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ECONOMIC EVALUATION OF AN IRRIGATION PROJECT IN THE MORDEN-WINKLER AREA

by

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INTRODUCTION

The Morden-Winkler area in Southern Manitoba requires large amounts of water for irrigation and municipal and industrial water supply purposes. Many studies have been undertaken since 1907 by Canadian authorities both independently and in cooperation with the United States to justify engineering works that would make water available to this region.

The latest studies,[1,2*] were carried out during the years 1960 - 1964 for the International Joint Commission (I.J.C.) by the International Pembina River Engineering Board. The Board's objective was to formulate a plan for cooperative development of the Pembina River that would provide a high degree of optimization of the total net benefits to both countries.

The plan recommended by the Board to meet its objective consists of two large dams on the Pembina River, one in Canada (Pembina Dam) and one in the United States (Pembilier Dam). The resulting reservoirs would assure dependable supplies of water to both North Dakota and Southern Manitoba and also provide some flood control benefits. These latter largely accrue to North Dakota.

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* Numbers refer to Bibliography

Under the proposed plan, Manitoba would be guaranteed a dependable supply of water to irrigate 12,800 productive acres in the Morden-Winkler area and also a dependable flow of 5,000 acre-feet annually for the municipal and industrial requirements of the region. Manitoba's share of the cost under the plan amounts to $14,169,000 (1963 prices). In terms of 1974 dollars this has been estimated at $30,000,000.

At that time some thought was given for Manitoba to proceed unilaterally in the development of the Pembina River. However, preliminary studies suggested that it was not feasible and plans were discarded in favour of the joint development schemes.

There are three good reasons at this time why Manitoba should re-evaluate its position before participating in the recommended joint plan of development.

1. Manitoba will have no control over the source of water.

   Under the proposed plan Manitoba's share of the water would be delivered by a canal from a reservoir located in the United States. In other words the source of the water which Manitoba would pay to develop would be located entirely in a foreign country. The United States, of course, would be bound by International agreement to release established amounts of water to Manitoba. However, in times of severe drought when the demand for water by both parties is high and the supply is low, is an agreement a good enough guarantee that Manitoba will get its fair share of the water?

2. The plan favours the United States unduly. Under the plan the total primary benefits accruing to the United States would amount to approximately 1½ times the benefits accruing to Canada even though the Canadian reservoir would store 2½ times the amount of water stored in the United States reservoir. In terms of flooded areas this means that Canada would loose an additional 2,300 acres of land over what would be lost to the United States.

3. The Plan is expensive. Manitoba's share of the cost in 1974 prices has been estimated at $30,000,000. The writer believes that there are alternative means to supply the same amounts of water to the Morden-Winkler area at more economical costs.

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The aim of the present study is to investigate a plan of development of the Pembina River that Manitoba could undertake independently of the United States and that would not have the drawbacks of the combined scheme. It is also hoped that in the event the joint venture is undertaken the knowledge gained from this study will strengthen Manitoba's bargaining position on cost-sharing with the Americans.

The plan of unilateral development proposed in this report consists of a storage reservoir on the Pembina River and a pumping scheme to raise the water over the height of land into the Deadhorse Creek; thence it will then flow by gravity into the existing Morden Reservoir. From there a gravity supply canal will distribute it to the project area. (See Figure 1) The plan as presented will assure a dependable flow for the irrigation of 11,975 productive acres (12,800 for the I.J.C. scheme) and also will guarantee an additional 5,000 acre-feet of water annually for the future municipal and industrial needs of the area. The capital cost of the project has been estimated at $22,235,000. Annual benefits directly attributed to the project have been estimated at $2,874,000. The ratio of the annual primary benefits to the annual cost of the project is 1.2.

DESCRIPTION OF THE AREA

Location

The Morