | MW | $\$x10^3$ | \$/KM | $\$x10^3$ | \$/Ha | $\$x10^3$ |
| A1A | 94.3 | 0 | 0 | | 0 | 990 | 74250 | 1650 | 353000 |
| A1B | 222.4 | 0 | 0 | | 0 | 1510 | 67950 | 1650 | 353000 |
| A1C | 58.4 | 0 | 0 | | 0 | 780 | 105300 | 1650 | 177000 |
| A1AB | 318.5 | 0 | 0 | | 0 | | 142200 | 1650 | 706000 |
| A2A | 202.6 | 0 | 0 | | 0 | 1430 | 71500 | 1650 | 472000 |
| A2B | 203.7 | 0 | 0 | | 0 | 1430 | 78650 | 1650 | 472000 |
| A2C | 99.9 | 74 | 62268 | 51 | 9712 | 1020 | 25500 | 1650 | 236000 |
| A2CR | 99.9 | 8 | 33729 | 6 | 1619 | 1020 | 10200 | 1650 | 236000 |
| A3A | 279.4 | 63 | 124536 | 121 | 22635 | 1660 | 215800 | 1650 | 634000 |
| A3B | 186.3 | 30 | 57079 | 38 | 7545 | 1370 | 89050 | 1650 | 422000 |
| A3AR | 279.4 | 0 | 0 | | 0 | 1660 | 215800 | 1650 | 634000 |
| A3BR | 186.3 | 0 | 0 | | 0 | 1370 | 89050 | 1650 | 422000 |
| M1 | 66.3 | 52 | 36323 | 24 | 21477 | 850 | 34000 | 1410 | 169000 |
| M2 | 49.4 | 49 | 32172 | 17 | 24025 | 730 | 21900 | 1370 | 123000 |

NOTES: 1) All costs shown are capital costs
2) MW is electrical capacity of pumps in Megawatts
3) DISTR SYSTEM is water distribution system

TABLE 4-7 COSTS OF RESERVOIRS

| RESERVOIR | NODE | CAPITAL COST $\$ \times 10^6$ | MAXIMUM STORAGE CAPACITY $DAM^3 \times 10^3$ | UNIT COST OF STORAGE $\$/DAM^3$ |
|---|---|---|---|---|
| Highgate | 17 | 393.2 | 4875 | 81 |
| Callaghan | 18 | 280.9 | 4380 | 64 |
| McDonald | 10 | 12.2 | 78 | 156 |
| Meridian | 8 | 356.3 | 1950 | 183 |
| Rocky Mountain | 13 | 295.3 | 987 | 299 |
| Horseguard | 13 | 97.9 | 586 | 167 |
| Raven | 6 | 38.5 | 168 | 229 |
| Dalemead | 3 | 268.0 | 1345 | 199 |
| Holland | 2 | 51.4 | 765 | 67 |
| Lake Diefenbaker | 10 | EXISTING | 9365 | N/A |

NOTE: Based on SNBB Costs [73] escalated by 3.21 (USBR 1968 to 1987).

TABLE 4-8 COSTS OF FLOW DIVERSION

| DIVERSION | FLOW CAPACITY $M^3/S$ | CAPITAL COST $\$ \times 10^6$ | ANNUAL ENERGY USE MWhr |
|---|---|---|---|
| N.Saskatchewan to | 28.3 | 410 | 0.0 |
| Red Deer River | 56.6 | 420 | 0.0 |
| | 84.9 | 425 | 0.0 |
| | 27.0 | 410 | 0.0 |
| Red Deer River to | 56.6 | 305 | 100.0 |
| Bow River | 15.4 | 120 | 27.2 |
| Bow River to | 56.6 | 360 | 0.0 |
| Oldman River | 28.3 | 334 | 0.0 |
| (ie. A3RB) | 48.1 | 353 | 0.0 |

NOTE: Annual energy use is energy required by pump in addition to hydroelectric energy generated by flow, based on pump efficiency of 70% and generating efficiency of 90%.

SOURCE: Adapted from SNBB [73].

# CHAPTER 5 ECONOMIC ANALYSIS

## 5.1 INTRODUCTION

The decision to irrigate the areas identified in this study will be a political act incorporating the best judgment of the various agencies and parties interested in large scale irrigation of the prairies. This decision should be based on a whole plethora of information including the overall social benefits and costs, who they accrue to, the income distribution, employment, and the sociological problems and solutions offered by these developments. An economic analysis cannot select what project can best satisfy all of the requirements and priorities of the different agencies involved in irrigation development, but it can provide a very effective tool by which their judgment can be sharpened. When the amount of resources available for development is restricted, as it was in this study for both water and capital funds, then economic analysis can be used to identify economically optimal projects as well as to rank the projects in order of their economic attractiveness. These rankings could be used to assess just how much of the prairies should be irrigated from the available prairie water resources, and what areas should be developed and in what order. This procedure inherently assumes that project selection is based strictly on economics and that all non-economic or non-quantifiable considerations would be approximately equal for all of the potential developments. This assumption can be readily disproved on an individual case level by noting that while it is possible for a pumping plant and a storage reservoir to have identical direct benefit and cost streams, the direct and indirect benefits and costs of each will differ considerably and accrue to different sectors of the community. When viewing overall systems which are composed of reservoirs, canals, and pumping plants then the assumption becomes considerably more valid. This simplifying assumption was used to examine the system of irrigation developments which would allow full utilization of the prairie water resources available for irrigation. Given that the priorities upon the economic, non-economic, and non-quantitative considerations will vary with the viewpoint of each affected or concerned individual, the data presented can be readily used to examine other systems and other viewpoints.

An essential step in the economic analysis of an irrigation development is the identification of the total costs and benefits associated with the development. One of the difficulties with irrigation projects is that often the total costs and benefits to society are very difficult to quantify with any degree of certainty.

## 5.2 BENEFITS OF IRRIGATION

### 5.2.1 Direct Benefits of Irrigation

The direct benefits of developing the irrigable areas identified in Chapter 2 were taken to be the total net increase in on-farm income, as presented in Tables 2-25 to 2-32. It should be noted that the calculation of these benefits inherently assumes that no significant changes in farm size will result from the irrigation development. This assumption does not wholly agree with the pattern exhibited in previous developments on the prairies, but any alterations in farm size which may occur will not significantly affect the project benefits. Given the nature and scale of this study, the possible effects of land and field redistribution were neglected.

The calculations of the present worth of the direct benefits were based on the 15 year development period suggested in Chapter 2, with the benefits assumed to increase linearly from the first year of development to full annual benefits by the fifteenth year, while the life of the project was assumed to be 50 years. Given adequate farm and soil management, the actual life of the developments should be perpetuity, but the present worth of the benefits would not deviate significantly from that determined for the 50 year project life assumed in this study.

### 5.2.2 Indirect Benefits

The indirect benefits of irrigation are typically 1 to 2.5 times the direct benefits of irrigation [83], and are so named because they are only associated with the irrigation development, rather than arising directly from the increased crop production. These benefits would include:

- the economic activity generated by the increased purchases of farm inputs such as fertilizer, chemicals, and irrigation equipment
- the economic activity generated by increased expenditures on services and products due to the increased farm income
- the expansion of the local, regional, and national crop processing industries

- any other economic activities associated with the irrigation development

The difference between the benefits and costs of the above activities is termed the value added, and are the actual indirect (or secondary) benefits of the increased agricultural production. Several recent studies on agriculture and irrigation on the prairies have determined that these indirect benefits typically range from 1 to 1.5 times the direct benefits [84,85].

It has been argued by some analysts that these benefits should not be included in the economic analysis of irrigation development, since the additional purchases of input will simply reduce the amount available to other sectors, the net result of which is that there has been no value added to the economy. This reasoning is only correct if the input supply or capacity is limited and cannot expand in response to any alteration in demand. As this is certainly not the case with agricultural inputs in Canada, these secondary benefits appear to warrant some consideration in the economic analysis of the irrigation developments. For the purposes of this study, the majority of the analyses used only the direct benefits, but some scenarios were examined using indirect benefits equal to 1.5 times the direct benefits of irrigation. While this factor agrees with several previous studies of indirect benefits of irrigation [83,85], it is considerably less than the 2.47 factor derived from analysis of the South Saskatchewan River Irrigation Development [84] or the 6.67 factor derived from analysis of irrigation districts in Alberta [86]. For the purposes of this study the 1.5 multiplier used to determine the indirect benefits was deemed sufficiently valid, however, a more rigorous study of the potential for irrigation development of the prairies would probably require a more formal analysis of the indirect benefits using such methods as an input-output model.

In addition to the direct and indirect economic benefits associated with the increased agricultural production in these districts, there will also be considerable social and economic benefits associated with the relatively stable crop yields. Irrigation will provide for a continued supply of food and economic activity in drought years, thus dampening the boom-bust cycle so frequently observed in the prairie agri-business.

The construction of the works required to supply water to the irrigation districts, and the maintenance of the supply systems, are expected to provide considerable employment benefits given the current high rate of unemployment on the prairies. In some agricultural development studies the social benefits of this employment are included in the economic analysis by reducing the project's capital cost by some proportion reflecting the amount of labour included in the total capital cost [82,83]. For the purposes of this study, the employment benefits resulting from the works were not used to reduce the capital costs of the works required throughout the economic analyses of the irrigation developments.

An additional benefit associated with the construction of any reservoirs is the recreation benefits which could arise from the impoundment. Given the paucity of scenic lakes upon the prairies, these recreation benefits could be considerable if the water level fluctuations were constrained to produce a suitable habitat for aquaculture and an aesthetically pleasing shoreline. No attempt was made to include these possible economic, social, and aesthetic benefits into the analysis due to the difficulty of quantifying them and the nature of this study, but it is apparent that they could be significant and must be considered in a more rigorous study of potential large scale irrigation on the prairies. Recent studies in the United States indicate that although recreation benefits are often neglected in the initial economic analysis of water resource projects, after a number of years they often come to exceed the forecast direct benefits for the primary purpose of the reservoir [87].

## 5.3 COSTS OF IRRIGATION

### 5.3.1 Direct Costs

The direct costs of developing the irrigable areas identified in Chapter 2 are the sum of the project costs presented in Tables 4-6 to 4-8, and the cost of the required pump energy. To calculate the present worth of each of these costs, the annual cost of each component was calculated and was then converted to its present worth assuming a project life of 50 years. This allows the analysis to include the varying lives of the different components of the supply system. The annual energy costs of pumping the average water requirement at each site were determined using the pump energy cost relationships presented in Chapter 4, and were based on the \$.04 per Kwh and \$.08 per Kwh energy values. The present worth of the pump energy costs assumed a linear development pattern from year 1 to year 15, since the water volume required is expected to be proportional to the developed area.

## 5.3.2 Indirect Costs of Irrigation

Just as the development of an irrigated area produces indirect benefits which are difficult to quantify, so too are produced indirect costs which are exceedingly difficult or even impossible to identify and quantify. Many of the social costs involved can in no way be readily quantified in terms of dollars. Some of the potential indirect costs which may be associated with the large scale development of irrigation on the prairies include:

a) the salinization of low lying farmland adjacent to the irrigation districts due to excessive applications of water, or a raised local water table due to seepage from the canals and distribution system

b) displacement of farmsteads located within the required right of way for the canals and reservoirs, over and above the direct costs of $1500 per hectare

c) the environmental degradation which could occur during the construction and operation of the conveyance system

d) the degradation in water quality for other instream users, including the existing flora and fauna, due to the large scale withdrawals and/or impoundment of flow

e) the changes in river regime induced by the flow withdrawals, diversions, and impoundments required for development of the projects

f) the increased transportation costs to farmers to bypass the reservoirs or to go to the canal crossings

g) the loss of energy from the various hydroelectric generating stations located on the prairie river network due to the decreased river flows.

It is apparent that these indirect costs could be extremely significant, especially if neglected during the planning stages of the proposed developments. Given careful design and planning however, it is extremely probable that many of the adverse effects of developing the areas identified could be mitigated or would be partially offset by the non-quantifiable benefits. For the case of the decreased hydroelectric energy production, the approximate direct costs can be calculated, however the validity of their inclusion into the analysis may be questionable, as is discussed in the subsequent section.

For the purpose of this study, no attempt was made to incorporate indirect costs into the overall analysis of the identified projects, due to the difficulty in assessing their largely non-quantifiable costs and the possibility of their partial mitigation in the final design of the projects.

### 5.3.3 LOSS OF HYDROELECTRIC GENERATION BENEFITS

The value of the energy production lost due to development of the irrigated areas is most readily determined from unit energy per flow volume values derived from the data presented in the PPWB report [70], which lists the total energy generated along with the gross flows for the different basins and prairie provinces. Based on this data, the unit energy value is approximately \$4.80 per $dam^3$ for flows in Alberta, \$4.00 per $dam^3$ on the Saskatchewan rivers, and \$3.00 per $dam^3$ on the Manitoba rivers, for an energy cost of \$.04 per Kwh. As the hydroelectric generating plants in Alberta are located upstream of the irrigable areas, only the energy production of the Manitoba and Saskatchewan hydroelectric plants would be affected by development of the proposed irrigation projects. Assuming that all of the potential irrigation projects identified were fully developed, then in an average year the power production in Manitoba would drop by about 8 percent from the present conditions, for an annual economic loss of about \$40 million. The difficulty with including this cost into the economic analysis of irrigation development is that the cost of the energy losses can not be placed directly upon the irrigation development, since the terms of the provincial flow apportionment agreement will still be satisfied. This loss of energy production will occur whether the flows are utilized for industrial, municipal, irrigation, or any other purpose by the upstream province, and are truly a cost to Manitoba induced by the development and utilization of the upstream provinces water resources, and thus may eventually occur whether irrigation development proceeds or not. The identical comments as above also apply to Saskatchewan, which will see its hydroelectric generation decreased by the development and utilization by Alberta of its share of the flow apportionments. The possible loss of energy costs directly attributable to each development could be readily determined, and should be examined in a more rigorous study of the problem, but for the purposes of this study the indirect costs due to the decreased generation of hydroelectric energy were neglected, since they will accrue to whatever development occurs on the prairie river network, and because of the limited scope of this study.

## 5.4 ECONOMIC DISCOUNT RATE

To compare investments having cost and benefit streams which vary considerably over the life of the investment or project, an economic discount rate is required to relate all of the costs and benefits to a common baseline to facilitate comparison of the alternatives. This common base could be the present worth of the benefits and costs, the future worth, or their equivalent annual worth. For the financing of water resource or irrigation development projects, the economic discount rate should correspond to the free market interest rate at which the development agency can obtain the necessary capital. For the purposes of this study, the free market interest rate available for irrigation development was assumed to be between 5 and 12 percent. Currently the free market interest rate for the federal government is approximately 9.0 percent.

It should be noted that these free market interest rates do not include the effects of inflation, which can be especially significant in irrigation development since the majority of the capital costs are generally at the onset of the project, while the dollar value of the yearly benefits will rise as inflation increases their apparent worth. To analyze the cost and benefit streams in equivalent or constant dollars, the effects of inflation must be eliminated. This is most readily done by subtracting the expected inflation rate from the economic discount rate [82], the difference of which is termed the real effective interest rate. Based on the current inflation rate of about

4 percent, the real effective interest rates utilized in this study for relating the cost and benefits streams ranged from 1 to 8 percent. Historically, real effective interest rates have ranged from 2 to 5 percent , but generally the rate has been about 4 percent [88]. The upper range of the rates examined also corresponds closely to the present "free market" interest rate of about 9.0 percent.

## 5.5 METHODS OF ECONOMIC ANALYSIS

There are three basic measures of the economic efficiency and desirability of an investment of capital into water resource or irrigation development:

1) The benefit - cost (or B/C) ratio is the benefits of the proposed development divided by the total cost of the development, with a specified interest rate being used to equilibrate the cost and benefit cash flows to a common baseline such as the future, present, or equivalent annual worth.

2) The net benefits (or B-C) of a project is the arithmetic difference between the benefits and the costs of the development, with the cash flows being equilibrated with a specified interest rate.

3) The internal rate of return (or IRR) of a project is the economic discount rate at which the project costs will equal the benefits when equilibrated to a common baseline.

While all of the above values are useful indicators of the economic desirability of developing a proposed area, the significance of each measure will vary with the particular economic scenario which prevails at the time of the analysis, as is fully described in the excellent discussions in references [82] and [83], and shall not be duplicated here. For this particular study, both investment capital and the volume of water available for irrigation were expected to be in relatively short supply. Given this constraint of limited resources, the most appropriate measure of the economic attractiveness of a proposed development will generally be the internal rate of return. Assuming that all of the total benefits and costs to society are quantified and all non-quantifiable aspects are approximately equal for each project, then the project selection would begin at the project with the highest rate of return and proceed in order of decreasing rates of return until the budget, be it capital or water volume, is exhausted.

The internal rate of return and the benefit-cost ratios for each project for interest rates ranging from 1 to 8 percent are presented in Tables 5-1 to 5-3 on pages 156 to 158 for the various economic scenarios examined in this study. These analyses are based on the direct costs and benefits of irrigation development, with all of the costs and benefits of the developments being converted to their present worth.

## 5.6 ECONOMICS OF IRRIGATION DEVELOPMENT OF THE PRAIRIES

As can be observed from Tables 5-1 to 5-3, the economic attractiveness of developing the potential irrigation projects identified in this study is greatly dependent upon the scenario examined. For the purposes of this study, the defined present agricultural practices and crop values shall be considered as the most representative of the scenarios examined. The other scenarios such as varying the present crop values by −25 to +100 percent, and the envisioned changes to dryland farming on the prairies, should be viewed as components of the sensitivity analysis, since the probability of either a change in dryland cultivation practices or a significant real increase in crop value is unknown, and any assessment of their probability of occurrence would be largely speculative.

### 5.6.1 Irrigation Development Under Present Conditions

For the defined present conditions, the projects examined in this study had rate of returns ranging from 4.7 percent to less than 1 percent based on only the direct benefits, and rates of returns ranging from 8 percent to less than 1 percent if indirect benefits equal to 1.5 times the direct benefits were included. For the best estimate real interest rate of 4 percent, the benefit-cost ratios for the direct benefits range from 1.16 for S5 to 0.16 for S20, and range from 2.90 to 0.40 if indirect benefits are included. Of the 32 potential sites examined by this study, 18 projects have benefit-cost ratios greater than 0.5 based on direct benefits at a real interest rate of 4 percent, which would correspond to a benefit-cost ratio of 1.25 if indirect benefits are included.

From the values presented in Table 5-1, it is apparent that if only the direct benefits are included in the analysis of the present conditions, then some of the proposed projects are not economically attractive even at interest rates as low as 1.0 percent. If the indirect benefits of the development are included in the analysis, then the attractiveness of all of the projects improves, but several projects still remain economically unattractive under the defined present conditions. It must be stressed that the intent of this study was merely to assess the irrigation potential of the Canadian prairies, and to determine which projects warrant further, more detailed examination. For the purposes of this study, any project having a rate of return less than 1.0 percent for its direct and indirect benefits under present conditions was considered economically infeasible. This is not to imply that any project having a rate of return in excess of this defined criteria is economically attractive, since that is a decision for the agency funding the development, but rather, under some conditions the potential economic worth of the projects could be quite significant and the projects should be examined in greater detail.

It should be noted from Tables 5-1 to 5-3 that the savings in the pump energy costs resulting from the decreased pumping heads produced by the construction of any new reservoirs did not justify the cost of building the reservoirs, as all of the projects which pump directly from the river have greater rate of returns. These reservoirs may be justifiable if the recreation and other benefits excluded from the analysis were incorporated into this study, but to simplify the analysis the only benefits from the construction of reservoir considered in this study were the reduction in pumping head and the storage volume available for flow regulation. As will be discussed in Section 5.7 and Chapter 6 of this report, new reservoirs were required to develop some of the projects examined due to a shortage of water during the irrigation season.

### 5.6.2 Sensitivity Analysis of the Project Economics

To determine the sensitivity of the benefits and costs of the projects examined in this study, several alternate scenarios and assumptions were included in the analysis of the economic worth of developing the potential projects. The factors examined in the sensitivity analysis included:

- variations in the real effective interest rate
- the envisioned future cropping conditions
- variation of the present crop prices
- variations in the cost of energy
- variation of the area requiring sub-surface drainage

The effects of each of these factors can be observed from Tables 5-1 to 5-3, and are briefly discussed below.

a) Variation of Real Effective Interest Rates

As was expected, the economic worth of the projects examined were quite sensitive to the real effective interest rates used to analyses the projects. The benefit-cost ratio for an interest rate of 1 percent was approximately 4 to 11 times the benefit-cost ratio for an interest rate of 8 percent. For the purposes of this study a real interest rate of 4 percent was considered as the most realistic value for analysis, however the results for rates ranging from 1 to 8 percent are also presented for comparative purposes.

b) Variation in Crop Prices

The sensitivity of the economic worth of the projects to changes in the crop price values can be observed from Table 5-2, which presents the benefit-cost ratios for the proposed developments for crop prices ranging from 75 percent to 200 percent of the present crop prices used in the analyses. These crop values correspond to a change in crop prices of -25 percent to +100 percent. From the results of Table 5-2, it is apparent that the economic worth of irrigation development is extremely sensitive to the market value assumed for the crop of interest. To illustrate the extreme sensitivity, a 25 percent increase in crop prices roughly doubled the benefit-cost ratios for the majority of the projects, while a 25 percent reduction reduced the benefit-cost ratios by factors of 3 to 20, and reduced 12 projects to negative benefit-cost ratios. A negative ratio is produced when the on-farm irrigation costs are greater than the increase in crop production benefits. The crop price change that was required to produce a direct benefitcost ratio equal to one for each project, at an effective interest rate of 4 percent, is also presented in Table 5-2. These values range from a change of -4 percent for S5, to +140 percent for S17R.

For the purposes of this study, the present crop prices identified in Chapter 2 were considered as the most realistic crop values since any attempt to predict long term real crop prices is purely speculative given the current global market for grains. The values presented in Table 5-2 do indicate just how little an increase in crop values is required to greatly increase the economic attractiveness of irrigation development, as well as the impact a decrease in crop values would have upon the various projects.

c) Future Agricultural Practices

The future conditions envisioned in this study assume that the amount of crops grown on summerfallow will decrease substantially in the near future and that increased inputs will allow an increase in continuous cropping, if economic conditions (i.e. crop prices) warrant such a change. This move to increased continuous cropping may greatly reduce the on-farm benefits of irrigation, as is evident in Table 5-3, which presents the benefit-cost ratios and internal rate of returns for the projects under the defined future cropping conditions. Comparison with Table 5-1 reveals that all of the proposed developments have much lower benefit-cost ratios under future conditions than under present conditions. At a real interest rate of 4 percent, the benefit-cost ratios range from 0.70 for S16 to -.23 for M1. The negative benefit-cost ratio indicates that the net on-farm irrigation benefits are negative as the increased crop production under irrigation does not justify the increased on-farm costs of the irrigation system.

It is evident from Table 5-3 that should the envisioned change in dryland agriculture occur, then the economic worth of developing the potential projects may be greatly reduced or even eliminated. It is difficult to assess the probability of such a significant change in dryland farming, since these changes were forecast to arise from increased export demands for agricultural products and a subsequent increase in the real price of crops. Given the current weak global demand for grain exports, the probability for such a significant shift in dryland agriculture presently appears very small, but conditions could readily change in the future. For the purposes of this study, the present conditions were deemed to represent the most realistic scenario for examining the economic worth of large scale irrigation development on the prairies. A more rigorous analysis of the irrigation potential of the prairies should examine the issue of altered farm practices and crop production in greater detail, but any predictions as to future farming conditions and crop prices is likely to remain extremely speculative.

d) Variation of Energy Costs

The sensitivity of the economic worth of developing the various projects to variations in the cost of the energy used to divert and supply the water to the crops was assessed by increasing the energy cost from $0.04 per Kwh to $0.08 per Kwh. As can be observed from Table 5-1, the economic worth of the potential developments is relatively insensitive to large variations in the cost of energy, and the relative attractiveness of each project remains virtually unchanged.

e) Variation of the Area Requiring Sub-surface Drainage

The sensitivity of the economic worth of developing the various projects to variations in the sub-surface drainage scheme envisioned for each project was assessed by increasing the amount of land to be drained by 20 percent. As can be observed from Table 5-1, the economics of the projects are relatively insensitive to variations in the amount of drainage required, and the relative attractiveness of each project remains virtually unchanged.

## 5.7 ECONOMICS OF IRRIGATION DEVELOPMENTS : Phases I,II,& III

In the previous section, the relative economic worth of each particular project was determined to allow the projects to be ranked in order of their relative economic attractiveness. This selection or ranking criteria implicitly assumes that all of the true costs and benefits to society for each project are quantified, and any non-quantifiable effects are approximately equal for every project. The relative ranking of each project was used to examine the flow allocations required to develop those projects identified as being potentially attractive for development. As previously mentioned, only those projects having a rate of return based on direct and indirect benefits greater than 1 percent were deemed economically feasible under the defined present conditions. For the purposes of ranking the economic desirability of the various projects, the rate of return for developing only a portion of a project was assumed to equal that for the entire project where the volume of water available proved insufficient for full development. This assumption may not be consistent with scale economics, but greatly simplified the analysis and was reasonably consistent with the cost functions for the canals, pump plants, pipelines, and pump energy. The development of the economically attractive irrigation projects was separated into three distinct phases, with Phase I developing as many of the projects as could be developed using only the natural flow volumes of the prairie rivers, Phase II added new reservoirs to supplement the flow during the peak demand months of the irrigation season, while Phase III added intra-basin diversions to augment the flow of the South Saskatchewan River in Alberta. The flow allocations and works required for the various phases of development are presented in Chapter 6, while the economic analyses of the different phases is presented below.

### 5.7.1 Irrigation Development : Phase I

The first phase of irrigation development, termed Phase I, included only those projects which did not require reservoirs to supply their water requirements, since the economic analysis of the individual projects in Section 5.6 revealed that the costs of the reservoirs were greater than the benefits, provided that water was readily available for pumping throughout the irrigation season. The projects included in the Phase I development, along with the present worth of their direct costs and benefits at an effective interest rate of 4.0 percent, are presented in Table 5-4 on page 159. The total present worth of all costs associated with the Phase I development is approximately $8.23 billion, while the present worth of the direct benefits is approximately $5.6 billion, for a benefit-cost ratio of 0.68. If indirect benefits equal to 1.5 times the direct benefits are included in the analysis then the benefit-cost ratio increases to 1.70 for the best estimate interest rate of 4.0 percent.

Approximately 2,965,000 hectares of land would be irrigated under the Phase I development, which corresponds to the development of 74 percent of the total area identified in this study as potentially irrigable.

### 5.7.2 Irrigation Development : Phase II

To develop the full irrigation potential of the Alberta portion of the South Saskatchewan River basin and the Assiniboine River basin in Manitoba, several new reservoirs were added to the proposed irrigation system to increase the area irrigated. The resulting system of projects and reservoirs was termed Phase II of the development of the irrigation potential of the prairies. The total present worth of all of the costs associated with the Phase II development is approximately $9.65 billion, while the present worth of the direct benefits is $6.45 billion, for a benefit-cost ratio of 0.67 at an effective interest rate of 4.0 percent. If indirect benefits are included in the analysis, the benefit-cost ratio increases to 1.67. These values indicate that the incremental cost of adding the reservoirs to the irrigation system is greater than the incremental benefits produced by the further development.

Approximately 3,210,000 hectares of land would be irrigated under the Phase II development, which corresponds to the development of 80 percent of the total area identified in this study as potentially irrigable.

### 5.7.3 Irrigation Development : Phase III

The third phase of irrigation development, termed Phase III, was the development of the full irrigation potential of those sites which were supplied with water from the Bow and Red Deer rivers, which required water be imported to these basins since the Alberta portion of the provincial flow apportionment of the South Saskatchewan River is fully consumed by the Phase II development. The imported water would be diverted from the North Saskatchewan basin into the Red Deer and subsequently into the Bow River. The total present worth of the costs of the Phase III development is approximately $10.95 billion, while the present worth of the direct benefits is $6.75 billion, for a benefit-cost ratio of 0.62. If indirect benefits are included in the analysis, the benefit-cost ratio increases to 1.55. These values indicate that the incremental cost of adding the intra-basin flow diversions greatly exceed the additional benefits associated with the increased development.

Approximately 3,690,000 hectares of land would be irrigated under the Phase III development, which corresponds to the development of 93 percent of the total area identified in this study as potentially irrigable. The remaining area was found to have an internal rate of return of less than 1.0 percent even with indirect benefits included, and was therefore deemed economically infeasible under the defined present conditions. Should future conditions result in the development of these areas becoming more economically attractive, then additional flow diversions may be required from the North Saskatchewan, the Peace, the Smokey, and the other rivers of northern Canada. The benefits and costs of these additional diversions should be examined in a more comprehensive study of the irrigation potential of the prairies, however for this study, the flow diversions from the North Saskatchewan allowed the full development of all of the projects identified in this study as having the potential to be economically attractive under present conditions.

Based on the benefit-cost ratios for the individual projects and the different phases of irrigation development, it is apparent that the irrigation potential of the prairies warrants further, more detailed study than was possible in a study of this nature. In comparison to the amount of the potential direct and indirect benefits which could arise from large scale development of the irrigation potential of the prairies, the expected costs of such a study will be insignificant.

TABLE 5-1 BENEFIT COST RATIO, IRR: PRESENT CONDITIONS

| SITE | DIRECT BENEFIT-COST RATIOS FOR INTEREST RATES OF | | | | | ALT DRNGE | ALT ENRGY | IRR |
|---|---|---|---|---|---|---|---|---|
| | i = 1 B/C | i = 2 B/C | i = 4 B/C | i = 6 B/C | i = 8 B/C | i = 4 B/C | i = 4 B/C | % |
| S1 | 0.978 | 0.773 | 0.456 | 0.241 | 0.096 | 0.400 | 0.313 | <1.0 |
| S1R | 0.624 | 0.479 | 0.267 | 0.134 | 0.051 | 0.234 | 0.199 | <1.0 |
| S2 | 0.832 | 0.657 | 0.386 | 0.200 | 0.077 | 0.336 | 0.252 | <1.0 |
| S2R | 0.556 | 0.427 | 0.238 | 0.119 | 0.044 | 0.208 | 0.169 | <1.0 |
| S3 | 1.031 | 0.852 | 0.563 | 0.357 | 0.214 | 0.521 | 0.411 | 1.2 |
| S3R | 0.668 | 0.531 | 0.327 | 0.196 | 0.112 | 0.303 | 0.266 | <1.0 |
| S4 | 1.818 | 1.488 | 0.975 | 0.620 | 0.376 | 0.902 | 0.734 | 3.9 |
| S4R | 1.374 | 1.099 | 0.688 | 0.420 | 0.245 | 0.637 | 0.553 | 2.5 |
| S4R2 | 1.588 | 1.251 | 0.766 | 0.461 | 0.267 | 0.708 | 0.661 | 3.0 |
| S5 | 2.365 | 1.873 | 1.161 | 0.708 | 0.416 | 1.076 | 0.964 | 4.7 |
| S6 | 1.600 | 1.252 | 0.755 | 0.446 | 0.253 | 0.697 | 0.622 | 3.0 |
| S4R56 | 1.763 | 1.389 | 0.851 | 0.512 | 0.296 | 0.788 | 0.724 | 3.4 |
| S7 | 0.705 | 0.539 | 0.299 | 0.151 | 0.060 | 0.263 | 0.245 | <1.0 |
| S8 | 1.401 | 0.130 | 0.719 | 0.445 | 0.264 | 0.667 | 0.569 | 2.6 |
| S9 | 0.657 | 0.501 | 0.278 | 0.140 | 0.056 | 0.245 | 0.227 | <1.0 |
| S10 | 1.113 | 0.877 | 0.516 | 0.273 | 0.113 | 0.453 | 0.400 | 1.5 |
| S11 | 1.594 | 1.314 | 0.869 | 0.554 | 0.336 | 0.805 | 0.621 | 3.4 |
| S12 | 1.594 | 1.322 | 0.884 | 0.569 | 0.348 | 0.820 | 0.638 | 3.5 |
| S13 | 0.935 | 0.762 | 0.491 | 0.305 | 0.180 | 0.455 | 0.364 | <1.0 |
| S14 | 0.534 | 0.441 | 0.292 | 0.185 | 0.113 | 0.272 | 0.195 | <1.0 |
| S15 | 0.922 | 0.774 | 0.528 | 0.347 | 0.219 | 0.493 | 0.355 | <1.0 |
| S14,15 | 0.722 | 0.602 | 0.405 | 0.262 | 0.162 | 0.377 | 0.270 | <1.0 |
| S16 | 1.146 | 0.962 | 0.659 | 0.434 | 0.274 | 0.614 | 0.434 | 1.8 |
| S16R | 0.570 | 0.452 | 0.278 | 0.168 | 0.099 | 0.262 | 0.218 | <1.0 |
| S17 | 0.969 | 0.799 | 0.528 | 0.338 | 0.208 | 0.497 | 0.383 | 1.0 |
| S17R | 0.423 | 0.336 | 0.207 | 0.126 | 0.074 | 0.194 | 0.165 | <1.0 |
| S19 | 0.563 | 0.441 | 0.255 | 0.132 | 0.053 | 0.224 | 0.180 | <1.0 |
| S20 | 0.382 | 0.294 | 0.164 | 0.081 | 0.030 | 0.143 | 0.108 | <1.0 |
| S21 | 0.399 | 0.309 | 0.175 | 0.088 | 0.033 | 0.153 | 0.118 | <1.0 |
| A1A | 1.720 | 1.313 | 0.749 | 0.408 | 0.199 | 0.674 | 0.633 | 3.1 |
| A1B | 2.291 | 1.756 | 1.014 | 0.562 | 0.278 | 0.912 | 0.857 | 4.0 |
| A1C | 1.172 | 0.891 | 0.502 | 0.270 | 0.129 | 0.452 | 0.425 | 1.6 |
| A1AB | 2.194 | 1.680 | 0.968 | 0.535 | 0.264 | 0.871 | 0.819 | 3.9 |
| A2A | 2.383 | 1.825 | 1.052 | 0.580 | 0.284 | 0.944 | 0.863 | 4.1 |
| A2B | 2.342 | 1.793 | 1.033 | 0.569 | 0.278 | 0.927 | 0.847 | 4.0 |
| A2C | 1.305 | 1.043 | 0.641 | 0.367 | 0.183 | 0.575 | 0.459 | 2.2 |
| A2CR | 0.968 | 0.740 | 0.420 | 0.225 | 0.106 | 0.377 | 0.341 | <1.0 |
| A3A | 1.233 | 0.975 | 0.588 | 0.331 | 0.163 | 0.527 | 0.431 | 1.9 |
| A3B | 1.608 | 1.260 | 0.749 | 0.419 | 0.206 | 0.672 | 0.573 | 3.0 |
| A3AR | 1.406 | 1.069 | 0.603 | 0.324 | 0.154 | 0.541 | 0.495 | 2.3 |
| A3BR | 1.171 | 0.889 | 0.499 | 0.266 | 0.125 | 0.448 | 0.410 | 1.6 |
| M1 | 0.906 | 0.659 | 0.303 | 0.080 | -0.059 | 0.228 | 0.190 | <1.0 |
| M2 | 0.909 | 0.662 | 0.307 | 0.087 | -0.049 | 0.234 | 0.211 | <1.0 |

NOTES:
1) i is interest rate in %, IRR is internal rate of return in % for present conditions defined in Chapter 2
2) ALT DRNGE is alternate pattern of drainage
3) ALT ENRGY is alternate energy cost of $0.08 per Kwh

TABLE 5-2 BENEFIT-COST RATIOS: PRESENT CONDITIONS, VARIED PRICES

| | DIRECT BENEFIT-COST RATIOS FOR i = 4.0% | | | | | GI |
|---|---|---|---|---|---|---|
| SITE | GI=-25% | GI=+0% | GI=+25% | GI=+50% | GI=+100% | for |
| | B/C | B/C | B/C | B/C | B/C | B/C=1 |
| S1 | -0.033 | 0.456 | 0.934 | 1.411 | 2.365 | 28 |
| S1R | -0.019 | 0.267 | 0.547 | 0.826 | 1.384 | 65 |
| S2 | -0.037 | 0.386 | 0.797 | 1.205 | 2.032 | 35 |
| 92R | -0.023 | 0.238 | 0.493 | 0.747 | 1.256 | 75 |
| S3 | 0.084 | 0.563 | 0.974 | 1.384 | 2.206 | 26 |
| S3R | 0.049 | 0.627 | 0.566 | 0.805 | 1.283 | 70 |
| S4 | 0.148 | 0.975 | 1.684 | 2.393 | 3.811 | 1 |
| S4R | 0.104 | 0.688 | 1.189 | 1.689 | 2.693 | 15 |
| S4R2 | 0.116 | 0.765 | 1.324 | 1.881 | 2.996 | 10 |
| S5 | 0.167 | 1.161 | 2.013 | 2.859 | 4.555 | -4 |
| S6 | 0.094 | 0.755 | 1.323 | 1.890 | 3.025 | 10 |
| S4R2,5,6 | 0.125 | 0.851 | 1.473 | 2.094 | 3.337 | 6 |
| S7 | -0.007 | 0.299 | 0.600 | 0.900 | 1.501 | 60 |
| S8 | 0.118 | 0.719 | 1.231 | 1.744 | 2.768 | 14 |
| S9 | -0.006 | 0.278 | 0.557 | 0.837 | 1.395 | 65 |
| S10 | -0.012 | 0.516 | 1.034 | 1.551 | 2.387 | 25 |
| S11 | 0.125 | 0.869 | 1.504 | 2.138 | 3.407 | 5 |
| S12 | 0.134 | 0.884 | 1.525 | 2.164 | 3.444 | 5 |
| S13 | 0.074 | 0.491 | 0.846 | 1.201 | 1.911 | 36 |
| S14 | 0.030 | 0.291 | 0.498 | 0.702 | 1.110 | 86 |
| S15 | 0.073 | 0.528 | 0.887 | 1.242 | 1.952 | 32 |
| S14,15 | 0.049 | 0.404 | 0.685 | 0.962 | 1.517 | 53 |
| S16 | 0.078 | 0.658 | 1.116 | 1.569 | 2.475 | 18 |
| S16R | 0.033 | 0.278 | 0.472 | 1.663 | 1.046 | 100 |
| S17 | 0.068 | 0.528 | 0.891 | 1.251 | 1.969 | 33 |
| S17R | 0.027 | 0.207 | 0.350 | 0.491 | 0.773 | 140 |
| S19 | -0.014 | 0.255 | 0.520 | 0.786 | 1.317 | 70 |
| S20 | -0.018 | 0.164 | 0.343 | 0.523 | 0.882 | 115 |
| S21 | -0.017 | 0.175 | 0.363 | 0.552 | 0.923 | 110 |
| A1A | 0.032 | 0.749 | 1.436 | 2.124 | 3.499 | 9 |
| A1B | 0.043 | 1.014 | 1.945 | 2.876 | 4.737 | 0 |
| A1C | 0.021 | 0.502 | 0.964 | 1.425 | 2.348 | 27 |
| A1AB | 0.041 | 0.968 | 1.857 | 2.746 | 4.524 | 0 |
| A2A | 0.023 | 1.052 | 2.039 | 3.025 | 4.999 | 0 |
| A2B | 0.022 | 1.033 | 2.002 | 2.971 | 4.909 | 0 |
| A2C | 0.014 | 0.641 | 1.242 | 1.846 | 3.045 | 15 |
| A2CR | 0.009 | 0.420 | 0.814 | 1.208 | 1.996 | 37 |
| A3A | 0.013 | 0.588 | 1.139 | 1.690 | 2.793 | 18 |
| A3B | 0.016 | 0.749 | 1.451 | 2.154 | 3.558 | 9 |
| A3AR | 0.013 | 0.603 | 1.169 | 1.735 | 2.868 | 6 |
| 3BR | 0.011 | 0.499 | 0.968 | 1.436 | 2.373 | 27 |
| M1 | -0.259 | 0.303 | 0.858 | 1.414 | 2.525 | 31 |
| M2 | -0.239 | 0.307 | 0.847 | 1.388 | 2.469 | 32 |

NOTES:
1) All values based on effective interest rate of 4%
2) GI is increase of present crop prices, in percent
3) GI for B/C=1 values based on linear interpolation between calculated values

TABLE 5-3 BENEFIT-COST RATIOS, IRR: FUTURE CONDITIONS

| SITE | DIRECT BENEFIT-COST RATIOS | | | | | IRR |
|---|---|---|---|---|---|---|
| | i = 1 | i = 2 | i = 4 | i = 8 | i = 4 | |
| | GI=0% | GI=0% | GI=0% | GI=0% | GI=25% | % |
| S1 | 0.462 | 0.316 | 0.098 | -0.130 | 0.465 | <1.0 |
| S1R | 0.295 | 0.196 | 0.058 | -0.069 | 0.272 | <1.0 |
| S2 | 0.387 | 0.262 | 0.076 | -0.116 | 0.393 | <1.0 |
| S2R | 0.258 | 0.170 | 0.047 | -0.066 | 0.243 | <1.0 |
| S3 | 0.694 | 0.551 | 0.325 | 0.064 | 0.661 | <1.0 |
| S3R | 0.450 | 0.344 | 0.189 | 0.034 | 0.385 | <1.0 |
| S4 | 1.225 | 0.964 | 0.565 | 0.114 | 1.145 | 1.8 |
| S4R | 0.927 | 0.712 | 0.399 | 0.074 | 0.808 | <1.0 |
| S4R2 | 1.070 | 0.811 | 0.444 | 0.081 | 0.900 | 1.3 |
| S5 | 1.458 | 1.098 | 0.587 | 0.076 | 1.258 | 2.4 |
| S6 | 1.065 | 0.799 | 0.427 | 0.066 | 0.891 | 1.2 |
| S4R2,5,6 | 1.164 | 0.880 | 0.478 | 0.081 | 0.982 | 1.6 |
| S7 | 0.351 | 0.236 | 0.078 | -0.065 | 0.309 | <1.0 |
| S8 | 0.874 | 0.672 | 0.372 | 0.057 | 0.777 | <1.0 |
| S9 | 0.327 | 0.220 | 0.072 | -0.061 | 0.287 | <1.0 |
| S10 | 0.554 | 0.385 | 0.134 | -0.122 | 0.533 | <1.0 |
| S11 | 0.983 | 0.770 | 0.439 | 0.061 | 0.941 | <1.0 |
| S12 | 0.987 | 0.779 | 0.451 | 0.068 | 0.957 | <1.0 |
| S13 | 0.579 | 0.449 | 0.250 | 0.035 | 0.531 | <1.0 |
| S14 | 0.528 | 0.436 | 0.287 | 0.182 | 0.518 | <1.0 |
| S15 | 0.911 | 0.764 | 0.520 | 0.341 | 0.922 | <1.0 |
| S14,15 | 0.714 | 0.594 | 0.399 | 0.257 | 0.712 | <1.0 |
| S16 | 1.132 | 0.950 | 0.648 | 0.426 | 1.161 | 1.7 |
| S16R | 0.563 | 0.446 | 0.274 | 0.165 | 0.490 | <1.0 |
| S17 | 0.957 | 0.789 | 0.520 | 0.332 | 0.927 | <1.0 |
| S17R | 0.418 | 0.331 | 0.204 | 0.123 | 0.364 | <1.0 |
| S19 | 0.242 | 0.160 | 0.041 | -0.075 | 0.240 | <1.0 |
| S20 | 0.156 | 0.099 | -0.019 | -0.054 | 0.154 | <1.0 |
| S21 | 0.166 | 0.107 | -0.022 | -0.056 | 0.164 | <1.0 |
| A1A | 1.181 | 0.859 | 0.422 | 0.012 | 1.001 | 1.6 |
| A1B | 1.574 | 1.150 | 0.572 | 0.004 | 1.389 | 2.5 |
| A1C | 0.805 | 0.583 | 0.283 | 0.008 | 0.672 | <1.0 |
| A1AB | 1.507 | 1.100 | 0.546 | 0.015 | 1.295 | 2.4 |
| A2A | 1.625 | 1.184 | 0.583 | 0.004 | 1.414 | 2.6 |
| A2B | 1.598 | 1.164 | 0.572 | 0.003 | 1.389 | 2.5 |
| A2C | 0.890 | 0.677 | 0.355 | 0.002 | 0.861 | <1.0 |
| A2CR | 0.660 | 0.480 | 0.233 | 0.001 | 0.565 | <1.0 |
| A3A | 0.841 | 0.633 | 0.326 | 0.002 | 0.790 | <1.0 |
| A3B | 1.097 | 0.817 | 0.415 | 0.003 | 1.007 | 1.3 |
| A3AR | 0.959 | 0.693 | 0.334 | 0.002 | 0.811 | <1.0 |
| A3BR | 0.799 | 0.577 | 0.227 | 0.002 | 0.671 | <1.0 |
| M1 | 0.101 | -0.040 | -0.227 | -0.381 | 0.167 | <1.0 |
| M2 | 0.118 | -0.023 | -0.208 | -0.359 | 0.175 | <1.0 |

NOTES:
1) GI is increase in present crop prices in percent
2) i is effective interest rate in %
3) IRR is internal rate of return in % for future conditions defined in Chapter 2, for present crop prices.

TABLE 5-4 ECONOMICS OF IRRIGATION DEVELOPMENT: PHASES I, II, III

| PROJECT | PHASES OF DEVELOPMENT | % OF AREA | DIRECT BENEFITS $ X 10^6 | DIRECT COSTS $ X 10^6 | DIRECT B/C RATIO |
|---|---|---|---|---|---|
| S1 | 1,2,3 | 100.0 | 285.9 | 627.0 | .46 |
| S2 | 1,2,3 | 100.0 | 196.3 | 508.6 | .39 |
| S3 | 1,2,3 | 100.0 | 323.0 | 573.7 | .56 |
| S4 | 1,2,3 | 100.0 | 696.0 | 713.9 | .98 |
| S5 | 1,2,3 | 100.0 | 228.7 | 197.0 | 1.16 |
| S6 | 1,2,3 | 100.0 | 104.6 | 138.5 | .75 |
| S7 | 1,2,3 | 100.0 | 81.1 | 271.3 | .30 |
| S8 | 1,2,3 | 100.0 | 284.1 | 395.1 | .72 |
| S9 | 1,2,3 | 100.0 | 191.7 | 689.7 | .28 |
| S10 | 1,2,3 | 100.0 | 14.8 | 28.6 | .52 |
| S11 | 1,2,3 | 100.0 | 253.0 | 291.1 | .87 |
| S12 | 1,2,3 | 100.0 | 109.4 | 123.7 | .88 |
| S13 | 1,2,3 | 100.0 | 121.6 | 247.7 | .49 |
| S15 | 1,2,3 | 100.0 | 134.5 | 254.6 | .53 |
| S16 | 1,2,3 | 100.0 | 184.0 | 279.4 | .66 |
| S17 | 1,2,3 | 100.0 | 146.3 | 276.8 | .53 |
| M1 | 1 | 45.4 | 39.3 | 129.8 | .30 |
| M2 | 1,2,3 | 100.0 | 67.6 | 220.2 | .31 |
| A1AB | 1,2,3 | 100.0 | 807.1 | 833.8 | .97 |
| A2A | 1,2,3 | 100.0 | 496.7 | 472.1 | 1.05 |
| A2B | 1,2,3 | 100.0 | 496.7 | 480.8 | 1.03 |
| A2C | 1 | 25.9 | 71.1 | 111.1 | .64 |
| A3B | 1 | 66.5 | 281.0 | 375.2 | .75 |
| PHASE I TOTAL | | | 5614.5 | 8239.7 | .68 |
| M1R | 2 | 100.0 | 86.6 | 341.5 | .25 |
| A2C | 2 | 100.0 | 274.5 | 428.5 | .64 |
| A3B | 2 | 100.0 | 422.6 | 564.3 | .75 |
| A3AR | 2 | 73.6 | 475.9 | 693.5 | .69 |
| PHASE II TOTAL | | | 6482.7 | 9651.3 | .67 |
| A1CR | 3 | 100.0 | 137.8 | 402.8 | .34 |
| A3AR | 3 | 100.0 | 646.6 | 1593.6 | .40 |
| PHASE III TOTAL | | | 6791.2 | 10954.3 | .62 |

NOTE: All direct benefit and cost values are the present worth at a real interest rate of 4%

# CHAPTER 6 FLOW ALLOCATION FOR IRRIGATION OF THE PRAIRIES

## 6.1 INTRODUCTION

From the flow surpluses determined in Chapter 3, and the water requirements determined in Chapter 4 for the various projects, it is apparent that not all of the potential sites identified in this study can be developed with simple on-stream pump plants, since some of the source nodes of the river network do not have sufficient surplus flow available. Assuming that economic attractiveness was the sole criteria for project selection, the projects should be developed in order of their economic attractiveness, as measured by their internal rate of return, until the surplus flow volumes were entirely allocated or until the projects remaining to be developed had rate of returns less than the minimum attractive rate of return, which was defined to be 1 percent. To examine the flow allocations required for development of these projects, the water balance model developed and described in Chapter 3 was enhanced to incorporate the irrigation withdrawals for the new developments, the return flows associated with the new irrigation developments, the possible intra-basin flow diversions, and any new storage reservoirs required to satisfy the irrigation demands of the new developments.

## 6.2 WATER BALANCE MODEL FOR IRRIGATION OF THE PRAIRIES

As was previously described in Chapter 3, the water balance model comprises a number of nodes or points throughout the prairie river system (see Figure 6 on page 79), and is structured to examine the prairie river network for a duration of one average year, with the year being divided into four time periods of varying length. The model begins with the average natural flow volumes for each node during each of the four time periods, and then determines the total net lateral inflow between each node and the node or nodes immediately upstream from it in the prairie river network. The actual flow at a node is determined by adding the calculated lateral inflow, plus any diversion or change in storage at that node, to the flow at the upstream nodes, and then subtracting the new and existing water requirements at the node of interest. The same procedure is then followed for each and every node throughout the model network, moving from the most upstream nodes in the Rocky Mountains to the most downstream nodes in Manitoba. This procedure can be stated mathematically as:

$$QR_{jt} = QR_{kt} + LI_{jt} - (QMI_j)(KMI_t) - (QEI_j)(KIR_t) - (QNI_j)(KIR_t)(1-KRF) + QD_{jt} + QSTR_{jt}$$

where $QR_{jt}$ = river flow at node j during time t in $dam^3$

$QR_{kt}$ = river flow at nodes k immediately upstream from node j during time t in $dam^3$

$LI_{jt}$ = lateral inflow at node j during time t

= natural $QR_{jt}$ − $QR_{kt}$

$QMI_j$ = existing annual net demand for municipal and industrial water use at node j, assumed constant throughout year

$KMI_t$ = (number of months in time period t) / (12)

$QEI_j$ = annual <u>net</u> water consumption of existing irrigation supplied from node j

$KIR_t$ = proportion of annual crop water requirement supplied during time period t

$QNI_j$ = annual gross water withdrawals from node j for irrigation of the proposed developments

KRF = proportion of return flow to new irrigation withdrawal

$QD_{jt}$ = volume diverted to/from node j during time period t

$QSTR_{jt}$ = change in storage at node j during time period t

The model determines the difference between the calculated flow and the minimum release required to maintain acceptable flow regime for the other instream water users at each node. At a node where the minimum release has previously been defined (i.e. Table 3-2 on page 90), the defined release was used in place of the release required to maintain a suitable flow regime. The model also determines the flow difference between the flow provided and the flow allocation required to satisfy the provisions of the Master Apportionment agreement at those nodes located adjacent to a provincial boundary.

By examining the flow surpluses (i.e. positive differences) and flow deficits throughout the system one can readily observe where additional withdrawals for irrigation of the proposed areas can be made, and where additional storage of flow is required.

## 6.3 RETURN FLOWS

It should be noted that implicit to the flow algorithm is the assumption that the return flow from a new development will enter the river network at the node from which the irrigation demands for the project were withdrawn. This is expected to be the case for the majority of the areas examined in this study, since the nodes of the network are generally quite far apart and most of the proposed areas are quite close to the supply source node, and thus the majority of the return flow is expected to enter quite close to or at the source node. For the purposes of this study, this simplifying assumption was judged adequate as it is quite difficult to determine the exact point where these return flow volumes would enter the river network. For a more detailed study, it may be desirable to determine exactly where the return flows from a proposed development will enter the river network, as well as the significance of any time lag between the diversion of the flow and the return of some portion of that flow.

The return flow from the diversion for irrigation of the new developments was assumed to equal 20 percent of the gross water diversion required to irrigate the development (i.e. Table 4-1 on page 123). This flow was expected to arise from the canal and distribution system water losses, the effluent flow from the subsurface drainage system, and the water losses of the irrigation system during the application of the water to the fields. The constant return flow value of 20 percent was based on an examination of the expected losses, as well as the estimated return flows for several existing projects [28,61]. In reality the volume of return flow from a given development will be a function of the local groundwater flows, the soil, the moisture level of the soil, the topography, and the method of irrigation. Given the uncertainties involved in all of the relevant parameters, the assumption of a return flow equal to a constant 20 percent of the gross diversion for the development during that time period was deemed sufficiently valid for the purposes of this study.

## 6.4 FLOW ALLOCATIONS FOR IRRIGATION

The flow allocations required for developing the irrigation developments identified in this study were determined using the water balance model described previously. The basic philosophy of the allocation pattern was to develop the proposed projects in order of their internal rate of return, as determined in Chapter 5, until the flow at a node became less than the defined minimum allowable flow at that node, whereupon no further development could occur without supplementary measures such as diversion or storage and subsequent release of flow. Provided sufficient water was available at a node, development of the proposed projects would continue until the projects remaining to be developed had rate of returns of less than 1.0 percent for their direct and indirect benefits and costs.

It should be noted that throughout all of the model solutions for the various development scenarios, the flows down the South Saskatchewan river at the Alberta-Saskatchewan border were allowed to drop below the flow required for the provincial apportionment during July, but the annual flow apportionment was balanced over the average year simulated by the model. Currently, there is no defined time period for which the provincial flow apportionments must be balanced, but in practice it is taken to be on an annual basis.

The development of the potential irrigation sites identified as economically feasible in Chapter 5 were separated into three distinct phases, based on the nature of the measures required to supply the proposed sites with water.

### 6.4.1 Phase I Development : Natural Flows

The first phase of irrigation development examined the flow allocations required to supply the new projects with natural river flows without requiring new storage reservoirs nor inter-basin diversions. For the purposes of ranking the economic desirability of the various projects, the rate of return for developing only a portion of the project was assumed to equal that for the entire project where water volumes proved insufficient for full development of a project. This assumption may not be consistent with scale economics, but greatly simplified the analysis and was reasonably consistent with the cost functions for the canals, pump plants, pipelines, and pumping energy.

The proposed projects which could be developed under the conditions outlined in the above scenario are presented in Table 6-1, while the complete water balance model solution for the Phase I irrigation development is presented in Appendix A. The total area that can be irrigated under the Phase I development is 1,235,000 hectares in Alberta, 1,590,000 hectares in Saskatchewan, and 140,000 hectares in Manitoba, for a total area of 2,965,000 hectares, which is 74 percent of the total area identified as potentially irrigable in this study.

It must be stressed that the results of the water balance model are of a preliminary nature only, since the flow allocations determined are based purely on the recorded natural flow volumes, rather than the actual flows which result from the present or future operation of the many control works and reservoirs on the prairie river network. It should also be noted that the flow allocations for irrigation from the model represent a reasonable upper bound value for the water available for irrigation, since the minimum flow releases utilized in the model are quite low for the other instream users. Since the intent of this study is merely to determine what projects warrant further, more detailed study, the veracity of the flow allocations from the model were deemed suitable given the reconnaissance nature of this study.

It should be noted that the only reservoir in operation under this scenario is that of Lake Diefenbaker, from which many of the proposed developments are supplied with water. To simplify the analysis, the water demands for those projects supplied from the Qu'Appelle River were assumed to be satisfied directly from Lake Diefenbaker, rather than release the water from the Lake Diefenbaker reservoir into the Qu'Appelle through the existing riparian outlet at the Qu'Appelle Dam.

### 6.4.2 Phase II Development : Storage of Flow

The second phase of irrigation development examined the flow allocations required when storage reservoirs were added to the model network to allow the further development of the potentially irrigable areas. Storage was required at Lethbridge (node 2), Calgary (3), and Holland (26) to ensure that minimum allowable flows were maintained throughout the simulation period.

The proposed projects which could be developed under the conditions outlined in the above scenario are presented in Table 6-1, while the complete solution of the water balance model for the Phase II development is presented in Appendix A. The total area that can be irrigated under the Phase II development is 1,710,000 hectares in Alberta, 1,590,000 hectares in Saskatchewan, and 210,000 hectares in

Manitoba, for a total area of 3,510,000 hectares or 80 percent of the total area identified as potentially irrigable in this study.

### 6.4.3 Phase III Development : Flow Diversion and Storage

The third phase of irrigation development examined the flow allocations required when flow was diverted from the North Saskatchewan river basin to the Red Deer and Bow rivers for full development of the proposed irrigation developments at Bindloss (node 7) and Calgary (node 3) respectively. Additional flow was required for the full development of these sites since the Alberta share of the South Saskatchewan flow apportionment was already fully committed under the second phase of irrigation development. The diversion works were based on those detailed in the SNBB project catalogue [70]. The flow capacity of the works were determined from the volume of water required, and assumed the diversions would only operate for a five month period during the summer to limit winter flow and ice problems. To minimize the flow capacity required, the minimum live storage at Calgary also had to be slightly increased.

The proposed projects which could be developed under the conditions outlined in the above scenario are presented in Table 6-1, while the complete solution of the water balance model for the Phase III development is presented in Appendix A. The total area that can be irrigated under the third phase of irrigation development is 1,890,000 hectares in Alberta, 1,590,000 hectares in Saskatchewan, and 210,000 hectares in Manitoba, for a total area of 3,690,000 hectares or 93 percent of the total area identified as potentially irrigable in this study. Development of the remaining area was found to be economically infeasible under present economic conditions, as discussed in Chapter 5. Should future conditions increase the economic attractiveness of these currently infeasible projects, then additional diversion of flow from the North Saskatchewan, the Peace, the Smokey, and the other rivers of northern Canada may be required to develop the irrigation potential of these additional areas. For this study, the flow diversions from the North Saskatchewan were sufficient for full development of those projects which appear to have the potential to be economically attractive under present conditions.

It must be noted that in general, inter-basin transfers of flow can be quite controversial due to the environmental concerns associated with the potential for transfer of biota, and due to the politics involved when a resource is taken from one region to allow further development of a another region. In the case of this study, the only transfer of flows examined in the simulations are small volume diversions from one sub-basin to an adjoining sub-basin which are connected further downstream, and thus no major environmental concerns are foreseen, other than those associated with the construction and operation of the actual diversion works themselves, which may be quite significant but were deemed beyond the scope of this study.

Because of the possible contentious nature of such diversions and flow transfers, it is possible that the envisioned diversions would be deemed politically and/or environmentally infeasible. For this reason, the development of irrigation projects which are dependent upon inter-basin or subbasin transfers of flow was analyzed as a phase of development distinct from the previous two phases of irrigation development.

## 6.5 FLOW SHORTAGES AND RISK

An implicit assumption to all of the flow allocation patterns determined in this study is that a shortage of water volume in any of the three time periods of May-June, July, and August-September will reduce the overall annual benefits of the area not supplied during the shortage to zero, that is, any crop area not supplied with its full water demands throughout the irrigation period was assumed to have no benefits, and thus should not be supplied with water. This assumption is only of limited validity, since the actual crop damage and the subsequent loss of benefits associated with a water shortage will vary with the degree of the shortage, the crop response to the sub-optimal amount of water supplied, and the timing of the shortage. Significant water shortages immediately prior to or during maturing can greatly reduce the yield of cereal grains, but the damage may be greatly mitigated by rainfall and/or changes in the soil moisture stored. For the case of water shortages which occur in the peak demand month of July, as they do throughout the simulations for this study, the assumption is valid and greatly simplified the analysis.

## 6.6 STORAGE REQUIREMENTS FOR IRRIGATION

The required changes in storage volume at the various proposed and existing reservoirs were determined heuristically using engineering judgment, since the simplicity of the network and the rapid solution time of the model greatly facilitated such a solution. Initially, several complex storage control schemes were formulated and incorporated into the model, but the heuristic (or trial and trend) method of solution proved to be the easiest to formulate and provided the most flexibility for incorporating engineering judgment into the solution process.

In general, the change in storage volume for each time period was selected such that the minimum acceptable outflow was maintained throughout each time period. The net annual change in storage volume at each reservoir site was constrained to equal zero, since the simulation period is for one average year and any changes in reservoir storage must be achievable throughout the majority of the life of the projects. The storage capacities of the proposed reservoirs were determined from the pattern of storage changes, and the maximum capacity required was constrained to be less than the largest of those presented in the SNBB project catalogue [70] for that particular site. The storage capacities required at the different proposed reservoirs for each of the various stages of irrigation development are presented in Table 6-1.

It must be noted that the only existing reservoir included in the model is that of Lake Diefenbaker, which proved to be essential for proper modeling of the flow withdrawals for the many proposed irrigation developments supplied from the reservoir. While there is no theoretical difficulty to incorporating all of the existing reservoirs of the prairies into the model presented herein, the uncertainty of their future operating policies and the increased model complexity would greatly limit any increase in the veracity of the flow allocations. The inclusion of all of the existing reservoirs of the prairies was deemed beyond the scope of a study of this nature, but should be included in a more rigorous analysis of the flow allocations required for large scale development of irrigation on the Canadian prairies.

## 6.7 IMPACT OF IRRIGATION DEVELOPMENT ON WATER QUALITY

Given the large areal extent of the potential irrigation developments being examined in this study, and the volume of the potential return flows associated with these developments, it is possible that water quality problems could arise in some of the lower portions of the prairie river network during low flow periods should significant portions of the prairies be irrigated. Presently the water quality on the major prairie rivers is quite good, and in combination with the flows required to satisfy the provincial apportionment agreement is expected to preclude serious water quality problems on the major rivers in Saskatchewan and Alberta. If all of the potential projects identified in this study are developed, it is possible that the flows entering Manitoba may not be of acceptable quality during extremely low flow years, since the total volume of return flow from the upstream irrigation developments could be as great as 20 percent of the total flow at The Pas. This extremely qualitative and limited water quality analysis neglects the dilution and concentration that occurs as flows are added and then withdrawn along the river network, but it does indicate that should all of the potential areas be developed then it is possible that some water quality problems may occur on the lower portions of the river network, the exact extent of which was deemed beyond the scope of this study. It is apparent that a more rigorous analysis of the large scale irrigation potential of the prairies must examine the water quality aspects of the return flows associated with the large scale irrigation developments in considerably greater detail than did this study.

It is interesting to note that at present there are no water quality limitations in the provincial water apportionment agreement.

## 6.8 EFFECTS OF FLOW ALLOCATION ON RIVER REGIME

An alluvial river always maintains a dynamic equilibrium between its riverbed or course, the flows down it, and the sediment carried by and within the riverflow. Any alteration in the pattern of flows or sediment transport will induce changes in the river network as the river attempts to return to a dynamic equilibrium. These changes may include aggradation in reservoirs, degradation downstream of reservoirs, an increase or decrease in the meander length of the river, bank instability, or a change in the character of the stream such as from a braided to meandering channel. Given the uncertainties inherent to river regime theory, and the uncertainty of the actual flow allocations required for large scale development of irrigation of the prairies, the specific response of the prairie river network to the flow allocations presented herein was deemed beyond the scope of this study. It is apparent that the possible changes in river regime should be one component of a more detailed analysis of the proposed conveyance works and the flow allocations required for large scale irrigation of the prairies.

TABLE 6-1 IRRIGATION DEVELOPMENT: PHASES I,II, III

| PROJECT | PHASES OF DEVELOPMENT | WATER USE $DAM^3 10^3$ | % DEV | SOURCE NODE | STORAGE REQUIRED NODE | STORAGE REQUIRED VOL | DIVERSION REQUIRED NODE | DIVERSION REQUIRED VOL |
|---|---|---|---|---|---|---|---|---|
| S1 | 1,2,3 | 419.39 | 100.0 | 17 | | | | |
| S2 | 1,2,3 | 322.56 | 100.0 | | | | | |
| S3 | 1,2,3 | 313.75 | 100.0 | 17 | | | | |
| S4 | 1,2,3 | 647.93 | 100.0 | 17 | | | | |
| S5 | 1,2,3 | 262.88 | 100.0 | 10 | 10 | 1100 | | |
| S6 | 1,2,3 | 130.05 | 100.0 | 10 | | | | |
| S7 | 1,2,3 | 94.01 | 100.0 | 10 | | | | |
| S8 | 1,2,3 | 280.21 | 100.0 | 10 | | | | |
| S9 | 1,2,3 | 245.34 | 100.0 | 10 | | | | |
| S10 | 1,2,3 | 15.23 | 100.0 | 22 | | | | |
| S11 | 1,2,3 | 288.58 | 100.0 | 10 | | | | |
| S12 | 1,2,3 | 112.98 | 100.0 | 10 | | | | |
| S13 | 1,2,3 | 133.75 | 100.0 | 10 | | | | |
| S15 | 1,2,3 | 142.57 | 100.0 | 10 | | | | |
| S16 | 1,2,3 | 282.41 | 100.0 | 10 | | | | |
| S17 | 1,2,3 | 177.09 | 100.0 | 10 | | | | |
| M1 | 1 | 205.79 | 45.4 | 26 | | | | |
| M2 | 1,2,3 | 131.55 | 100.0 | 26 | | | | |
| A1AB | 1,2,3 | 953.31 | 100.0 | 7 | | | | |
| A2A | 1,2,3 | 668.81 | 100.0 | 3 | | | | |
| A2B | 1,2,3 | 672.65 | 100.0 | 3 | | | | |
| A2C | 1 | 329.88 | 25.9 | 3 | | | | |
| A3B | 1 | 627.33 | 66.5 | 2 | | | | |
| M1R | 2 | 205.79 | 100.0 | 26 | 26 | 25 | | |
| A2C | 2 | 329.88 | 100.0 | 3 | 3 | 350 | | |
| A3B | 2 | 627.33 | 100.0 | 2 | 2 | 100 | | |
| A3AR | 2 | 94.10 | 73.6 | 3 | | | | |
| A1CR | 3 | 174.89 | 100.0 | 7 | | | 7 | 150 |
| A3AR | 3 | 94.10 | 100.0 | 3 | 3 | 400 | 3 | 200 |

<u>NOTES</u>:
1) Water use volumes are in $Dam^3 x10^3$, $1.0 \; Dam^3 = 1000 \; m^3$
2) % Dev is the percentage of the total project area that can be supplied with water
3) All storage and diversion volumes are in $dam^3 x10^3$ per year

# CHAPTER 7 CONCLUSIONS OF THE STUDY

## 7.1 GENERAL CONCLUSIONS OF THE STUDY

The purpose of this reconnaissance study was to examine the irrigation potential of the Canadian prairies and identify potential irrigation projects that may warrant further, more comprehensive analysis. The level of detail which could be examined in this study was extremely limited due to the nature of this study and the large number of projects examined, 41 in all.

The decision to develop the potential irrigation projects identified in this study will be a political act incorporating the best judgment of the various agencies interested in large scale development of the irrigation potential of the Canadian prairies. Based on the analysis presented herein, approximately 2,965,000 hectares of prairie farmland could be irrigated by the Phase I development scenario, in which only the naturally available river flow volumes are used for irrigation, at a total cost of approximately $8.2 billion, and would produce direct benefits with a present worth of $5.6 billion, for a benefit-cost ratio of 0.68 at the best estimate effective interest rate of 4.0 percent. If indirect benefits are included, the actual benefits could approach $14.0 billion, for a benefit-cost ratio of 1.70 at an effective interest rate of 4.0 percent. The area irrigated represents the development of approximately 74 percent of the area identified in this study as potentially irrigable. The irrigated area could be increased to 3,691,000 hectares through the construction of additional storage reservoirs and intra-basin flow diversions under the Phase III development scenario, but the costs increase to approximately $10.95 billion, while the direct benefits only increase to $6.75 billion, for a benefit-cost ratio of 0.62. The area irrigated in the Phase III development scenario represents the development of approximately 93 percent of the area identified as potentially irrigable in this study.

It should be noted that this study examined the irrigation of only those areas which had previously been identified as well suited for irrigation (i.e. class 1 and 2 soils only). While the majority of the land currently cultivated on the prairies would benefit from supplementary water, providing it was of suitable quality, the costs of the drainage and conveyance works required are expected to be considerably more prohibitive than for the class 1 and 2 soils examined in this study. Should future conditions alter the relative attractiveness of irrigation development, then the potential of the class 3 and 4 soils should undergo further, more detailed evaluation.

The economic attractiveness of developing the irrigation projects examined in this study were found to be extremely sensitive to the effective interest rate used to equilibrate the benefits and costs, and to variations in the crop prices used in the analyses. As an example of this sensitivity, a 25 percent increase in grain prices would increase the total benefits of the Phase I development from $5.6 billion to approximately $10.5 billion, for a direct benefit-cost ratio of 1.27. Due to the uncertainty of future crop prices and interest rates, this study used the present conditions with an effective interest rate of

4.0 percent as the most probable conditions for evaluating the economic attractiveness of developing the proposed irrigation projects.

While the total costs of developing the irrigation potential of the prairies may appear prohibitive, the overall system comprises eighteen to twenty discrete irrigation projects whose costs range from $29 million up to $1.59 billion, and whose direct benefit-cost ratios range from 0.30 to 1.16. Should future studies and conditions determine that large scale irrigation of the prairies is desirable, it is expected that development of the areas and construction of the conveyance works will be staged over a prolonged period, thus limiting the total amount of capital required each year.

Based on the information presented herein and summarized above, it is apparent that the potential for large scale irrigation of the prairies warrants further, more comprehensive study than was possible for this study. The expected costs of such a study would be insignificant in comparison with the amount of potential direct and indirect benefits which could be produced by irrigation of the prairies.

## 7.2 AREAS FOR FURTHER STUDY

There are innumerable areas which require much more detailed and comprehensive examination than was possible in this study, many of which have been outlined and discussed in the relevant sections of this report. Areas which must be examined in greater detail would include, but by no means be limited to:

- the on-farm benefits (or disbenefits) of irrigation under the present crop conditions as well as the probable future crop conditions which may exist at the completion of the irrigation development period

- the indirect benefits and costs associated with the development of irrigation projects

- the conveyance systems required to supply the proposed projects including the canals, pump plants, pipelines, storage and balancing reservoirs, distribution system, drainage system, and any other components

- the actual flow volumes available throughout a prolonged period of record for each portion of the prairie river network, and the possible influence the existing and envisioned reservoirs and control works could have upon the flow volumes available

- the environmental degradation and changes induced by the construction and operation of the control works, and the flow withdrawals required for the proposed irrigation projects

- the changes to the regime of the prairie river network induced by the withdrawals and diversions of flow

- the volume of return flows produced by large scale irrigation of the prairies, and the possible water quality problems which may result from the return flows and/or the increased concentration of wastes and effluent due to the decreased river flows

- the irrigation potential of the class 3 and 4 soils, should future conditions increase the relative attractiveness of irrigation development

While it should be noted that this study provides a limited examination of a very complex problem, and many simplifications and assumptions were required to facilitate the analysis, the information presented herein provides a good basis for subsequent discussion and study of the irrigation potential of the Canadian prairies.

## LIST OF REFERENCES

1. Agriculture Canada, Challenge for Growth on Agri-Food Strategy for Canada. Agriculture Canada, AGR-6-81DP, 1981.

2. Advisory Committee to Canadian Wheat Board, Opening Remarks. Prairie Production Symposium, Saskatoon, Canada, 1980.

3. Marvin Shaffer & Associates, Economic Impacts Associated With Increased Agricultural Production In Western Canada. Canada West Foundation, 1980.

4. Veeman, Terry, and Veeman, Michele, The Future of Grain. Canadian Institute of for Economic Policy, 1984.

5. Bentley, Fred, Agricultural Land and Canada's Future. Agricultural Institute of Canada, 1981.

6. Topham, H.L., History of Irrigation in Western Canada. Prairie Farm Rehabilitation Administration, Department of Agriculture, 1982.

7. Vowinckel, E., Evaporation on the Canadian Prairies, Arctic Meteorology Research Group. Department of Meteorology, McGill University, Montreal, Publication in Meteorology No.88, 1967.

8. Hansen, V.E., Isrealson, O.W., and Stringham, G.E., Irrigation Principles and Practices. Fourth Edition, John Wiley and Sons, 1980.

9. Canada Grains Council, Canadian Grains Industry Statistical Handbook 85. Canada Grains Council, 1985.

10. Smith, E.G., and Lee, G.E., Potential Grain Production on the Canadian Prairies by 1990. Department of Agricultural Economics, University of Saskatoon, 1981.

11. Lee, G.E., Production Responses in Light of Increased Market Demands. Prairie Production Symposium, Saskatoon, Canada, 1980.

12. Acton, D.F., Dumanski, J., and Stewart, R.B., Land Resources of the Prairie Provinces for Grain Production. Prairie Production Symposium, Saskatoon, Canada, 1980.

13. de Jong, E. and Cameron, D.R., Efficiency of Water Use by Agriculture Dryland Crop Production. Prairie Production Symposium, Saskatoon, Canada, 1980.

14. Strange, H.G.L., A Short History of Prairie Agriculture. Searle Grain Company Ltd., Winnipeg, Manitoba, 1954.

15. Campbell, C.A. and Beiderbeck, V.D., Changes in the Quality of Prairie Soils as a Result of Agricultural Production. Prairie Production Symposium, Saskatoon, Canada, 1980.

16. Hedlin, R.A., The Place of Summerfallow in Agriculture on the Canadian Prairies. Prairie Production Symposium, Saskatoon, Canada, 1980.

17. Nicholaichuk, W., Snow Management to Provide Additional Water for Agriculture. Prairie Production Symposium, Saskatoon, Canada, 1980.

18. Rennie, D.A., More Efficient Soil Management. In Proc. Western Canada Fertilizer Assoc. Meetings, Richmond, B.C., 1979.

19. Pelton, W., Tillage for Cereal Crop Production. Prairie Production Symposium, Saskatoon, Canada, 1980.

20. Beaton, J.D., The Role of N.P.K.D.. Prairie Production Symposium, Saskatoon, Canada, 1980.

21. Rennie, D.A., Beaton, J.D., and Hedlin, R.A., The Role of Fertilizer Nutrients in Western Canada Development. Publication M58. Saskatchewan Institute of Pedology, University of Saskatoon, 1979.

22. Staple, W.J. and Lehane, J.J., The Influence of Field Shelterbelts on Wind Velocity, Evaporation, Soil Moisture, and Crop Yield. Am. J. Agriculture Science 35, 1965.

23. Black, A.L. and Siddoway, F.H., Dryland Cropping Sequences Within a Tall Wheat Grass Barrier System. Journal of Soil and Water Conservation 31, 1976.

24. Carter, M.R. and Rennie, D.A., Soil Moisture Changes and Water Use Efficiency in Zero and Conventional Tillage Systems for Spring Wheat. 1982 Soils and Crops Workshop, Saskatoon, Canada, 1982.

25. Benson, V.W., Everson, C.A. and Sharp, R.L., Irrigation System Selection in an Energy Short Economy. Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture ERS-670, 1981.

26. Withers and Vipond, Irrigation Design and Practice. Cornell University Press, 1980.

27. Saskatchewan Agriculture, Irrigation Water Delivery Systems. Irrigation Extension Branch of Saskatchewan Agriculture, Outlook, Saskatchewan, 1983.

28. USBR, Use of Water on Federal Irrigation Projects 1965-1969. Summary Report. U.S. Department of Interior, Bureau of Reclamation, 1970.

29. Eisenhauer, D.E. and Fischbach, P.E., Cost of Conventional and Improved Irrigation Systems. Nebraska Short Course Proceedings, Lincoln, Nebraska, 1977.

30. Linsley, J. and Hamlin, T., Production Costs and Yields 1985 Irrigated Crops, Outlook Area. Irrigation Extension Branch of Saskatchewan Agriculture, Outlook, Saskatchewan, 1985.

31. Freitag and Stegman, Semi-Automated Water Balance Scheduling for Center Pivots. Presented at Amer. Soc. Agric. Eng. meeting December, 1982.

32. Lamb, Meyer, and Fischbach, Micro-Processor Automation of a Solid Set Irrigation Facility for Research and Demonstration. Presented at Amer. Soc. Agric. Eng. meeting December, 1982.

33. Threadgill, E.D., Chemigation Via Sprinkler Irrigation: Current Status and Future Development. Presented at 1984 Summer Meeting of Amer. Soc. Agric. Eng. June, 1984.

34. Alberta Agriculture, Alberta Irrigation Management Course. Alberta Agriculture Irrigation Division, 1981.

35. Shearer, M. and Vomocil, J., Twenty-five Years of Modern Irrigation Scheduling Promotional Efforts. Proceedings Amer. Soc. of Agric. Engineers Irrigation Scheduling Conference, December, 1981.

36. PFRA, Handbook for the Classification of Irrigated Land in the Prairie Provinces. Prairie Farm Rehabilitation Administration, Agriculture Canada, Regina, Saskatchewan, 1964.

37. Alberta Agriculture, Standards for the Classification of Land for Irrigation in the Province of Alberta. Alberta Agriculture Irrigation Council, 1983.

38. Michalyna, W., Suitability of Manitoba Soils for Irrigation. Irrigation Seminars in Portage and Brandon, Manitoba, 1978.

39. Garrison Study Board, Irrigation Potential in Manitoba. Garrison Study Board, 1976.

40. Saskatchewan Agriculture, Preliminary Study of Irrigable Soils in Saskatchewan, p.c. Saskatchewan Agriculture Irrigation Branch personnel, 1984.

41. Marvin Anderson and Assoc., Irrigation on the Blood Indian Reserve: a Feasibility Study, Supplement 2: Agronomy. Blood Indian Irrigation Tripartite Committee, 1982.

42. Canada West Foundation 1982.

43. Pedology Consultants 1980.

44. Abrahamson, B.T. and Ireland, B.H., A Preliminary Assessment of the Irrigation Potential in Saskatchewan. Presented at Canadian Water Resources Association Annual Meeting, June, 1985.

45. Hedlin, R.A. and Shaykewich, C., An examination of Moisture Deficits and Irrigable Land in Relation to the Potential for Irrigation Development in the Prairie Provinces. Aggassiz Center for Water Studies, No. 1, 1969.

46. P.F.R.A., Land Degradation and Soil Conservation Issues on the Canadian Prairies. Prairie Farm Rehabilitation Administration, Agriculture Canada, Regina, Saskatchewan, 1983.

47. Rennie, D.A., More Efficient Soil Management. Proc. Western Canada Fertilizer Assoc. Meetings, Richmond, B.C., 1979.

48. Rennie, D.A. and Ellis, J.G., The Shape of Saskatchewan. S.I.P. Pub. M41, University of Saskatchewan, Saskatoon, Saskatchewan, 1978.

49. Vander Pluym, H., Dryland Saline Seepage Controls. Effective Use of Nutrient Resources in Crop Production. Proc. 1979 Alta. Soil Sc. Workshop, Lethbridge, Alberta, 1979.

50. Bennet, D.R., Webster, G.R., Paterson, B.A., and Harker, D.B., Drainage of an Irrigated Saline Soil in Alberta. Can. J. Soil Sci. 62, 1982.

51. Harker, D.B. and Paterson, B.A., Shallow Tile Drainage of Glaciated Soils Within the Irrigated Portion of Alberta, Canada. Twelfth Congress, International Commission on Irrigation and Drainage Q39 R17, 1982.

52. Laliberte, G.E., Eilers, R.G., and Mustafa, G., Estimating Farm Drainage Costs Under Irrigation. Dept. of Agricultural Economics, University of Manitoba, Winnipeg, 1982.

53. Canwest Foundation, Western Canada Agriculture to 1990. A Canwest Foundation Special Task Force Report, 1980.

54. Hamlin, T., Can Irrigated Hard Wheat Pay in 83. Saskatchewan Department of Agriculture Irrigation Branch, Outlook, Saskatchewan, 1983.

55. Saskatchewan Department of Agriculture, Socio-Economic Research, Outlook Irrigation Branch, Saskatchewan Department of Agriculture, 1979.

56. Underwood McLellan Ltd., Irrigation on the Blood Indian Reserve: A Feasibility Study, Supplement for Economics. Blood Indian Irrigation Tripartite Committee, 1982.

57. Narayanan, A.U.S., Colwell, H.T.M., Beaulieu, Y., and Zentner, R.D., Economics of Selected On-Farm Adjustments for Prairie Grain Growers in Response to Rising Future Energy Prices. Canadian Farm Economics, Agriculture Canada, Vol. 18, No. 2, 1983.

58. Saskatchewan Agriculture, Agricultural Statistics 1982. Statistics and Public Information Branch, Saskatchewan Agriculture, Regina, Saskatchewan, 1982.

59. Manitoba Agriculture, 1982 Manitoba Agriculture Yearbook. Economic Analysis Branch, Manitoba Agriculture, Winnipeg, Manitoba, 1982.

60. Alberta Agriculture, Agriculture Statistics Yearbook 1981. Alberta Agriculture, Edmonton, Alberta, 1981.

61. Prairie Provinces Water Board, Water Demand Study, Historical and Current Water Uses in the Saskatchewan-Nelson Basin, Agricultural Water Uses, Appendix 3. Prairie Provinces Water Board, Regina, Saskatchewan, 1982.

62. Huff, H.B., Long Term Outlook for Canadian Agriculture to the Year 2000. Proceedings: Canadian Agriculture Outlook Conference, December, 1981.

63. Marv Anderson and Associates, Oldman River Basin Study, Phase II, Economic Evaluation of Water Supply Alternatives, 1978.

64. Krogman, K.K. and Hobbs, E.H., Field Evaporation as Affected by Soil Variability. International Commission on Irrigation and Drainage, Seventh Congress, 1969.

65. Sonmor, L.G., Seasonal Consumptive Use of Water by Crops Grown in Southern Alberta and Its Relationship to Evaporation. Can. J. Soil Sci., August, 1963.

66. Agriculture Canada, Agro-Climatic Atlas of Canada. Agriculture Canada, Ottawa, Ontario, 1977.

67. P.F.R.A, Riverhurst East Irrigation Study, Prairie Farm Rehabilitation Administration, Agriculture Canada, 1985.

68. Henry, J.L. Problem Water Utilization in Relation to Soil Salinity. Proceedings of Forth Annual Western Provincial Conference, Rationalization of Water and Soil Research and Management. Saskatchewan Water Corporation, 1986.

69. Saskatchewan Nelson Basin Board. Water Supply for the Saskatchewan Nelson Basin: Appendix 4, Volumes 1 and 2, Hydrology. Governments of Canada, Alberta, Saskatchewan, and Manitoba, 1972

70. Prairie Provinces Water Board, Water Demand Study, Historical and Current Water Uses in the Saskatchewan-Nelson Basin. Prairie Provinces Water Board, Regina, Saskatchewan, 1982.

71. Canada West Foundation, Nature's Lifeline: Prairie and Northern Waters. Canada West Foundation, 1982

72. Tennant, Donald M., Instream Flow regimes For Fish, Wildlife, Recreation and Related Resources. Fisheries #1 (JulyAugust 1976)

73. Saskatchewan Nelson Basin Board. Water Supply for the Saskatchewan Nelson Basin: Appendix 3, Project Catalogue. Governments of Canada, Alberta, Saskatchewan, and Manitoba, 1972.

74. Irrigation Division of Alberta Agriculture, Design of Canal and Conveyance Systems. Irrigation Division of Alberta Agriculture, 1982

75. Irrigation Division of Alberta Agriculture, Estimating Construction Costs. Project Planning Branch, Irrigation Division of Alberta Agriculture, 1980.

76. Abrahamson, B.T., Irrigation Demand Criteria for Preliminary Studies. Internal report presented at Prairie Farm Rehabilitation Administration Engineering Service Seminar, March 12 and 13, 1985

77. Smith, C.D., Hydraulic Structures. University of Saskatchewan Printing Services, 1978.

78. American Iron and Steel Institute, Welded Steel Pipe, Steel Plate Engineering Data, Volume 3, published by American Iron and Steel Institute, 1983

79. Saskatchewan Nelson Basin Board. Water Supply for the Saskatchewan Nelson Basin: Appendix 3, Project Investigations. Governments of Canada, Alberta, Saskatchewan, and Manitoba, 1972.

80. Bureau of Reclamation, Water and Power Construction Costs. published quarterly in Engineering News Record, McGraw-Hill, 1960 to 1987

81. P.F.R.A., Assiniboine South Hespeler Area Study, Internal Report, Prairie Farm Rehabilitation Administration, Agriculture Canada, 1987.

82. Kuiper, E., Water Resource Project Economics, Buttersworth and Co., London, England, 1967.

83. Gittinger, J.P., Economic Analysis of Agricultural Projects. Economic Development Institute, International Bank for Reconstruction and Development. John Hopkins University Press, Baltimore, Maryland, 1972.

84. Johnson, Thomas G. , Impact of Irrigation Agriculture on the Aggregate Economy of Saskatchewan. Final Report to Outlook Irrigation Branch, Saskatchewan Department of Agriculture, 1980.

85. Johnson, Thomas G., Kulshreshtha, Surendra N., Nature of Intersectoral Relations of Saskatchewan Agriculture: An Input Output Analysis. Department of Agricultural Economics, University of Saskatchewan, Technical Bulletin 81-06, 1981.

86. Kulshreshtha, S.N., Russel, K.D., Ayers, G., Palmer, B.C., Economic Impacts of Irrigation Development In Alberta Upon the Provincial and Canadian Economy. Canadian Journal of Water Resources, Volume 10, Number 2, 1985.

87. Palanisami, K, Ex Post Evaluation of Flood Control Investments: A Case Study of Projects in North Dakota. Water Resources Research, Vol 12, 1984.

88. Riggs, James L., Engineering Economics. McGraw-Hill Pub. Co., 1977.

89. Boyle, D.M., Riverhurst East Irrigation Study. Canadian Farm Economics, Vol. 20, No. 2, 1986.

90. PFRA, Engineering Study of the Water Storage Potential in Frenchman River Basin, Prairie Farm Rehabilitation Administration, Dept. of Regional Economic Expansion, Canada, 1976.

91. Fortin, M, McBean, E, Forecasting Relative Price Movements for Projects Evaluation. Water Resources Research, Vol 20, No. 10, October 1984.

# APPENDIX A

## SOLUTIONS OF THE WATER BALANCE MODEL

GMNTWRK AUG 1/87 1.00 1.00 1.00PRESENT 0.80

WATER NTWK

| SITE | NODE | MIN FLW 1E6M3/MNTH | DIVERTED 1E6M3/MNTH | FROM /TO | STORAGE M3X1E6 | WTR USE 1000 DAM3 MUNICIPAL | INDUSTRIAL | EXST IRRG | NEW IRRGN WTHDRWL | TOTAL IRRGN RQM | OCT - APR NTRL FLW | INCR FLW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FT MACLEOD | 1 | | | | 0 | 0.00 | 0.00 | 100.00 | 0.0 | 100.0 | 322.64 | 322.64 |
| LTHBRDGE | 2 | | | | 0 | 4.42 | 2.38 | 375.00 | 0.0 | 375.0 | 837.98 | 515.34 |
| CALGARY | 3 | | 0.00 | 13-6-3 | 0 | 29.75 | 16.91 | 0.00 | 0.0 | 0.0 | 642.14 | 642.14 |
| BASSANO | 4 | | | | 0 | 0.00 | 0.00 | 352.00 | 0.0 | 352.0 | 958.18 | 315.04 |
| MEDCN HAT | 5 | | | | 0 | 2.75 | 3.98 | 225.75 | 0.0 | 225.8 | 1840.69 | 44.53 |
| RED DEER | 6 | 42.10 | 0.00 | 13-6 | 0 | 2.25 | 2.74 | 330.00 | 0.0 | 330.0 | 418.81 | 418.81 |
| BINDLOSS | 7 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 639.83 | 221.02 |
| LEMSFORD | 8 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2511.57 | 31.05 |
| SWIFT CRNT | 9 | | | | 0 | 0.17 | 1.50 | 49.05 | 0.0 | 49.1 | 65.90 | 65.90 |
| L.DIEFBKR | 10 | | 0.00 | 10-12 | 0 | 0.00 | 179.00 | 132.00 | 0.0 | 132.0 | 2587.09 | 58.92 |
| SASKATOON | 11 | 112.00 | | | 0 | 7.56 | 1.50 | 0.00 | 0.0 | 0.0 | 2593.33 | 5.24 |
| LUMSDEN | 12 | | 0.00 | 10-12 | 0 | 6.62 | 1.19 | 40.75 | 0.0 | 40.8 | 49.30 | 49.30 |
| ROCKY MTN | 13 | | 0.00 | 13-6&3 | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 771.48 | 771.48 |
| EDMONTON | 14 | 262.98 | | | 0 | 19.72 | 34.85 | 48.50 | 0.0 | 48.5 | 1335.65 | 564.17 |
| DEER CRK | 15 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 1451.00 | 115.35 |
| BATTLE RVR | 16 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 65.31 | 65.31 |
| N.BATTLFRD | 17 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 1622.35 | 105.04 |
| PRNC ALBRT | 18 | | | | 0 | 2.04 | 1.93 | 26.80 | 0.0 | 26.8 | 1622.35 | 0.00 |
| NIPAWIN | 19 | 394.50 | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 4529.79 | 314.11 |
| THE PAS | 20 | 736.30 | | | 0 | 0.69 | 0.59 | 0.00 | 0.0 | 0.0 | 5738.55 | 1208.76 |
| KAMSACK | 21 | | | | 0 | 0.78 | 0.01 | 5.15 | 0.0 | 5.1 | 122.50 | 122.50 |
| RUSSEL | 22 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 169.34 | 46.84 |
| TANTALLON | 23 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 67.02 | 17.72 |
| ESTEVAN | 24 | | | | 0 | 0.68 | 0.01 | 15.24 | 0.0 | 15.2 | 42.52 | 42.52 |
| OXBOW | 25 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 0.00 | 0.00 |
| MELITA | 26 | | | | 0 | 0.12 | 0.01 | 5.15 | 0.0 | 5.2 | 13.03 | -29.49 |
| HOLLAND | 27 | | | | 0 | 1.91 | 0.39 | 21.42 | 0.0 | 21.4 | 518.59 | 336.22 |
| SMOKEY RVR | 28 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2487.52 | 2487.52 |
| PEACE RVR | 29 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 12187.74 | 9700.22 |

0.00 1.00IRRN% 0.41

| WTR USE | CHNG IN STRG | FLOW | FL>MIN | MAY&JUNE NTRL FLW | INCR FLW | DRVTD FLOW | WTR USE | CHNG IN STRGE | FLOW | FL>MIN | JULY NTRL FLW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.0 | 322.64 | 138.34 | 777.89 | 777.89 | 0.00 | 41.00 | 0.0 | 736.89 | 644.74 | 167.09 |
| 3.97 | 0.0 | 829.01 | 352.66 | 1893.49 | 1115.60 | 0.00 | 154.21 | 0.0 | 1698.28 | 1460.10 | 488.95 |
| 27.22 | 0.0 | 614.92 | 219.81 | 1061.49 | 1061.49 | 0.00 | 3.19 | 0.0 | 1058.30 | 860.75 | 626.47 |
| 0.00 | 0.0 | 930.96 | 386.81 | 1532.47 | 470.98 | 0.00 | 144.32 | 0.0 | 1384.96 | 1112.89 | 798.67 |
| 3.93 | 0.0 | 1800.58 | 788.00 | 3343.60 | -82.37 | 0.00 | 93.02 | 0.0 | 2907.85 | 2401.56 | 1305.04 |
| 2.91 | 0.0 | 415.90 | 121.20 | 591.50 | 591.50 | 0.00 | 135.64 | 0.0 | 455.86 | 371.66 | 269.05 |
| 0.00 | 0.0 | 636.92 | 330.29 | 639.45 | 47.95 | 0.00 | 0.00 | 0.0 | 503.81 | 350.50 | 639.45 |
| 0.00 | 0.0 | 2468.54 | 1212.76 | 3807.60 | -175.44 | 0.00 | 0.00 | 0.0 | 3236.22 | 1332.42 | 1711.04 |
| 0.97 | 0.0 | 64.93 | 54.39 | 9.98 | 9.98 | 0.00 | 20.22 | 0.0 | -10.24 | -15.52 | 1.86 |
| 104.42 | 0.0 | 2443.23 | 1110.77 | 3811.70 | 23.76 | 0.00 | 66.35 | 0.0 | 3170.98 | 2504.75 | 1907.17 |
| 5.28 | 0.0 | 2444.19 | 1650.19 | 3675.20 | -136.50 | 0.00 | 0.62 | 0.0 | 3033.86 | 2809.86 | 1864.44 |
| 4.56 | 0.0 | 44.74 | 32.74 | 29.64 | 29.64 | 0.00 | 17.24 | 0.0 | 12.40 | 6.40 | 6.48 |
| 0.00 | 0.0 | 771.48 | 240.65 | 959.22 | 959.22 | 0.00 | 0.00 | 0.0 | 959.22 | 693.80 | 1008.14 |
| 31.83 | 0.0 | 1303.82 | -537.04 | 2282.21 | 1322.99 | 0.00 | 23.61 | 0.0 | 2258.60 | 1732.64 | 1494.42 |
| 0.00 | 0.0 | 1419.17 | 693.67 | 2301.33 | 19.14 | 0.00 | 0.00 | 0.0 | 2277.74 | 1127.06 | 1537.83 |
| 0.00 | 0.0 | 65.31 | 38.96 | 92.56 | 92.56 | 0.00 | 0.00 | 0.0 | 92.56 | 79.38 | 18.54 |
| 0.00 | 0.0 | 1590.52 | 575.71 | 2313.56 | -80.35 | 0.00 | 0.00 | 0.0 | 2289.95 | 1782.54 | 1626.60 |
| 2.32 | 0.0 | 1588.20 | 573.40 | 2313.56 | 0.00 | 0.00 | 11.26 | 0.0 | 2278.69 | 1771.28 | 1626.60 |
| 0.00 | 0.0 | 4346.50 | 1585.00 | 5884.06 | -104.70 | 0.00 | 0.00 | 0.0 | 5207.85 | 4418.85 | 3724.50 |
| 0.75 | 0.0 | 5554.51 | 400.41 | 6589.12 | 705.06 | 0.00 | 0.09 | 0.0 | 5912.82 | 4440.22 | 4186.64 |
| 0.46 | 0.0 | 122.04 | 85.45 | 105.55 | 105.55 | 0.00 | 2.17 | 0.0 | 103.38 | 85.09 | 18.10 |
| 0.00 | 0.0 | 168.88 | 108.23 | 200.84 | 95.29 | 0.00 | 0.00 | 0.0 | 198.67 | 168.35 | 47.29 |
| 0.00 | 0.0 | 62.46 | 39.95 | 65.83 | 36.19 | 0.00 | 0.00 | 0.0 | 48.59 | 37.33 | 19.88 |
| 0.40 | 0.0 | 42.12 | 33.70 | 17.95 | 17.95 | 0.00 | 5.29 | 0.0 | 11.66 | 7.45 | 2.16 |
| 0.00 | 0.0 | 0.00 | -1.24 | 7.37 | 7.37 | 0.00 | 0.00 | 0.0 | 7.37 | 6.75 | 1.27 |
| 0.18 | 0.0 | 12.55 | 9.24 | 9.23 | -8.72 | 0.00 | 2.12 | 0.0 | 0.82 | -0.84 | 1.94 |
| 1.34 | 0.0 | 516.31 | 323.02 | 614.21 | 404.14 | 0.00 | 8.94 | 0.0 | 594.69 | 498.04 | 172.47 |
| 0.00 | 0.0 | 2487.52 | 921.00 | 5428.17 | 5428.17 | 0.00 | 0.00 | 0.0 | 5428.17 | 4644.91 | 1885.22 |
| 0.00 | 0.0 | 12187.74 | 4397.26 | 27331.92 | 21903.75 | 0.00 | 0.00 | 0.0 | 27331.92 | 23436.68 | 10309.07 |

WATER BALANCE MODEL : PRESENT WATER USES ONLY

| INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.46CHNG IN STRGE | FLOW | FL>MIN | AUG&SEPT NTRL FLW | INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.13CHNG IN STRGE | FLOW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 157.19 | 0.00 | 45.50 | 0.0 | 121.49 | 75.41 | 114.64 | 114.64 | 0.00 | 13.40 | 0.0 | 101.24 |
| 321.96 | 0.00 | 171.26 | 0.0 | 272.09 | 153.00 | 352.20 | 237.56 | 0.00 | 50.40 | 0.0 | 288.40 |
| 626.47 | 0.00 | 1.77 | 0.0 | 624.70 | 525.92 | 633.19 | 633.19 | 0.00 | 1.04 | 0.0 | 632.15 |
| 172.20 | 0.00 | 160.51 | 0.0 | 636.38 | 500.35 | 791.81 | 158.62 | 0.00 | 47.17 | 0.0 | 743.60 |
| 17.42 | 0.00 | 103.20 | 0.0 | 822.70 | 569.56 | 1105.02 | -38.99 | 0.00 | 30.40 | 0.0 | 962.61 |
| 259.05 | 0.00 | 150.67 | 0.0 | 118.38 | 76.28 | 313.94 | 313.94 | 0.00 | 44.33 | 0.0 | 269.60 |
| 370.40 | 0.00 | 0.00 | 0.0 | 488.78 | 412.12 | 380.98 | 57.04 | 0.00 | 0.00 | 0.0 | 336.64 |
| -233.45 | 0.00 | 0.00 | 0.0 | 1078.03 | 222.51 | 1419.87 | -65.13 | 0.00 | 0.00 | 0.0 | 1233.13 |
| 1.36 | 0.00 | 22.43 | 0.0 | -20.57 | -23.21 | 1.34 | 1.34 | 0.00 | 6.61 | 0.0 | -5.27 |
| 200.75 | 0.00 | 66.99 | 0.0 | 1203.61 | 870.50 | 1587.51 | 270.91 | 0.00 | 21.69 | 0.0 | 1478.10 |
| -42.73 | 0.00 | 0.34 | 0.0 | 1160.54 | 1048.54 | 1624.66 | -62.85 | 0.00 | 0.20 | 0.0 | 1415.05 |
| 6.48 | 0.00 | 18.88 | 0.0 | -12.40 | -15.40 | 4.62 | 4.62 | 0.00 | 5.63 | 0.0 | -1.02 |
| 1008.14 | 0.00 | 0.00 | 0.0 | 1008.14 | 875.43 | 1242.42 | 1242.42 | 0.00 | 0.00 | 0.0 | 1242.42 |
| 486.28 | 0.00 | 24.19 | 0.0 | 1470.23 | 1207.25 | 1806.81 | 564.39 | 0.00 | 7.72 | 0.0 | 1799.09 |
| 43.41 | 0.00 | 0.00 | 0.0 | 1513.64 | 744.73 | 1980.47 | 173.66 | 0.00 | 0.00 | 0.0 | 1972.75 |
| 18.54 | 0.00 | 0.00 | 0.0 | 18.54 | 11.95 | 21.22 | 21.22 | 0.00 | 0.00 | 0.0 | 21.22 |
| 70.23 | 0.00 | 0.00 | 0.0 | 1602.41 | 1348.71 | 2048.53 | 45.84 | 0.00 | 0.00 | 0.0 | 2040.81 |
| -0.00 | 0.00 | 12.37 | 0.0 | 1590.03 | 1336.33 | 2048.53 | -0.00 | 0.00 | 3.68 | 0.0 | 2037.13 |
| 233.46 | 0.00 | 0.00 | 0.0 | 2984.03 | 2589.53 | 3965.32 | 192.13 | 0.00 | 0.00 | 0.0 | 3644.31 |
| 452.14 | 0.00 | 0.05 | 0.0 | 3446.13 | 2709.83 | 5530.71 | 1655.39 | 0.00 | 0.03 | 0.0 | 5309.68 |
| 18.10 | 0.00 | 2.38 | 0.0 | 15.72 | 6.57 | 28.30 | 28.30 | 0.00 | 0.71 | 0.0 | 27.59 |
| 29.19 | 0.00 | 0.00 | 0.0 | 44.91 | 29.75 | 37.38 | 9.09 | 0.00 | 0.00 | 0.0 | 36.68 |
| 13.40 | 0.00 | 0.30 | 0.0 | 1.00 | -4.63 | 16.16 | 11.54 | 0.00 | 0.00 | 0.0 | 10.53 |
| 2.16 | 0.00 | 6.97 | 0.0 | -4.81 | -6.92 | 0.52 | 0.52 | 0.00 | 2.06 | 0.0 | -1.54 |
| 1.27 | 0.00 | 0.00 | 0.0 | 1.27 | 0.96 | 0.67 | 0.67 | 0.00 | 0.00 | 0.0 | 0.67 |
| -0.22 | 0.00 | 2.36 | 0.0 | -7.39 | -8.22 | 0.67 | 0.15 | 0.00 | 0.69 | 0.0 | -2.08 |
| 123.25 | 0.00 | 9.86 | 0.0 | 150.90 | 102.58 | 144.47 | 106.41 | 0.00 | 2.92 | 0.0 | 138.09 |
| 1885.22 | 0.00 | 0.00 | 0.0 | 1885.22 | 1493.59 | 1947.99 | 1947.99 | 0.00 | 0.00 | 0.0 | 1947.99 |
| 8423.85 | 0.00 | 0.00 | 0.0 | 10309.07 | 8361.45 | 8599.89 | 6651.90 | 0.00 | 0.00 | 0.0 | 8599.89 |

| FL>MIN | ANNUAL NAT FLW | ANNUAL FLOW | MINIMUM FL>MIN | ANNUAL FL>MIN | TTL CHNG STORAGE | TOTAL ANN USE | TOTAL ANN DVR | ANNL FL EXT/NTRL | NO STRG PTNL IRRG FLOW |
|---|---|---|---|---|---|---|---|---|---|
| 9.09 | 1382.26 | 1282.26 | 9.09 | 867.58 | 0.0 | 100.00 | 0.00 | 0.93 | 67.83 |
| 50.22 | 3572.62 | 3087.78 | 50.22 | 2015.99 | 0.0 | 381.80 | 0.00 | 0.86 | 335.54 |
| 434.50 | 2963.29 | 2930.07 | 219.81 | 2041.08 | 0.0 | 46.66 | 0.00 | 0.99 | 1153.33 |
| 471.52 | 4081.13 | 3695.91 | 386.81 | 2471.57 | 0.0 | 352.00 | 0.00 | 0.91 | 1097.25 |
| 456.32 | 7594.35 | 6493.75 | 455.32 | 4215.44 | 0.0 | 232.48 | 0.00 | 0.86 | 1249.03 |
| 185.40 | 1593.29 | 1259.74 | 76.28 | 754.54 | 0.0 | 334.99 | 0.00 | 0.79 | 167.28 |
| 183.33 | 2299.71 | 1966.15 | 183.33 | 1276.24 | 0.0 | 0.00 | 0.00 | 0.85 | 854.87 |
| 523.19 | 9450.08 | 8015.92 | 222.51 | 3290.88 | 0.0 | 0.00 | 0.00 | 0.85 | 487.96 |
| -10.54 | 79.08 | 28.84 | -23.21 | 5.12 | 0.0 | 50.72 | 0.00 | 0.36 | -78.67 |
| 811.87 | 9993.47 | 8295.93 | 811.87 | 5297.89 | 0.0 | 311.00 | 0.00 | 0.83 | 1908.99 |
| 1191.05 | 9757.63 | 8053.64 | 1048.54 | 6709.64 | 0.0 | 9.36 | 0.00 | 0.83 | 2299.43 |
| -7.02 | 90.03 | 43.72 | -15.40 | 16.71 | 0.0 | 48.56 | 0.00 | 0.49 | -52.39 |
| 977.00 | 3981.26 | 3981.26 | 240.65 | 2786.88 | 0.0 | 0.00 | 0.00 | 1.00 | 1692.20 |
| 1273.13 | 6919.08 | 6831.73 | -537.04 | 3675.97 | 0.0 | 103.07 | 0.00 | 0.99 | 2647.47 |
| 982.52 | 7270.65 | 7183.30 | 693.67 | 3547.97 | 0.0 | 0.00 | 0.00 | 0.99 | 1633.17 |
| 8.05 | 197.63 | 197.63 | 8.05 | 138.34 | 0.0 | 0.00 | 0.00 | 1.00 | 26.22 |
| 1533.41 | 7611.04 | 7523.69 | 575.71 | 5240.37 | 0.0 | 0.00 | 0.00 | 0.99 | 2957.70 |
| 1529.73 | 7611.04 | 7494.05 | 573.40 | 5210.74 | 0.0 | 30.77 | 0.00 | 0.98 | 2930.55 |
| 2855.31 | 18003.66 | 16182.69 | 1585.00 | 11448.69 | 0.0 | 0.00 | 0.00 | 0.90 | 5678.80 |
| 3837.08 | 22045.02 | 20223.14 | 400.41 | 11387.54 | 0.0 | 1.28 | 0.00 | 0.92 | 5942.61 |
| 9.29 | 274.44 | 268.73 | 6.57 | 186.40 | 0.0 | 5.94 | 0.00 | 0.98 | 14.41 |
| 6.35 | 454.85 | 449.14 | 6.35 | 312.68 | 0.0 | 0.00 | 0.00 | 0.99 | 47.40 |
| -0.73 | 168.89 | 122.58 | -4.63 | 71.91 | 0.0 | 0.00 | 0.00 | 0.73 | -10.15 |
| -5.75 | 63.15 | 47.42 | -6.92 | 28.48 | 0.0 | 15.93 | 0.00 | 0.75 | -42.88 |
| 0.05 | 9.31 | 9.31 | -1.24 | 6.51 | 0.0 | 0.00 | 0.00 | 1.00 | 0.37 |
| -3.74 | 24.87 | 3.90 | -8.22 | -3.57 | 0.0 | 5.28 | 0.00 | 0.16 | -27.90 |
| 41.44 | 1449.74 | 1399.99 | 41.44 | 965.07 | 0.0 | 23.72 | 0.00 | 0.97 | 224.95 |
| 1164.73 | 11748.90 | 11748.90 | 921.00 | 8224.23 | 0.0 | 0.00 | 0.00 | 1.00 | 3275.42 |
| 4704.65 | 58428.62 | 58428.62 | 4397.26 | 40900.03 | 0.0 | 0.00 | 0.00 | 1.00 | 18336.51 |
| | | | | | | | 0.00 | | |

WATER BALANCE MODEL : PRESENT WATER USES ONLY continued

| GMNTWRK AUG 1/87 | | 1.00 | 1.00 | | | 4.00FUTURE | | | | | 0.80 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WATER NTWK | | MIN FLW | DIVERTED | FROM | STORAGE | WTR USE | 1000 DAM3 | | NEW IRRGN | TOTAL | OCT - APR | |
| SITE | NODE | 1E6M3/MNTH | 1E6M3/MNTH | /TO | M3X1E6 | MUNICIPAL | INDUSTRIAL | EXST IRRG | WTHDRWL | IRRGN RQM | NTRL FLW | INCR FLW |
| FT MACLEOD | 1 | | | | 0 | 0.00 | 0.00 | 100.00 | 0.0 | 100.0 | 322.64 | 322.64 |
| LTHBRDGE | 2 | | | | 0 | 17.68 | 9.52 | 375.00 | 0.0 | 375.0 | 837.98 | 515.34 |
| CALGARY | 3 | | 0.00 | 13-6-3 | 0 | 119.00 | 67.66 | 0.00 | 0.0 | 0.0 | 642.14 | 642.14 |
| BASSANO | 4 | | | | 0 | 0.00 | 0.00 | 352.00 | 0.0 | 352.0 | 958.18 | 316.04 |
| MEDCN HAT | 5 | | | | 0 | 10.99 | 15.93 | 225.75 | 0.0 | 225.8 | 1840.69 | 44.53 |
| RED DEER | 6 | 42.10 | 0.00 | 13-6 | 0 | 9.00 | 10.96 | 330.00 | 0.0 | 330.0 | 418.81 | 418.81 |
| BINDLOSS | 7 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 639.83 | 221.02 |
| LEMSFORD | 8 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2511.57 | 31.05 |
| SWIFT CRNT | 9 | | | | 0 | 0.68 | 6.00 | 49.05 | 0.0 | 49.1 | 65.90 | 65.90 |
| L.DIEFBKR | 10 | | 0.00 | 10-12 | 0 | 0.00 | 179.00 | 132.00 | 0.0 | 132.0 | 2587.09 | 58.92 |
| SASKATOON | 11 | 112.00 | | | 0 | 30.24 | 6.00 | 0.00 | 0.0 | 0.0 | 2593.33 | 6.24 |
| LUMSDEN | 12 | | 0.00 | 10-12 | 0 | 26.48 | 4.76 | 40.75 | 0.0 | 40.8 | 49.30 | 49.30 |
| ROCKY MTN | 13 | | 0.00 | 13-6&3 | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 771.48 | 771.48 |
| EDMONTON | 14 | 262.98 | | | 0 | 78.88 | 139.40 | 48.50 | 0.0 | 48.5 | 1335.65 | 564.17 |
| DEER CRK | 15 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 1451.00 | 115.35 |
| BATTLE RVR | 16 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 65.31 | 65.31 |
| N.BATTLFRD | 17 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 1622.35 | 105.04 |
| PRNC ALBRT | 18 | | | | 0 | 8.16 | 7.72 | 26.80 | 0.0 | 26.8 | 1622.35 | 0.00 |
| NIPAWIN | 19 | 394.50 | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 4529.79 | 314.11 |
| THE PAS | 20 | 736.30 | | | 0 | 2.76 | 2.36 | 0.00 | 0.0 | 0.0 | 5738.55 | 1208.76 |
| KAMSACK | 21 | | | | 0 | 3.12 | 0.03 | 5.15 | 0.0 | 5.1 | 122.50 | 122.50 |
| RUSSEL | 22 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 169.34 | 45.84 |
| TANTALLON | 23 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 67.02 | 17.72 |
| ESTEVAN | 24 | | | | 0 | 2.74 | 0.02 | 15.24 | 0.0 | 15.2 | 42.52 | 42.52 |
| OXBOW | 25 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 0.00 | 0.00 |
| MELITA | 26 | | | | 0 | 0.47 | 0.05 | 5.15 | 0.0 | 5.2 | 13.03 | -29.49 |
| HOLLAND | 27 | | | | 0 | 7.63 | 1.56 | 21.42 | 0.0 | 21.4 | 518.59 | 336.22 |
| SMOKEY RVR | 28 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2487.52 | 2487.52 |
| PEACE RVR | 29 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 12187.74 | 9700.22 |
| | | | | | | | | | 0.0 | | | |

| | 0.03 | | | | | | 1.00IRRN% | 0.41 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | CHNG IN | | | MAY&JUNE | | DRVTD | | CHNG IN | | | JULY |
| WTR USE | STRG | FLOW | FL>MIN | NTRL FLW | INCR FLW | FLOW | WTR USE | STRGE | FLOW | FL>MIN | NTRL FLW |
| 0.00 | 0.0 | 322.54 | 138.34 | 777.89 | 777.89 | 0.00 | 41.00 | 0.0 | 736.89 | 644.74 | 167.09 |
| 15.87 | 0.0 | 817.11 | 340.76 | 1893.49 | 1115.60 | 0.00 | 155.61 | 0.0 | 1696.88 | 1458.71 | 488.95 |
| 108.88 | 0.0 | 533.26 | 138.15 | 1061.49 | 1061.49 | 0.00 | 12.75 | 0.0 | 1048.74 | 851.18 | 626.47 |
| 0.00 | 0.0 | 849.30 | 305.15 | 1532.47 | 470.98 | 0.00 | 144.32 | 0.0 | 1375.40 | 1103.32 | 798.67 |
| 15.71 | 0.0 | 1695.24 | 682.65 | 3343.60 | -82.37 | 0.00 | 94.40 | 0.0 | 2895.51 | 2389.22 | 1305.04 |
| 11.54 | 0.0 | 407.16 | 112.46 | 591.50 | 591.50 | 0.00 | 136.66 | 0.0 | 454.83 | 370.63 | 269.05 |
| 0.00 | 0.0 | 628.19 | 321.56 | 639.45 | 47.95 | 0.00 | 0.00 | 0.0 | 502.79 | 349.47 | 639.45 |
| 0.00 | 0.0 | 2354.47 | 1098.69 | 3807.60 | -175.44 | 0.00 | 0.00 | 0.0 | 3222.86 | 1319.06 | 1711.04 |
| 3.93 | 0.0 | 62.01 | 51.46 | 9.98 | 9.98 | 0.00 | 20.57 | 0.0 | -10.59 | -15.86 | 1.86 |
| 104.42 | 0.0 | 2326.23 | 993.77 | 3811.70 | 23.76 | 0.00 | 66.35 | 0.0 | 3157.28 | 2491.05 | 1907.17 |
| 21.14 | 0.0 | 2311.34 | 1527.34 | 3675.20 | -136.50 | 0.00 | 2.48 | 0.0 | 3018.30 | 2794.30 | 1864.44 |
| 18.22 | 0.0 | 31.07 | 19.07 | 29.64 | 29.64 | 0.00 | 18.84 | 0.0 | 10.80 | 4.80 | 6.48 |
| 0.00 | 0.0 | 771.48 | 240.65 | 959.22 | 959.22 | 0.00 | 0.00 | 0.0 | 959.22 | 693.80 | 1008.14 |
| 127.33 | 0.0 | 1208.32 | -632.54 | 2282.21 | 1322.99 | 0.00 | 34.80 | 0.0 | 2247.41 | 1721.45 | 1494.42 |
| 0.00 | 0.0 | 1323.67 | 598.17 | 2301.35 | 19.14 | 0.00 | 0.00 | 0.0 | 2266.55 | 1115.87 | 1537.83 |
| 0.00 | 0.0 | 65.31 | 38.96 | 92.56 | 92.56 | 0.00 | 0.00 | 0.0 | 92.56 | 79.38 | 18.54 |
| 0.00 | 0.0 | 1495.02 | 480.21 | 2313.56 | -80.35 | 0.00 | 0.00 | 0.0 | 2278.76 | 1771.36 | 1626.60 |
| 9.26 | 0.0 | 1485.76 | 470.95 | 2313.56 | 0.00 | 0.00 | 12.07 | 0.0 | 2266.69 | 1759.28 | 1626.60 |
| 0.00 | 0.0 | 4111.20 | 1349.70 | 5884.06 | -104.70 | 0.00 | 0.00 | 0.0 | 5180.29 | 4391.29 | 3724.50 |
| 2.99 | 0.0 | 5316.97 | 162.87 | 6589.12 | 705.06 | 0.00 | 0.35 | 0.0 | 5885.00 | 4412.40 | 4186.64 |
| 1.84 | 0.0 | 120.66 | 84.07 | 105.55 | 105.55 | 0.00 | 2.33 | 0.0 | 103.22 | 84.93 | 18.10 |
| 0.00 | 0.0 | 167.50 | 105.85 | 200.84 | 95.29 | 0.00 | 0.00 | 0.0 | 198.51 | 168.19 | 47.29 |
| 0.00 | 0.0 | 48.80 | 26.28 | 65.83 | 36.19 | 0.00 | 0.00 | 0.0 | 46.99 | 35.73 | 19.88 |
| 1.51 | 0.0 | 40.91 | 32.49 | 17.95 | 17.95 | 0.00 | 6.44 | 0.0 | 11.51 | 7.30 | 2.16 |
| 0.00 | 0.0 | 0.00 | -1.24 | 7.37 | 7.37 | 0.00 | 0.00 | 0.0 | 7.37 | 6.75 | 1.27 |
| 0.31 | 0.0 | 11.12 | 7.80 | 9.23 | -8.72 | 0.00 | 2.15 | 0.0 | 0.65 | -1.01 | 1.94 |
| 5.36 | 0.0 | 509.48 | 316.18 | 614.21 | 404.14 | 0.00 | 9.41 | 0.0 | 593.89 | 497.24 | 172.47 |
| 0.00 | 0.0 | 2487.52 | 921.00 | 5428.17 | 5428.17 | 0.00 | 0.00 | 0.0 | 5428.17 | 4644.91 | 1885.22 |
| 0.00 | 0.0 | 12187.74 | 4397.26 | 27331.92 | 21903.75 | 0.00 | 0.00 | 0.0 | 27331.92 | 23436.68 | 10309.07 |
| | 0.0 | | | | | | | 0.0 | | | |

WATER BALANCE MODEL : FUTURE WATER USES ONLY

| INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.46CHNG IN STRGE | FLOW | FL>MIN | AUG&SEPT NTRL FLW | INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.13CHNG IN STRGE | FLOW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 167.09 | 0.00 | 45.60 | 0.0 | 121.49 | 75.41 | 114.54 | 114.64 | 0.00 | 13.40 | 0.0 | 101.24 |
| 321.85 | 0.00 | 172.03 | 0.0 | 271.32 | 152.23 | 352.20 | 237.56 | 0.00 | 50.86 | 0.0 | 287.94 |
| 626.47 | 0.00 | 7.09 | 0.0 | 619.38 | 520.60 | 533.19 | 633.19 | 0.00 | 4.17 | 0.0 | 629.02 |
| 172.20 | 0.00 | 160.51 | 0.0 | 631.07 | 495.03 | 791.81 | 158.62 | 0.00 | 47.17 | 0.0 | 740.47 |
| 17.42 | 0.00 | 103.97 | 0.0 | 815.84 | 562.70 | 1105.02 | -38.99 | 0.00 | 30.85 | 0.0 | 958.58 |
| 269.05 | 0.00 | 151.24 | 0.0 | 117.81 | 75.71 | 313.94 | 313.94 | 0.00 | 44.67 | 0.0 | 269.27 |
| 370.40 | 0.00 | 0.00 | 0.0 | 488.21 | 411.55 | 380.98 | 67.04 | 0.00 | 0.00 | 0.0 | 336.31 |
| -233.45 | 0.00 | 0.00 | 0.0 | 1070.60 | 215.08 | 1419.87 | -66.13 | 0.00 | 0.00 | 0.0 | 1228.76 |
| 1.85 | 0.00 | 22.62 | 0.0 | -20.76 | -23.40 | 1.34 | 1.34 | 0.00 | 6.72 | 0.0 | -5.38 |
| 200.75 | 0.00 | 66.99 | 0.0 | 1195.99 | 862.88 | 1587.51 | 270.91 | 0.00 | 21.69 | 0.0 | 1473.62 |
| -42.73 | 0.00 | 1.38 | 0.0 | 1151.88 | 1039.88 | 1524.66 | -62.85 | 0.00 | 0.81 | 0.0 | 1409.97 |
| 6.48 | 0.00 | 19.77 | 0.0 | -13.29 | -16.29 | 4.62 | 4.62 | 0.00 | 6.16 | 0.0 | -1.54 |
| 1008.14 | 0.00 | 0.00 | 0.0 | 1008.14 | 875.43 | 1242.42 | 1242.42 | 0.00 | 0.00 | 0.0 | 1242.42 |
| 486.28 | 0.00 | 30.41 | 0.0 | 1464.01 | 1201.03 | 1806.81 | 554.39 | 0.00 | 11.37 | 0.0 | 1795.43 |
| 43.41 | 0.00 | 0.00 | 0.0 | 1507.42 | 738.50 | 1980.47 | 173.66 | 0.00 | 0.00 | 0.0 | 1969.10 |
| 18.54 | 0.00 | 0.00 | 0.0 | 18.54 | 11.95 | 21.22 | 21.22 | 0.00 | 0.00 | 0.0 | 21.22 |
| 70.23 | 0.00 | 0.00 | 0.0 | 1596.19 | 1342.49 | 2048.53 | 46.84 | 0.00 | 0.00 | 0.0 | 2037.16 |
| -0.00 | 0.00 | 12.82 | 0.0 | 1583.36 | 1329.66 | 2048.53 | -0.00 | 0.00 | 3.95 | 0.0 | 2033.21 |
| 233.46 | 0.00 | 0.00 | 0.0 | 2968.71 | 2574.21 | 3865.32 | 192.13 | 0.00 | 0.00 | 0.0 | 3635.30 |
| 452.14 | 0.00 | 0.19 | 0.0 | 3430.56 | 2694.36 | 5530.71 | 1665.39 | 0.00 | 0.11 | 0.0 | 5300.58 |
| 18.10 | 0.00 | 2.47 | 0.0 | 15.53 | 6.48 | 28.30 | 28.30 | 0.00 | 0.76 | 0.0 | 27.54 |
| 29.19 | 0.00 | 0.00 | 0.0 | 44.82 | 29.66 | 37.38 | 9.09 | 0.00 | 0.00 | 0.0 | 36.62 |
| 13.40 | 0.00 | 0.00 | 0.0 | 0.11 | -5.52 | 16.16 | 11.54 | 0.00 | 0.00 | 0.0 | 10.00 |
| 2.16 | 0.00 | 7.05 | 0.0 | -4.89 | -7.00 | 0.52 | 0.52 | 0.00 | 2.10 | 0.0 | -1.58 |
| 1.27 | 0.00 | 0.00 | 0.0 | 1.27 | 0.96 | 0.67 | 0.67 | 0.00 | 0.00 | 0.0 | 0.67 |
| -0.22 | 0.00 | 2.37 | 0.0 | -7.49 | -8.32 | 0.67 | 0.15 | 0.00 | 0.70 | 0.0 | -2.14 |
| 123.25 | 0.00 | 10.12 | 0.0 | 150.45 | 102.13 | 144.47 | 106.41 | 0.00 | 3.08 | 0.0 | 137.83 |
| 1885.22 | 0.00 | 0.00 | 0.0 | 1885.22 | 1493.59 | 1947.99 | 1947.99 | 0.00 | 0.00 | 0.0 | 1947.99 |
| 8423.85 | 0.00 | 0.00 | 0.0 | 10309.07 | 8361.45 | 8599.89 | 6651.90 | 0.00 | 0.00 | 0.0 | 8599.89 |
| | | | 0.0 | | | | | | | 0.0 | |

| FL>MIN | ANNUAL NAT FLW | ANNUAL FLOW | MINIMUM FL>MIN | ANNUAL FL>MIN | TTL CHNG STORAGE | TOTAL ANN USE | TOTAL ANN DVR | ANNL FL EXT/NTRL | NO STRG PTNL IRRG FLOW |
|---|---|---|---|---|---|---|---|---|---|
| 9.09 | 1382.26 | 1282.26 | 9.09 | 867.58 | 0.0 | 100.00 | 0.00 | 0.93 | 67.83 |
| 49.77 | 3572.62 | 3073.25 | 49.77 | 2001.47 | 0.0 | 402.20 | 0.00 | 0.86 | 333.84 |
| 431.47 | 2963.29 | 2830.39 | 138.15 | 1941.40 | 0.0 | 186.66 | 0.00 | 0.96 | 1141.67 |
| 458.40 | 4081.13 | 3596.23 | 305.15 | 2371.89 | 0.0 | 352.00 | 0.00 | 0.88 | 1085.59 |
| 452.29 | 7594.35 | 6365.17 | 452.29 | 4086.86 | 0.0 | 252.67 | 0.00 | 0.84 | 1233.98 |
| 185.07 | 1593.29 | 1249.08 | 75.71 | 743.88 | 0.0 | 349.96 | 0.00 | 0.78 | 166.04 |
| 183.00 | 2299.71 | 1955.49 | 183.00 | 1265.58 | 0.0 | 0.00 | 0.00 | 0.85 | 852.37 |
| 518.83 | 9450.08 | 7876.69 | 215.08 | 3151.64 | 0.0 | 0.00 | 0.00 | 0.83 | 471.66 |
| -10.55 | 79.08 | 25.28 | -23.40 | 1.55 | 0.0 | 55.73 | 0.00 | 0.32 | -79.51 |
| 807.39 | 9993.47 | 8153.13 | 807.39 | 5155.09 | 0.0 | 311.00 | 0.00 | 0.82 | 1892.27 |
| 1185.97 | 9757.63 | 7891.49 | 1039.88 | 6547.49 | 0.0 | 36.24 | 0.00 | 0.81 | 2280.45 |
| -7.54 | 90.03 | 27.04 | -16.29 | 0.03 | 0.0 | 71.99 | 0.00 | 0.30 | -56.29 |
| 977.00 | 3981.26 | 3981.26 | 240.65 | 2786.88 | 0.0 | 0.00 | 0.00 | 1.00 | 1692.20 |
| 1259.47 | 6919.08 | 6715.17 | -632.54 | 3559.41 | 0.0 | 266.78 | 0.00 | 0.97 | 2633.83 |
| 978.85 | 7270.65 | 7066.73 | 598.17 | 3431.41 | 0.0 | 0.00 | 0.00 | 0.97 | 1619.53 |
| 8.05 | 197.63 | 197.63 | 8.05 | 138.34 | 0.0 | 0.00 | 0.00 | 1.00 | 26.22 |
| 1529.75 | 7511.04 | 7407.12 | 480.21 | 5123.81 | 0.0 | 0.00 | 0.00 | 0.97 | 2944.05 |
| 1525.91 | 7611.04 | 7369.01 | 470.95 | 5085.70 | 0.0 | 42.68 | 0.00 | 0.97 | 2915.92 |
| 2846.30 | 18003.66 | 15895.50 | 1349.70 | 11161.50 | 0.0 | 0.00 | 0.00 | 0.88 | 5645.19 |
| 3827.98 | 22045.02 | 19933.21 | 152.87 | 11097.61 | 0.0 | 5.12 | 0.00 | 0.90 | 5908.67 |
| 9.24 | 274.44 | 267.05 | 6.48 | 184.72 | 0.0 | 8.30 | 0.00 | 0.97 | 14.21 |
| 6.30 | 454.85 | 447.45 | 6.30 | 311.00 | 0.0 | 0.00 | 0.00 | 0.98 | 47.01 |
| -1.25 | 168.89 | 105.90 | -5.52 | 55.23 | 0.0 | 0.00 | 0.00 | 0.63 | -12.10 |
| -5.79 | 63.15 | 45.95 | -7.00 | 27.00 | 0.0 | 18.00 | 0.00 | 0.73 | -43.23 |
| 0.05 | 9.31 | 9.31 | -1.24 | 6.51 | 0.0 | 0.00 | 0.00 | 1.00 | 0.37 |
| -3.79 | 24.87 | 2.14 | -8.32 | -5.32 | 0.0 | 5.68 | 0.00 | 0.09 | -28.31 |
| 41.18 | 1449.74 | 1391.55 | 41.18 | 956.73 | 0.0 | 30.51 | 0.00 | 0.96 | 223.98 |
| 1154.73 | 11748.90 | 11748.90 | 921.00 | 8224.23 | 0.0 | 0.00 | 0.00 | 1.00 | 3275.42 |
| 4709.55 | 58428.62 | 58428.62 | 4397.26 | 40900.03 | 0.0 | 0.00 | 0.00 | 1.00 | 18336.51 |

**WATER BALANCE MODEL : FUTURE WATER USES ONLY continued**

GMNWP1 AUG 1/87 1.00 1.00 PHASE1 4.00 0.80

| WATER NTWK SITE | NODE | MIN FLW 1E6M3/MNTH | DIVERTED 1E6M3/MNTH | FROM /TO | STORAGE M3X1E6 | WTR USE MUNICIPAL | 1000 DAM3 INDUSTRIAL | EXST IRRG | NEW IRRGN WTHDRWL | TOTAL IRRGN RQM | OCT - APR NTRL FLW | INCR FLW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FT MACLEOD | 1 | | | | 0 | 0.00 | 0.00 | 100.00 | 0.0 | 100.0 | 322.64 | 322.64 |
| LTHBRDGE | 2 | | | | 0 | 17.68 | 9.52 | 375.00 | 417.3 | 708.8 | 837.98 | 515.34 |
| CALGARY | 3 | | 0.00 | 13-6-3 | 0 | 119.00 | 67.66 | 0.00 | 1427.5 | 1142.0 | 642.14 | 642.14 |
| BASSANO | 4 | | | | 0 | 0.00 | 0.00 | 352.00 | 0.0 | 352.0 | 958.18 | 315.04 |
| MEDCN HAT | 5 | | | | 0 | 10.99 | 15.93 | 225.75 | 0.0 | 225.8 | 1840.69 | 44.53 |
| RED DEER | 6 | 42.10 | 0.00 | 13-6 | 0 | 9.00 | 10.96 | 330.00 | 0.0 | 330.0 | 418.81 | 418.81 |
| BINDLOSS | 7 | | | | 0 | 0.00 | 0.00 | 0.00 | 953.0 | 762.4 | 639.83 | 221.02 |
| LEMSFORD | 8 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2511.57 | 31.05 |
| SWIFT CRNT | 9 | | | | 0 | 0.68 | 6.00 | 49.05 | 0.0 | 49.1 | 65.90 | 65.90 |
| L.DIEFBKR | 10 | | 0.00 | 10-12 | 9700 | 0.00 | 179.00 | 132.00 | 2149.9 | 1851.9 | 2587.09 | 58.92 |
| SASKATOON | 11 | 112.00 | | | 0 | 30.24 | 6.00 | 0.00 | 0.0 | 0.0 | 2593.33 | 5.24 |
| LUMSDEN | 12 | | 0.00 | 10-12 | 0 | 26.48 | 4.76 | 40.75 | 0.0 | 40.8 | 49.30 | 49.30 |
| ROCKY MTN | 13 | | 0.00 | 13-6&3 | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 771.48 | 771.48 |
| EDMONTON | 14 | 262.98 | | | 0 | 78.86 | 139.40 | 48.50 | 0.0 | 48.5 | 1335.65 | 564.17 |
| DEER CRK | 15 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 1451.00 | 115.35 |
| BATTLE RVR | 16 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 65.31 | 65.31 |
| N.BATTLFRD | 17 | | | | 0 | 0.00 | 0.00 | 0.00 | 1704.0 | 1363.2 | 1622.35 | 105.04 |
| PRNC ALBRT | 18 | | | | 0 | 8.16 | 7.72 | 26.80 | 0.0 | 26.8 | 1622.35 | 0.00 |
| NIPAWIN | 19 | 394.50 | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 4529.79 | 314.11 |
| THE PAS | 20 | 736.30 | | | 0 | 2.76 | 2.36 | 0.00 | 0.0 | 0.0 | 5738.55 | 1208.76 |
| KAMSACK | 21 | | | | 0 | 3.12 | 0.03 | 5.15 | 0.0 | 5.1 | 122.50 | 122.50 |
| RUSSEL | 22 | | | | 0 | 0.00 | 0.00 | 0.00 | 15.2 | 12.2 | 169.34 | 45.84 |
| TANTALLON | 23 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 67.02 | 17.72 |
| ESTEVAN | 24 | | | | 0 | 2.74 | 0.02 | 15.24 | 0.0 | 15.2 | 42.52 | 42.52 |
| OXBOW | 25 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 0.00 | 0.00 |
| MELITA | 26 | | | | 0 | 0.47 | 0.05 | 5.15 | 0.0 | 5.2 | 13.03 | -29.49 |
| HOLLAND | 27 | | | | 0 | 7.63 | 1.56 | 21.42 | 211.8 | 190.9 | 518.59 | 336.22 |
| SMOKEY RVR | 28 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2487.52 | 2487.52 |
| PEACE RVR | 29 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 12187.74 | 9700.22 |
| | | | | | 0 | | | | | | | |

0.00 1.00 IRRNX 0.41

| WTR USE | CHNG IN STRG | FLOW | FL>MIN | MAY&JUNE NTRL FLW | INCR FLW | DRVTD FLOW | WTR USE | CHNG IN STRGE | FLOW | FL>MIN | JULY NTRL FLW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.0 | 322.64 | 139.34 | 777.89 | 777.89 | 0.00 | 41.00 | 0.0 | 736.89 | 644.74 | 167.09 |
| 15.87 | 0.0 | 817.11 | 340.76 | 1893.49 | 1115.60 | 0.00 | 292.48 | 0.0 | 1560.01 | 1321.83 | 488.95 |
| 108.88 | 0.0 | 533.26 | 139.15 | 1061.49 | 1061.49 | 0.00 | 480.97 | 0.0 | 580.52 | 382.96 | 626.47 |
| 0.00 | 0.0 | 849.30 | 305.15 | 1532.47 | 470.98 | 0.00 | 144.32 | 0.0 | 907.18 | 635.10 | 798.67 |
| 15.71 | 0.0 | 1695.24 | 682.65 | 3343.50 | -82.37 | 0.00 | 94.40 | 0.0 | 2290.42 | 1784.13 | 305.04 |
| 11.54 | 0.0 | 407.16 | 112.46 | 591.50 | 591.50 | 0.00 | 136.66 | 0.0 | 454.83 | 370.63 | 269.05 |
| 0.00 | 0.0 | 628.19 | 321.56 | 639.45 | 47.95 | 0.00 | 312.58 | 0.0 | 190.20 | 36.89 | 639.45 |
| 0.00 | 0.0 | 2354.47 | 1098.69 | 3807.60 | -175.44 | 0.00 | 0.00 | 0.0 | 2305.18 | 401.38 | 1711.04 |
| 3.90 | 0.0 | 62.01 | 51.46 | 9.98 | 9.98 | 0.00 | 20.57 | 0.0 | -10.59 | -15.86 | 1.86 |
| 104.42 | 700.0 | 1639.90 | 307.44 | 3811.70 | 23.76 | 0.00 | 771.52 | 385.0 | 1151.03 | 484.80 | 1907.17 |
| 21.14 | 0.0 | 1625.01 | 841.01 | 3675.20 | -135.50 | 0.00 | 2.48 | 0.0 | 1012.06 | 788.06 | 1864.44 |
| 18.22 | 0.0 | 31.07 | 19.07 | 29.64 | 29.64 | 0.00 | 18.84 | 0.0 | 10.80 | 4.80 | 6.48 |
| 0.00 | 0.0 | 771.48 | 240.65 | 959.22 | 959.22 | 0.00 | 0.00 | 0.0 | 959.22 | 693.80 | 1008.14 |
| 127.33 | 0.0 | 1208.32 | -632.54 | 2282.21 | 1322.99 | 0.00 | 34.80 | 0.0 | 2247.41 | 1721.45 | 1494.42 |
| 0.00 | 0.0 | 1323.67 | 598.17 | 2301.35 | 17.14 | 0.00 | 0.00 | 0.0 | 2266.55 | 1115.87 | 1537.83 |
| 0.00 | 0.0 | 65.31 | 38.96 | 92.56 | 92.56 | 0.00 | 0.00 | 0.0 | 92.56 | 79.38 | 18.54 |
| 0.00 | 0.0 | 1495.02 | 480.21 | 2313.56 | -80.35 | 0.00 | 558.91 | 0.0 | 1719.85 | 1212.44 | 1626.60 |
| 9.26 | 0.0 | 1485.76 | 470.95 | 2313.56 | 0.00 | 0.00 | 12.07 | 0.0 | 1707.77 | 1200.37 | 1626.60 |
| 0.00 | 0.0 | 3424.87 | 653.37 | 5884.06 | -104.70 | 0.00 | 0.00 | 0.0 | 2615.13 | 1826.13 | 3724.50 |
| 2.99 | 0.0 | 4530.64 | -523.46 | 6589.12 | 705.05 | 0.00 | 0.35 | 0.0 | 3319.84 | 1847.24 | 4186.64 |
| 1.84 | 0.0 | 120.56 | 84.07 | 105.55 | 105.55 | 0.00 | 2.33 | 0.0 | 103.22 | 84.93 | 18.10 |
| 0.00 | 0.0 | 167.50 | 106.85 | 200.84 | 95.29 | 0.00 | 4.99 | 0.0 | 193.53 | 163.20 | 47.29 |
| 0.00 | 0.0 | 48.80 | 25.28 | 65.83 | 36.19 | 0.00 | 0.00 | 0.0 | 46.99 | 35.73 | 19.88 |
| 1.51 | 0.0 | 40.91 | 32.49 | 17.95 | 17.95 | 0.00 | 5.44 | 0.0 | 11.51 | 7.30 | 2.16 |
| 0.00 | 0.0 | 0.00 | -1.24 | 7.37 | 7.37 | 0.00 | 0.00 | 0.0 | 7.37 | 6.75 | 1.27 |
| 0.31 | 0.0 | 11.12 | 7.80 | 9.23 | -8.72 | 0.00 | 2.15 | 0.0 | 0.65 | -1.01 | 1.94 |
| 5.36 | 0.0 | 509.48 | 316.18 | 614.21 | 404.14 | 0.00 | 78.88 | 0.0 | 519.43 | 422.78 | 172.47 |
| 0.00 | 0.0 | 2487.52 | 921.00 | 5428.17 | 5428.17 | 0.00 | 0.00 | 0.0 | 5428.17 | 4644.91 | 1885.22 |
| 0.00 | 0.0 | 12187.74 | 4397.26 | 27331.92 | 21903.75 | 0.00 | 0.00 | 0.0 | 27331.92 | 23436.68 | 10309.07 |
| | 0.0 | | | | | | | | | | |

WATER BALANCE MODEL : FUTURE WATER USES & PHASE I DEVELOPMENT

| INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.46CHNG IN STRGE | FLOW | FL>MIN | AUG&SEPT NTRL FLW | INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.13CHNG IN STRGE | FLOW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 157.09 | 0.00 | 45.60 | 0.0 | 121.49 | 75.41 | 114.64 | 114.64 | 0.00 | 13.40 | 0.0 | 101.24 |
| 321.96 | 0.00 | 324.26 | 0.0 | 119.09 | -0.00 | 352.20 | 237.56 | 0.00 | 95.59 | 0.0 | 243.21 |
| 626.47 | 0.00 | 527.94 | 0.0 | 98.63 | -0.15 | 633.19 | 633.19 | 0.00 | 157.20 | 0.0 | 475.99 |
| 172.20 | 0.01 | 160.51 | 0.0 | 110.31 | -25.72 | 791.81 | 158.62 | 0.00 | 47.17 | 0.0 | 587.45 |
| 17.42 | 0.00 | 103.97 | 0.0 | 142.86 | -110.29 | 1105.02 | -38.99 | 0.00 | 30.85 | 0.0 | 760.82 |
| 259.05 | 0.00 | 151.24 | 0.0 | 117.81 | 75.71 | 313.94 | 313.94 | 0.00 | 44.67 | 0.0 | 269.27 |
| 370.40 | 0.00 | 347.65 | 0.0 | 140.56 | 63.90 | 380.98 | 57.04 | 0.00 | 102.16 | 0.0 | 234.15 |
| -233.45 | 0.00 | 0.00 | 0.0 | 49.96 | -805.56 | 1419.87 | -65.13 | 0.00 | 0.00 | 0.0 | 928.84 |
| 1.96 | 0.00 | 22.62 | 0.0 | -20.75 | -23.40 | 1.34 | 1.34 | 0.00 | 6.72 | 0.0 | -5.38 |
| 200.75 | 0.00 | 851.28 | -1035.0 | 426.96 | 93.85 | 1587.51 | 270.91 | 0.00 | 252.15 | -50.0 | 993.75 |
| -42.73 | 0.00 | 1.38 | 0.0 | 382.85 | 270.85 | 1624.66 | -62.85 | 0.00 | 0.81 | 0.0 | 930.10 |
| 6.48 | 0.00 | 19.77 | 0.0 | -13.29 | -16.29 | 4.62 | 4.62 | 0.00 | 6.16 | 0.0 | -1.54 |
| 1008.14 | 0.00 | 0.00 | 0.0 | 1008.14 | 875.43 | 1242.42 | 1242.42 | 0.00 | 0.00 | 0.0 | 1242.42 |
| 486.28 | 0.00 | 30.41 | 0.0 | 1464.01 | 1201.03 | 1806.81 | 564.39 | 0.00 | 11.37 | 0.0 | 1795.43 |
| 43.41 | 0.00 | 0.00 | 0.0 | 1507.42 | 738.50 | 1980.47 | 173.66 | 0.00 | 0.00 | 0.0 | 1969.10 |
| 18.54 | 0.00 | 0.00 | 0.0 | 18.54 | 11.95 | 21.22 | 21.22 | 0.00 | 0.00 | 0.0 | 21.22 |
| 70.23 | 0.00 | 621.62 | 0.0 | 974.57 | 720.87 | 2148.53 | 45.84 | 0.00 | 182.67 | 0.0 | 1854.49 |
| -0.00 | 0.00 | 12.82 | 0.0 | 961.74 | 708.04 | 2148.53 | -0.00 | 0.00 | 3.95 | 0.0 | 1850.54 |
| 233.46 | 0.00 | 0.00 | 0.0 | 1578.06 | 1183.56 | 3965.32 | 192.13 | 0.00 | 0.00 | 0.0 | 2972.76 |
| 462.14 | 0.00 | 0.19 | 0.0 | 2040.01 | 1303.71 | 5530.71 | 1665.39 | 0.00 | 0.11 | 0.0 | 4638.04 |
| 18.10 | 0.00 | 2.47 | 0.0 | 15.63 | 6.48 | 28.30 | 28.30 | 0.00 | 0.76 | 0.0 | 27.54 |
| 29.19 | 0.00 | 5.54 | 0.0 | 39.27 | 24.11 | 37.38 | 9.09 | 0.00 | 1.63 | 0.0 | 34.99 |
| 13.40 | 0.00 | 0.00 | 0.0 | 0.11 | -5.52 | 16.16 | 11.54 | 0.00 | 0.00 | 0.0 | 10.00 |
| 2.16 | 0.00 | 7.05 | 0.0 | -4.89 | -7.00 | 0.52 | 0.52 | 0.00 | 2.10 | 0.0 | -1.58 |
| 1.27 | 0.00 | 0.00 | 0.0 | 1.27 | 0.96 | 0.67 | 0.67 | 0.00 | 0.00 | 0.0 | 0.67 |
| -0.22 | 0.00 | 2.37 | 0.0 | -7.49 | -8.32 | 0.57 | 0.15 | 0.00 | 0.70 | 0.0 | -2.14 |
| 123.25 | 0.00 | 87.38 | .0 | 67.65 | 19.32 | 144.47 | 106.41 | 0.00 | 25.78 | 0.0 | 113.49 |
| 1885.22 | 0.00 | 0.00 | 0.0 | 1885.22 | 1493.59 | 1947.99 | 1947.99 | 0.00 | 0.00 | 0.0 | 1947.99 |
| 8423.85 | 0.00 | 0.00 | 0.0 | 10309.07 | 8361.45 | 8599.89 | 6651.90 | 0.00 | 0.00 | 0.0 | 8599.89 |

| FL>MIN | ANNUAL NAT FLW | ANNUAL FLOW | MINIMUM FL>MIN | ANNUAL FL>MIN | TTL CHNG STORAGE | TOTAL ANN USE | TOTAL ANN DVR | ANNL FL EXT/NTRL | NO STRG PTVL IRRG FLOW |
|---|---|---|---|---|---|---|---|---|---|
| 9.09 | 1382.26 | 1282.26 | 9.09 | 867.58 | 0.0 | 100.00 | 0.00 | 0.93 | 67.83 |
| 5.03 | 3572.62 | 2739.41 | -0.00 | 1667.63 | 0.0 | 736.04 | 0.00 | 0.77 | -0.00 |
| 278.44 | 2963.29 | 1688.39 | -0.15 | 799.40 | 0.0 | 1328.66 | 0.00 | 0.57 | -0.33 |
| 315.37 | 4081.13 | 2454.23 | -25.72 | 1229.89 | 0.0 | 352.00 | 0.00 | 0.60 | -56.41 |
| 254.53 | 7594.35 | 4889.33 | -110.29 | 2611.02 | 0.0 | 252.67 | 0.00 | 0.64 | -241.86 |
| 185.07 | 1593.29 | 1249.08 | 75.71 | 743.88 | 0.0 | 349.96 | 0.00 | 0.78 | 166.04 |
| 80.83 | 2299.71 | 1193.09 | 35.89 | 503.18 | 0.0 | 762.40 | 0.00 | 0.52 | 89.97 |
| 218.90 | 9450.08 | 5638.45 | -805.56 | 913.40 | 0.0 | 0.00 | 0.00 | 0.60 | -1766.58 |
| -10.55 | 79.08 | 25.28 | -23.40 | 1.55 | 0.0 | 55.73 | 0.00 | 0.32 | -79.51 |
| 327.52 | 9993.47 | 4211.55 | 93.85 | 1213.61 | 0.0 | 2030.92 | 0.00 | 0.42 | 205.80 |
| 706.10 | 9757.63 | 3950.01 | 270.85 | 2606.01 | 0.0 | 36.24 | 0.00 | 0.40 | 593.98 |
| -7.54 | 90.03 | 27.04 | -15.29 | 0.03 | 0.0 | 71.99 | 0.00 | 0.30 | -56.29 |
| 977.00 | 3981.26 | 3981.26 | 240.65 | 2786.89 | 0.0 | 0.00 | 0.00 | 1.00 | 1692.20 |
| 1259.47 | 6919.08 | 6715.17 | -632.54 | 3559.41 | 0.0 | 266.78 | 0.00 | 0.97 | 2633.83 |
| 978.86 | 7270.65 | 7066.73 | 598.17 | 3431.41 | 0.0 | 0.00 | 0.00 | 0.97 | 1619.53 |
| 8.05 | 197.63 | 197.63 | 8.05 | 138.34 | 0.0 | 0.00 | 0.00 | 1.00 | 26.22 |
| 1347.08 | 7611.04 | 6043.92 | 480.21 | 3760.61 | 0.0 | 1363.20 | 0.00 | 0.79 | 1580.85 |
| 1343.14 | 7511.04 | 6005.81 | 470.95 | 3722.50 | 0.0 | 42.68 | 0.00 | 0.79 | 1552.72 |
| 2183.76 | 18003.66 | 10590.82 | 653.37 | 5856.82 | 0.0 | 0.00 | 0.00 | 0.59 | 2595.52 |
| 3165.44 | 22045.02 | 14528.53 | -523.46 | 5792.93 | 0.0 | 5.12 | 0.00 | 0.66 | 2859.00 |
| 9.24 | 274.44 | 267.05 | 5.48 | 184.72 | 0.0 | 8.30 | 0.00 | 0.97 | 14.21 |
| 4.57 | 454.85 | 435.29 | 4.67 | 298.84 | 0.0 | 12.16 | 0.00 | 0.96 | 34.85 |
| -1.26 | 158.89 | 105.90 | -5.52 | 55.23 | 0.0 | 0.00 | 0.00 | 0.63 | -12.10 |
| -5.79 | 63.15 | 45.95 | -7.00 | 27.00 | 0.0 | 18.00 | 0.00 | 0.73 | -43.23 |
| 0.05 | 9.31 | 9.31 | -1.24 | 6.51 | 0.0 | 0.00 | 0.00 | 1.00 | 0.37 |
| -3.79 | 24.87 | 2.14 | -8.32 | -5.32 | 0.0 | 5.68 | 0.00 | 0.09 | -28.31 |
| 16.84 | 1449.74 | 1210.05 | 16.84 | 775.13 | 0.0 | 200.05 | 0.00 | 0.83 | 42.38 |
| 1164.73 | 11748.90 | 11748.90 | 921.00 | 8224.23 | 0.0 | 0.00 | 0.00 | 1.00 | 3275.42 |
| 4704.55 | 58428.62 | 58428.62 | 4397.26 | 40900.03 | 0.0 | 0.00 | 0.00 | 1.00 | 18336.51 |
| | | | | | | | 0.00 | | |

WATER BALANCE MODEL : FUTURE WATER USES & PHASE I DEVELOPMENT cont'd

GMNWP2 AUG 1/87 PHASE2

WATER NTWK

| SITE | NODE | MIN FLW 1E6M3/MNTH (1.00) | DIVERTED 1E6M3/MNTH (0.00) | FROM /TO | STORAGE M3X1E6 | WTR USE (4.00) MUNICIPAL | 1000 DAM3 INDUSTRIAL | EXST IRRG | NEW IRRGN WTHDRWL | TOTAL IRRGN RQM (0.80) | OCT - APR NTRL FLW | INCR FLW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FT MACLEOD | 1 | | | | 0 | 0.00 | 0.00 | 100.00 | 0.0 | 100.0 | 322.64 | 322.64 |
| LTHBRDGE | 2 | | | | 100 | 17.68 | 9.52 | 375.00 | 627.3 | 876.8 | 837.98 | 515.34 |
| CALGARY | 3 | | 0.00 | 13-6-3 | 350 | 119.00 | 67.66 | 0.00 | 2364.0 | 1891.2 | 642.14 | 642.14 |
| BASSANO | 4 | | | | 0 | 0.00 | 0.00 | 352.00 | 0.0 | 352.0 | 958.18 | 316.04 |
| MEDCN HAT | 5 | | | | 0 | 10.99 | 15.93 | 225.75 | 0.0 | 225.8 | 1840.69 | 44.53 |
| RED DEER | 6 | 42.10 | 0.00 | 13-6 | 0 | 9.00 | 10.96 | 330.00 | 0.0 | 330.0 | 418.81 | 418.81 |
| BINDLOSS | 7 | | | | 0 | 0.00 | 0.00 | 0.00 | 953.0 | 762.4 | 639.83 | 221.02 |
| LEMSFORD | 8 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2511.57 | 31.05 |
| SWIFT CRNT | 9 | | | | 0 | 0.68 | 6.00 | 49.05 | 0.0 | 49.1 | 65.90 | 65.90 |
| L.DIEFBKR | 10 | | 0.00 | 10-12 | 9700 | 0.00 | 179.00 | 132.00 | 2149.9 | 1851.9 | 2587.09 | 58.92 |
| SASKATOON | 11 | 112.00 | | | 0 | 30.24 | 6.00 | 0.00 | 0.0 | 0.0 | 2593.33 | 5.24 |
| LUMSDEN | 12 | | 0.00 | 10-12 | 0 | 26.48 | 4.76 | 40.75 | 0.0 | 40.8 | 49.30 | 49.30 |
| ROCKY MTN | 13 | | 0.00 | 13-6&3 | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 771.48 | 771.48 |
| EDMONTON | 14 | 262.98 | | | 0 | 78.88 | 139.40 | 48.50 | 0.0 | 48.5 | 1335.65 | 564.17 |
| DEER CRK | 15 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 1451.00 | 115.35 |
| BATTLE RVR | 16 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 65.31 | 65.31 |
| N.BATTLFRD | 17 | | | | 0 | 0.00 | 0.00 | 0.00 | 1704.0 | 1363.2 | 1622.35 | 106.04 |
| PRNC ALBRT | 18 | | | | 0 | 8.16 | 7.72 | 26.80 | 0.0 | 26.8 | 1622.35 | 0.00 |
| NIPAWIN | 19 | 394.50 | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 4529.79 | 314.11 |
| THE PAS | 20 | 736.30 | | | 0 | 2.76 | 2.36 | 0.00 | 0.0 | 0.0 | 5738.55 | 1208.76 |
| KAMSACK | 21 | | | | 0 | 3.12 | 0.03 | 5.15 | 0.0 | 5.1 | 122.50 | 122.50 |
| RUSSEL | 22 | | | | 0 | 0.00 | 0.00 | 0.00 | 15.2 | 12.2 | 169.34 | 46.84 |
| TANTALLON | 23 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 67.02 | 17.72 |
| ESTEVAN | 24 | | | | 0 | 2.74 | 0.02 | 15.24 | 0.0 | 15.2 | 42.52 | 42.52 |
| OXBOW | 25 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 0.00 | 0.00 |
| MELITA | 26 | | | | 0 | 0.47 | 0.05 | 5.15 | 0.0 | 5.2 | 13.03 | -29.49 |
| HOLLAND | 27 | | | | 25 | 7.63 | 1.56 | 21.42 | 337.4 | 291.3 | 518.59 | 336.22 |
| SMOKEY RVR | 28 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2487.52 | 2487.52 |
| PEACE RVR | 29 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 12187.74 | 9700.22 |

| WTR USE | CHNG IN STRG (0.00) | FLOW | FL>MIN | MAY&JUNE NTRL FLW | INCR FLW | DRVTD FLOW | WTR USE (1.00IRRN%) | CHNG IN STRGE (0.41) | FLOW | FL>MIN | JULY NTRL FLW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.0 | 322.64 | 138.34 | 777.89 | 777.89 | 0.00 | 41.00 | 0.0 | 736.89 | 644.74 | 167.09 |
| 15.87 | 0.0 | 817.11 | 340.76 | 1893.49 | 1115.60 | 0.00 | 361.36 | 120.0 | 1371.13 | 1132.95 | 488.95 |
| 108.88 | 130.0 | 403.26 | 8.15 | 1061.49 | 1061.49 | 0.00 | 788.15 | 65.0 | 208.34 | 10.79 | 626.47 |
| 0.00 | 0.0 | 719.30 | 175.15 | 1532.47 | 470.98 | 0.00 | 144.32 | 0.0 | 535.00 | 262.93 | 798.67 |
| 15.71 | 0.0 | 1565.24 | 552.65 | 3343.60 | -82.37 | 0.00 | 94.40 | 0.0 | 1729.37 | 1223.08 | 1305.04 |
| 11.54 | 0.0 | 407.16 | 112.46 | 591.50 | 591.50 | 0.00 | 136.66 | 0.0 | 454.83 | 370.63 | 269.05 |
| 0.00 | 0.0 | 628.19 | 321.56 | 639.45 | 47.95 | 0.00 | 312.58 | 0.0 | 190.20 | 36.89 | 639.45 |
| 0.00 | 0.0 | 2224.47 | 968.69 | 3807.60 | -175.44 | 0.00 | 0.00 | 0.0 | 1744.12 | -159.68 | 1711.04 |
| 3.90 | 0.0 | 62.01 | 51.46 | 9.98 | 9.98 | 0.00 | 20.57 | 0.0 | -10.59 | -15.86 | 1.86 |
| 104.42 | 700.0 | 1509.90 | 177.44 | 3811.70 | 23.76 | 0.00 | 771.52 | 385.0 | 589.98 | -76.25 | 1907.17 |
| 21.14 | 0.0 | 1495.01 | 711.01 | 3675.20 | -136.50 | 0.00 | 2.48 | 0.0 | 451.00 | 227.00 | 1864.44 |
| 18.22 | 0.0 | 31.07 | 19.07 | 29.64 | 29.64 | 0.00 | 18.84 | 0.0 | 10.80 | 4.80 | 6.48 |
| 0.00 | 0.0 | 771.48 | 240.65 | 959.22 | 959.22 | 0.00 | 0.00 | 0.0 | 959.22 | 693.80 | 1008.14 |
| 127.33 | 0.0 | 1208.32 | -632.54 | 2282.21 | 1322.99 | 0.00 | 34.80 | 0.0 | 2247.41 | 1721.45 | 1494.42 |
| 0.00 | 0.0 | 1323.67 | 598.17 | 2301.35 | 19.14 | 0.00 | 0.00 | 0.0 | 2266.55 | 1115.87 | 1537.83 |
| 0.00 | 0.0 | 65.31 | 38.96 | 92.56 | 92.56 | 0.00 | 0.00 | 0.0 | 92.56 | 79.38 | 18.54 |
| 0.00 | 0.0 | 1495.02 | 480.21 | 2313.56 | -80.35 | 0.00 | 558.91 | 0.0 | 1719.85 | 1212.44 | 1626.60 |
| 9.26 | 0.0 | 1485.76 | 470.95 | 2313.55 | 0.00 | 0.00 | 12.07 | 0.0 | 1707.77 | 1200.37 | 1626.60 |
| 0.00 | 0.0 | 3294.87 | 533.37 | 5884.06 | -104.70 | 0.00 | 0.00 | 0.0 | 2054.08 | 1265.08 | 3724.50 |
| 2.99 | 0.0 | 4500.64 | -653.46 | 6589.12 | 705.06 | 0.00 | 0.35 | 0.0 | 2758.79 | 1286.19 | 4186.64 |
| 1.34 | 0.0 | 120.56 | 84.07 | 105.55 | 105.55 | 0.00 | 2.33 | 0.0 | 103.22 | 84.93 | 18.10 |
| 0.00 | 0.0 | 167.50 | 106.85 | 200.84 | 95.29 | 0.00 | 4.99 | 0.0 | 193.53 | 163.20 | 47.29 |
| 0.00 | 0.0 | 48.80 | 26.28 | 65.83 | 36.19 | 0.00 | 0.00 | 0.0 | 46.99 | 35.73 | 19.88 |
| 1.51 | 0.0 | 40.91 | 32.49 | 17.95 | 17.95 | 0.00 | 6.44 | 0.0 | 11.51 | 7.30 | 2.16 |
| 0.00 | 0.0 | 0.00 | -1.24 | 7.37 | 7.37 | 0.00 | 0.00 | 0.0 | 7.37 | 6.75 | 1.27 |
| 0.31 | 0.0 | 11.12 | 7.80 | 9.23 | -8.72 | 0.00 | 2.15 | 0.0 | 0.65 | -1.01 | 1.94 |
| 5.35 | 0.0 | 509.48 | 316.18 | 614.21 | 404.14 | 0.00 | 120.08 | 25.0 | 478.23 | 381.59 | 172.47 |
| 0.00 | 0.0 | 2487.52 | 921.00 | 5428.17 | 5428.17 | 0.00 | 0.00 | 0.0 | 5428.17 | 4644.91 | 1885.22 |
| 0.00 | 0.0 | 12187.74 | 4397.26 | 27331.92 | 21903.75 | 0.00 | 0.00 | 0.0 | 27331.92 | 23436.68 | 10309.07 |

WATER BALANCE MODEL : FUTURE WATER USES & PHASE II DEVELOPMENT

| INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.46 CHNG IN STRGE | FLOW | FL>MIN | AUG&SEPT NTRL FLW | INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.13 CHNG IN STRGE | FLOW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 167.09 | 0.00 | 45.50 | 0.0 | 121.49 | 75.41 | 114.64 | 114.64 | 0.00 | 13.40 | 0.0 | 101.24 |
| 321.95 | 0.00 | 400.87 | -100.0 | 142.48 | 23.39 | 352.20 | 237.56 | 0.00 | 118.10 | -20.0 | 240.70 |
| 626.47 | 0.00 | 869.48 | -355.0 | 121.99 | 23.21 | 533.19 | 633.19 | 0.00 | 257.59 | 170.0 | 205.60 |
| 172.20 | 0.00 | 160.51 | 0.0 | 133.68 | -2.36 | 791.81 | 158.62 | 0.00 | 47.17 | 0.0 | 317.05 |
| 17.42 | 0.00 | 103.97 | 0.0 | 189.61 | -63.53 | 1105.02 | -38.99 | 0.00 | 30.85 | 0.0 | 487.91 |
| 259.05 | 0.00 | 151.24 | 0.0 | 117.81 | 75.71 | 313.94 | 313.94 | 0.00 | 44.67 | 0.0 | 269.27 |
| 370.40 | 0.00 | 347.55 | 0.0 | 140.56 | 53.90 | 380.98 | 57.04 | 0.00 | 102.16 | 0.0 | 234.15 |
| -233.45 | 0.00 | 0.00 | 0.0 | 96.72 | -758.80 | 1419.87 | -66.13 | 0.00 | 0.00 | 0.0 | 655.93 |
| 1.96 | 0.00 | 22.62 | 0.0 | -20.75 | -23.40 | 1.34 | 1.34 | 0.00 | 6.72 | 0.0 | -5.38 |
| 200.75 | 0.00 | 351.28 | -1035.0 | 473.72 | 140.60 | 1587.51 | 270.91 | 0.00 | 252.15 | -50.0 | 720.85 |
| -42.73 | 0.00 | 1.38 | 0.0 | 429.61 | 317.61 | 1624.66 | -62.85 | 0.00 | 0.81 | 0.0 | 657.19 |
| 6.48 | 0.00 | 19.77 | 0.0 | -13.29 | -16.29 | 4.62 | 4.62 | 0.00 | 6.16 | 0.0 | -1.54 |
| 1008.14 | 0.00 | 0.00 | 0.0 | 1008.14 | 875.43 | 1242.42 | 1242.42 | 0.00 | 0.00 | 0.0 | 1242.42 |
| 486.28 | 0.00 | 30.41 | 0.0 | 1464.01 | 1201.03 | 1806.81 | 564.39 | 0.00 | 11.37 | 0.0 | 1795.43 |
| 43.41 | 0.00 | 0.00 | 0.0 | 1507.42 | 738.50 | 1980.47 | 173.66 | 0.00 | 0.00 | 0.0 | 1969.10 |
| 18.54 | 0.00 | 0.00 | 0.0 | 18.54 | 11.95 | 21.22 | 21.22 | 0.00 | 0.00 | 0.0 | 21.22 |
| 70.23 | 0.00 | 621.62 | 0.0 | 974.57 | 720.87 | 2048.53 | 45.84 | 0.00 | 182.67 | 0.0 | 1854.49 |
| -0.00 | 0.00 | 12.82 | 0.0 | 961.74 | 708.04 | 2048.53 | -0.00 | 0.00 | 3.95 | 0.0 | 1850.54 |
| 233.46 | 0.00 | 0.00 | 0.0 | 1624.81 | 1230.31 | 3965.32 | 192.13 | 0.00 | 0.00 | 0.0 | 2699.86 |
| 462.14 | 0.00 | 0.19 | 0.0 | 2086.75 | 1359.45 | 3530.71 | 1655.39 | 0.00 | 0.11 | 0.0 | 4365.14 |
| 18.10 | 0.00 | 2.47 | 0.0 | 15.63 | 6.48 | 28.30 | 28.30 | 0.00 | 0.76 | 0.0 | 27.54 |
| 29.19 | 0.00 | 5.54 | 0.0 | 39.27 | 24.11 | 37.38 | 9.09 | 0.00 | 1.63 | 0.0 | 34.99 |
| 13.40 | 0.00 | 0.00 | 0.0 | 0.11 | -5.52 | 16.16 | 11.54 | 0.00 | 0.00 | 0.0 | 10.00 |
| 2.16 | 0.00 | 7.05 | 0.0 | -4.89 | -7.00 | 0.52 | 0.52 | 0.00 | 2.10 | 0.0 | -1.58 |
| 1.27 | 0.00 | 0.00 | 0.0 | 1.27 | 0.96 | 0.67 | 0.67 | 0.00 | 0.00 | 0.0 | 0.67 |
| -0.22 | 0.00 | 2.37 | 0.0 | -7.49 | -8.32 | 0.67 | 0.15 | 0.00 | 0.70 | 0.0 | -2.14 |
| 123.25 | 0.00 | 133.20 | -25.0 | 21.83 | -26.49 | 144.47 | 106.41 | 0.00 | 39.24 | 0.0 | 100.03 |
| 1885.22 | 0.00 | 0.00 | 0.0 | 1885.22 | 1493.59 | 1947.99 | 1947.99 | 0.00 | 0.00 | 0.0 | 1947.99 |
| 8423.95 | 0.00 | 0.00 | 0.0 | 10309.07 | 8351.45 | 8399.89 | 6651.90 | 0.00 | 0.00 | 0.0 | 8599.89 |

| FL>MIN | ANNUAL NAT FLW | ANNUAL FLOW | MINIMUM FL>MIN | ANNUAL FL>MIN | TTL CHNG STORAGE | TOTAL ANN USE | TOTAL ANN DVR | ANNL FL EXT/NTRL | NO STRG PTNL IRRG FLOW |
|---|---|---|---|---|---|---|---|---|---|
| 9.09 | 1382.26 | 1282.26 | 9.09 | 867.59 | 0.0 | 100.00 | 0.00 | 0.93 | 67.83 |
| 2.52 | 3572.62 | 2571.41 | 2.52 | 1499.63 | 0.0 | 904.04 | 0.00 | 0.72 | 18.82 |
| 8.05 | 2963.29 | 939.19 | 8.05 | 50.20 | 0.0 | 2077.86 | 0.00 | 0.32 | 26.32 |
| 44.98 | 4081.13 | 1705.03 | -2.36 | 480.59 | 0.0 | 352.00 | 0.00 | 0.42 | -5.17 |
| -18.38 | 7594.35 | 3972.13 | -63.53 | 1693.82 | 0.0 | 252.57 | 0.00 | 0.52 | -139.32 |
| 135.07 | 1593.29 | 1249.08 | 75.71 | 743.88 | 0.0 | 349.96 | 0.00 | 0.78 | 166.04 |
| 80.83 | 2299.71 | 1193.09 | 36.89 | 503.18 | 0.0 | 762.40 | 0.00 | 0.52 | 89.97 |
| -54.00 | 9450.08 | 4721.25 | -758.80 | -3.80 | 0.0 | 0.00 | 0.00 | 0.50 | -1664.04 |
| -10.55 | 79.08 | 25.28 | -23.40 | 1.55 | 0.0 | 55.73 | 0.00 | 0.32 | -79.51 |
| 54.52 | 9993.47 | 3294.45 | -75.25 | 296.41 | 0.0 | 2030.92 | 0.00 | 0.33 | -185.98 |
| 433.19 | 9757.63 | 3032.81 | 227.00 | 1688.81 | 0.0 | 36.24 | 0.00 | 0.31 | 553.67 |
| -7.54 | 90.03 | 27.04 | -16.29 | 0.03 | 0.0 | 71.99 | 0.00 | 0.30 | -56.29 |
| 977.00 | 3981.26 | 3981.26 | 240.65 | 2786.88 | 0.0 | 0.00 | 0.00 | 1.00 | 1692.20 |
| 1259.47 | 6919.08 | 6715.17 | -632.54 | 3559.41 | 0.0 | 266.78 | 0.00 | 0.97 | 2633.83 |
| 978.95 | 7270.65 | 7066.73 | 598.17 | 3431.41 | 0.0 | 0.00 | 0.00 | 0.97 | 1619.53 |
| 8.05 | 197.63 | 197.63 | 8.05 | 138.34 | 0.0 | 0.00 | 0.00 | 1.00 | 26.22 |
| 1347.08 | 7511.04 | 6043.92 | 480.21 | 3760.51 | 0.0 | 1363.20 | 0.00 | 0.79 | 1580.85 |
| 1343.14 | 7611.04 | 6005.81 | 470.95 | 3722.50 | 0.0 | 42.68 | 0.00 | 0.79 | 1552.72 |
| 1910.36 | 18003.66 | 9673.62 | 533.37 | 4939.62 | 0.0 | 0.00 | 0.00 | 0.54 | 2698.06 |
| 2892.54 | 22045.02 | 13711.33 | -653.46 | 4875.73 | 0.0 | 5.12 | 0.00 | 0.62 | 2961.54 |
| 9.24 | 274.44 | 267.05 | 6.48 | 184.72 | 0.0 | 8.30 | 0.00 | 0.97 | 14.21 |
| 4.57 | 454.85 | 435.29 | 4.67 | 298.84 | 0.0 | 12.16 | 0.00 | 0.96 | 34.85 |
| -1.25 | 168.89 | 105.90 | -5.52 | 55.23 | 0.0 | 0.00 | 0.00 | 0.63 | -12.10 |
| -5.79 | 63.15 | 45.95 | -7.00 | 27.00 | 0.0 | 18.00 | 0.00 | 0.73 | -43.23 |
| 0.05 | 9.31 | 9.31 | -1.24 | 6.51 | 0.0 | 0.00 | 0.00 | 1.00 | 0.37 |
| -3.79 | 24.87 | 2.14 | -8.32 | -5.32 | 0.0 | 5.68 | 0.00 | 0.09 | -28.31 |
| 3.38 | 1449.74 | 1109.57 | -26.49 | 674.65 | 0.0 | 300.53 | 0.00 | 0.77 | -58.10 |
| 1154.73 | 11748.90 | 11748.90 | 921.00 | 8224.23 | 0.0 | 0.00 | 0.00 | 1.00 | 3275.42 |
| 4704.55 | 58428.62 | 58428.62 | 4397.26 | 40900.03 | 0.0 | 0.00 | 0.00 | 1.00 | 18336.51 |

WATER BALANCE MODEL : FUTURE WATER USES & PHASE II DEVELOPMENT cont'd

GMNWP3 AUG 1/87 1.00 1.00 PHASE3 4.00 0.80

| WATER NTWK SITE | NODE | MIN FLW 1E6M3/MNTH | DIVERTED 1E6M3/MNTH | FROM /TO | STORAGE M3K1ES | WTR USE MUNICIPAL | 1000 DAM3 INDUSTRIAL | EXST IRRG | NEW IRRGN WTHDRWL | TOTAL IRRGN RQM | OCT - APR NTRL FLW | INCR FLW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FT MACLEOD | 1 | | | | 0 | 0.00 | 0.00 | 100.00 | 0.0 | 100.0 | 322.64 | 322.64 |
| LTHBRDGE | 2 | | | | 100 | 17.68 | 9.52 | 375.00 | 627.3 | 876.8 | 837.98 | 515.34 |
| CALGARY | 3 | | 40.00 | 13-6-3 | 400 | 119.00 | 67.66 | 0.00 | 2612.0 | 2089.6 | 642.14 | 642.14 |
| BASSANO | 4 | | | | 0 | 0.00 | 0.00 | 352.00 | 0.0 | 352.0 | 958.18 | 316.04 |
| MEDCN HAT | 5 | | | | 0 | 10.99 | 15.93 | 225.75 | 0.0 | 225.8 | 1840.69 | 44.53 |
| RED DEER | 6 | 42.10 | 30.00 | 13-6 | 0 | 9.00 | 10.96 | 330.00 | 0.0 | 330.0 | 418.81 | 418.81 |
| BINDLOSS | 7 | | | | 0 | 0.00 | 0.00 | 0.00 | 1128.0 | 902.4 | 639.83 | 221.02 |
| LEMSFORD | 8 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2511.57 | 31.05 |
| SWIFT CRNT | 9 | | | | 0 | 0.68 | 6.00 | 49.05 | 0.0 | 49.1 | 65.90 | 65.90 |
| L.DIEFBKR | 10 | | 0.00 | 10-12 | 9700 | 0.00 | 179.00 | 132.00 | 2149.9 | 1851.9 | 2587.09 | 58.92 |
| SASKATOON | 11 | 112.00 | | | 0 | 30.24 | 6.00 | 0.00 | 0.0 | 0.0 | 2593.33 | 5.24 |
| LUMSDEN | 12 | | 0.00 | 10-12 | 0 | 26.48 | 4.76 | 40.75 | 0.0 | 40.8 | 49.30 | 49.30 |
| ROCKY MTN | 13 | | -70.00 | 13-6&3 | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 771.48 | 771.48 |
| EDMONTON | 14 | 262.98 | | | 0 | 78.88 | 139.40 | 48.50 | 0.0 | 48.5 | 1335.65 | 564.17 |
| DEER CRK | 15 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 1451.00 | 115.35 |
| BATTLE RVR | 16 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 65.31 | 65.31 |
| N.BATTLFRD | 17 | | | | 0 | 0.00 | 0.00 | 0.00 | 1704.0 | 1363.2 | 1622.35 | 106.04 |
| PRNC ALBRT | 18 | | | | 0 | 8.16 | 7.72 | 26.80 | 0.0 | 26.8 | 1622.35 | 0.00 |
| NIPAWIN | 19 | 394.50 | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 4529.79 | 314.11 |
| THE PAS | 20 | 736.30 | | | 0 | 2.76 | 2.36 | 0.00 | 0.0 | 0.0 | 5738.55 | 1208.76 |
| KAMSACK | 21 | | | | 0 | 3.12 | 0.03 | 5.15 | 0.0 | 5.1 | 122.50 | 122.50 |
| RUSSEL | 22 | | | | 0 | 0.00 | 0.00 | 0.00 | 15.2 | 12.2 | 169.34 | 46.84 |
| TANTALLON | 23 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 67.02 | 17.72 |
| ESTEVAN | 24 | | | | 0 | 2.74 | 0.02 | 15.24 | 0.0 | 15.2 | 42.52 | 42.52 |
| OXBOW | 25 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 0.00 | 0.00 |
| MELITA | 26 | | | | 0 | 0.47 | 0.05 | 5.15 | 0.0 | 5.2 | 13.03 | -29.49 |
| HOLLAND | 27 | | | | 25 | 7.63 | 1.56 | 21.42 | 337.4 | 291.3 | 518.59 | 336.22 |
| SMOKEY RVR | 28 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 2487.52 | 2487.52 |
| PEACE RVR | 29 | | | | 0 | 0.00 | 0.00 | 0.00 | 0.0 | 0.0 | 12187.74 | 9700.22 |

0.00 1.00IRRNX 0.41

| WTR USE | CHNG IN STRG | FLOW | FL>MIN | MAY&JUNE NTRL FLW | INCR FLW | DRVTD FLOW | WTR USE | CHNG IN STRGE | FLOW | FL>MIN | JULY NTRL FLW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.0 | 322.54 | 138.34 | 777.89 | 777.89 | 0.00 | 41.00 | 0.0 | 736.89 | 644.74 | 167.09 |
| 15.97 | 0.0 | 817.11 | 340.76 | 1893.49 | 1115.60 | 0.00 | 351.36 | 120.0 | 1371.13 | 1132.95 | 488.95 |
| 108.88 | 130.0 | 403.26 | 8.15 | 1061.49 | 1061.49 | 80.00 | 859.49 | 65.0 | 207.00 | 9.45 | 626.47 |
| 0.00 | 0.0 | 719.30 | 175.15 | 1532.47 | 470.98 | 0.00 | 144.32 | 0.0 | 533.66 | 261.58 | 798.67 |
| 15.71 | 0.0 | 1565.24 | 552.65 | 3343.60 | -82.37 | 0.00 | 94.40 | 0.0 | 1728.02 | 1221.73 | 1305.04 |
| 11.64 | 0.0 | 407.16 | 112.46 | 591.50 | 591.50 | 50.00 | 136.66 | 0.0 | 514.83 | 430.63 | 269.05 |
| 0.00 | 0.0 | 628.19 | 321.56 | 639.45 | 47.95 | 0.00 | 369.98 | 0.0 | 192.80 | 39.49 | 639.45 |
| 0.00 | 0.0 | 2224.47 | 968.69 | 3807.60 | -175.44 | 0.00 | 0.00 | 0.0 | 1745.38 | -158.42 | 1711.04 |
| 3.90 | 0.0 | 62.01 | 51.46 | 9.98 | 9.98 | 0.00 | 20.57 | 0.0 | -10.59 | -15.86 | 1.86 |
| 104.42 | 700.0 | 1509.90 | 177.44 | 3811.70 | 23.76 | 0.00 | 771.52 | 385.0 | 591.24 | -74.99 | 1907.17 |
| 21.14 | 0.0 | 1495.01 | 711.01 | 3675.20 | -135.50 | 0.00 | 2.48 | 0.0 | 452.26 | 228.26 | 1864.44 |
| 18.22 | 0.0 | 31.07 | 19.07 | 29.64 | 29.64 | 0.00 | 18.84 | 0.0 | 10.80 | 4.80 | 6.48 |
| 0.00 | 0.0 | 771.48 | 240.65 | 959.22 | 959.22 | -140.00 | 0.00 | 0.0 | 819.22 | 553.80 | 1008.14 |
| 127.33 | 0.0 | 1208.32 | -632.54 | 2282.21 | 1322.99 | 0.00 | 34.80 | 0.0 | 2107.41 | 1581.45 | 1494.42 |
| 0.00 | 0.0 | 1323.67 | 598.17 | 2301.35 | 19.14 | 0.00 | 0.00 | 0.0 | 2126.55 | 975.87 | 1537.83 |
| 0.00 | 0.0 | 65.31 | 38.96 | 92.56 | 92.56 | 0.00 | 0.00 | 0.0 | 92.56 | 79.38 | 18.54 |
| 0.00 | 0.0 | 1495.02 | 480.21 | 2313.56 | -80.35 | 0.00 | 558.91 | 0.0 | 1579.85 | 1072.44 | 1626.60 |
| 9.26 | 0.0 | 1485.76 | 470.95 | 2313.56 | 0.00 | 0.00 | 12.07 | 0.0 | 1567.77 | 1060.37 | 1626.60 |
| 0.00 | 0.0 | 3294.87 | 533.37 | 5884.06 | -104.70 | 0.00 | 0.00 | 0.0 | 1915.33 | 1126.33 | 3724.50 |
| 2.99 | 0.0 | 4500.54 | -653.46 | 5589.12 | 705.06 | 0.00 | 0.35 | 0.0 | 2620.05 | 1147.45 | 4186.64 |
| 1.84 | 0.0 | 120.56 | 84.07 | 105.55 | 105.55 | 0.00 | 2.33 | 0.0 | 103.22 | 84.93 | 18.10 |
| 0.00 | 0.0 | 167.50 | 106.85 | 200.84 | 95.29 | 0.00 | 4.99 | 0.0 | 193.53 | 163.20 | 47.29 |
| 0.00 | 0.0 | 48.80 | 26.28 | 65.83 | 36.19 | 0.00 | 0.00 | 0.0 | 46.99 | 35.73 | 19.88 |
| 1.51 | 0.0 | 40.91 | 32.49 | 17.95 | 17.95 | 0.00 | 5.44 | 0.0 | 11.51 | 7.30 | 2.16 |
| 0.00 | 0.0 | 0.00 | -1.24 | 7.37 | 7.37 | 0.00 | 0.00 | 0.0 | 7.37 | 6.75 | 1.27 |
| 0.31 | 0.0 | 11.12 | 7.80 | 9.23 | -8.72 | 0.00 | 2.15 | 0.0 | 0.65 | -1.01 | 1.94 |
| 5.36 | 0.0 | 509.48 | 316.18 | 614.21 | 404.14 | 0.00 | 120.08 | 25.0 | 478.23 | 381.59 | 172.47 |
| 0.00 | 0.0 | 2487.52 | 921.00 | 5428.17 | 5428.17 | 0.00 | 0.00 | 0.0 | 5428.17 | 4644.91 | 1885.22 |
| 0.00 | 0.0 | 12187.74 | 4397.26 | 27331.92 | 21903.75 | 0.00 | 0.00 | 0.0 | 27331.92 | 23436.68 | 10309.07 |

WATER BALANCE MODEL : FUTURE WATER USES & PHASE III DEVELOPMENT

| INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.46CHNG IN STRGE | FLOW | FL>MIN | AUG&SEPT NTRL FLW | INCR FLW | DRVTD FLOW | 1.00IRRN% WTR USE | 0.13CHNG IN STRGE | FLOW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 157.09 | 0.00 | 45.60 | 0.0 | 121.49 | 75.41 | 114.64 | 114.64 | 0.00 | 13.40 | 0.0 | 101.24 |
| 321.86 | 0.00 | 400.87 | -130.0 | 142.48 | 23.39 | 352.20 | 237.56 | 0.00 | 118.10 | -20.0 | 240.70 |
| 626.47 | 40.00 | 959.95 | -365.0 | 71.52 | -27.26 | 533.19 | 533.19 | 80.00 | 284.18 | 170.0 | 259.01 |
| 172.20 | 0.00 | 160.51 | 0.0 | 83.21 | -52.83 | 791.81 | 158.62 | 0.00 | 47.17 | 0.0 | 370.47 |
| 17.42 | 0.00 | 103.97 | 0.0 | 139.14 | -114.00 | 1105.02 | -38.99 | 0.00 | 30.85 | 0.0 | 541.33 |
| 269.35 | 30.00 | 151.24 | 0.0 | 147.81 | 105.71 | 313.94 | 313.94 | 60.00 | 44.67 | 0.0 | 329.27 |
| 370.43 | 0.00 | 411.49 | 0.0 | 106.72 | 30.06 | 380.98 | 67.04 | 0.00 | 120.92 | 0.0 | 275.39 |
| -233.45 | 0.00 | 0.00 | 0.0 | 12.41 | -843.11 | 1419.87 | -66.13 | 0.00 | 0.00 | 0.0 | 750.59 |
| 1.86 | 0.00 | 22.62 | 0.0 | -20.76 | -23.40 | 1.34 | 1.34 | 0.00 | 6.72 | 0.0 | -5.38 |
| 230.75 | 0.00 | 851.28 | -1035.0 | 389.41 | 56.29 | 1587.51 | 270.91 | 0.00 | 252.15 | -50.0 | 815.50 |
| -42.73 | 0.00 | 1.38 | 0.0 | 345.30 | 233.30 | 1524.66 | -62.85 | 0.00 | 0.81 | 0.0 | 751.85 |
| 6.48 | 0.00 | 19.77 | 0.0 | -13.29 | -16.29 | 4.62 | 4.62 | 0.00 | 6.16 | 0.0 | -1.54 |
| 1008.14 | -70.00 | 0.00 | 0.0 | 938.14 | 805.43 | 1242.42 | 1242.42 | -140.00 | 0.00 | 0.0 | 1102.42 |
| 486.28 | 0.00 | 30.41 | 0.0 | 1394.01 | 1131.03 | 1806.81 | 564.39 | 0.00 | 11.37 | 0.0 | 1655.43 |
| 43.41 | 0.00 | 0.00 | 0.0 | 1437.42 | 668.50 | 1980.47 | 173.66 | 0.00 | 0.00 | 0.0 | 1829.10 |
| 18.54 | 0.00 | 0.00 | 0.0 | 18.54 | 11.95 | 21.22 | 21.22 | 0.00 | 0.00 | 0.0 | 21.22 |
| 70.23 | 0.00 | 621.62 | 0.0 | 904.57 | 650.87 | 2048.53 | 45.84 | 0.00 | 182.67 | 0.0 | 1714.49 |
| -0.00 | 0.00 | 12.82 | 0.0 | 891.74 | 638.04 | 2048.53 | -0.00 | 0.00 | 3.95 | 0.0 | 1710.54 |
| 233.46 | 0.00 | 0.00 | 0.0 | 1470.50 | 1076.00 | 3865.32 | 192.13 | 0.00 | 0.00 | 0.0 | 2654.51 |
| 462.14 | 0.00 | 0.19 | 0.0 | 1932.45 | 1196.15 | 5530.71 | 1665.39 | 0.00 | 0.11 | 0.0 | 4319.79 |
| 18.10 | 0.00 | 2.47 | 0.0 | 15.53 | 6.48 | 28.30 | 28.30 | 0.00 | 0.76 | 0.0 | 27.54 |
| 29.19 | 0.00 | 5.54 | 0.0 | 39.27 | 24.11 | 37.38 | 9.09 | 0.00 | 1.63 | 0.0 | 34.99 |
| 13.43 | 0.00 | 0.00 | 0.0 | 0.11 | -5.52 | 16.16 | 11.54 | 0.00 | 0.00 | 0.0 | 10.00 |
| 2.16 | 0.03 | 7.05 | 0.0 | -4.89 | -7.00 | 0.52 | 0.52 | 0.00 | 2.10 | 0.0 | -1.58 |
| 1.27 | 0.00 | 0.00 | 0.0 | 1.27 | 0.96 | 0.67 | 0.67 | 0.00 | 0.00 | 0.0 | 0.67 |
| -0.22 | 0.00 | 2.37 | 0.0 | -7.49 | -8.32 | 0.67 | 0.15 | 0.00 | 0.70 | 0.0 | -2.14 |
| 123.25 | 0.00 | 133.20 | -25.0 | 21.83 | -26.49 | 144.47 | 106.41 | 0.00 | 39.24 | 0.0 | 100.03 |
| 1885.22 | 0.00 | 0.00 | 0.0 | 1885.22 | 1493.59 | 1947.99 | 1947.99 | 0.00 | 0.00 | 0.0 | 1947.99 |
| 8423.85 | 0.00 | 0.00 | 0.0 | 10309.07 | 8361.45 | 8599.89 | 6651.90 | 0.00 | 0.00 | 0.0 | 8599.89 |

| FL>MIN | ANNUAL NAT FLW | ANNUAL FLOW | MINIMUM FL>MIN | ANNUAL FL>MIN | TTL CHNG STORAGE | TOTAL ANN USE | TOTAL ANN DVR | ANNL FL EXT/NTRL | NO STRG PTNL IRRG FLOW |
|---|---|---|---|---|---|---|---|---|---|
| 9.09 | 1382.26 | 1282.26 | 9.09 | 867.58 | 0.0 | 100.00 | 0.00 | 0.93 | 67.83 |
| 2.52 | 3572.62 | 2571.41 | 2.52 | 1499.63 | 0.0 | 904.04 | 0.00 | 0.72 | 18.82 |
| 51.46 | 2963.29 | 940.79 | -27.26 | 51.80 | 0.0 | 2276.26 | 200.00 | 0.32 | -59.77 |
| 98.39 | 4081.13 | 1706.63 | -52.83 | 482.29 | 0.0 | 352.00 | 0.00 | 0.42 | -115.86 |
| 35.04 | 7594.35 | 3973.73 | -114.00 | 1695.42 | 0.0 | 252.67 | 0.00 | 0.52 | -250.00 |
| 245.07 | 1593.29 | 1399.08 | 105.71 | 893.88 | 0.0 | 349.96 | 150.00 | 0.88 | 231.83 |
| 122.07 | 2299.71 | 1203.09 | 30.06 | 513.18 | 0.0 | 902.40 | 0.00 | 0.52 | 65.92 |
| 40.65 | 9450.08 | 4732.85 | -843.11 | 7.80 | 0.0 | 0.00 | 0.00 | 0.50 | -1848.93 |
| -10.65 | 79.08 | 25.28 | -23.40 | 1.55 | 0.0 | 55.73 | 0.00 | 0.32 | -79.51 |
| 149.27 | 9993.47 | 3306.05 | -74.99 | 308.01 | 0.0 | 2030.92 | 0.00 | 0.33 | -182.91 |
| 527.85 | 9757.63 | 3044.41 | 228.26 | 1700.41 | 0.0 | 36.24 | 0.00 | 0.31 | 511.62 |
| -7.54 | 90.03 | 27.04 | -15.29 | 0.03 | 0.0 | 71.99 | 0.00 | 0.30 | -56.29 |
| 837.00 | 3981.26 | 3631.26 | 240.65 | 2436.88 | 0.0 | 0.00 | -350.00 | 0.91 | 1350.74 |
| 1129.47 | 6919.08 | 6365.17 | -632.54 | 3209.41 | 0.0 | 266.78 | 0.00 | 0.92 | 2480.32 |
| 838.36 | 7270.65 | 6715.73 | 598.17 | 3081.41 | 0.0 | 0.00 | 0.00 | 0.92 | 1466.02 |
| 8.05 | 197.63 | 197.53 | 8.05 | 138.34 | 0.0 | 0.00 | 0.00 | 1.00 | 26.22 |
| 1207.18 | 7611.04 | 5693.92 | 480.21 | 3410.61 | 0.0 | 1363.20 | 0.00 | 0.75 | 1427.34 |
| 1203.14 | 7611.04 | 5655.81 | 470.95 | 3372.50 | 0.0 | 42.68 | 0.00 | 0.74 | 1399.21 |
| 1855.51 | 18003.66 | 9335.22 | 533.37 | 4601.22 | 0.0 | 0.00 | 0.00 | 0.52 | 2359.66 |
| 2847.19 | 22045.02 | 13372.93 | -653.46 | 4537.33 | 0.0 | 5.12 | 0.00 | 0.61 | 2623.14 |
| 9.24 | 274.44 | 267.05 | 6.48 | 184.72 | 0.0 | 8.30 | 0.00 | 0.97 | 14.21 |
| 4.67 | 454.85 | 435.29 | 4.67 | 298.84 | 0.0 | 12.16 | 0.00 | 0.96 | 34.85 |
| -1.25 | 158.89 | 105.90 | -5.52 | 55.23 | 0.0 | 0.00 | 0.00 | 0.63 | -12.10 |
| -5.79 | 63.15 | 45.95 | -7.00 | 27.00 | 0.0 | 18.00 | 0.00 | 0.73 | -43.23 |
| 0.05 | 9.31 | 9.31 | -1.24 | 6.51 | 0.0 | 0.00 | 0.00 | 1.00 | 0.37 |
| -3.79 | 24.87 | 2.14 | -8.32 | -5.32 | 0.0 | 5.68 | 0.00 | 0.09 | -28.31 |
| 3.39 | 1449.74 | 1109.57 | -26.49 | 674.65 | 0.0 | 300.53 | 0.00 | 0.77 | -58.10 |
| 1154.73 | 11748.90 | 11748.90 | 921.00 | 8224.23 | 0.0 | 0.00 | 0.00 | 1.00 | 3275.42 |
| 4704.55 | 58428.62 | 58428.52 | 4397.26 | 40900.03 | 0.0 | 0.00 | 0.00 | 1.00 | 18336.51 |

WATER BALANCE MODEL : FUTURE WATER USES & PHASE III DEVELOPMENT cont'd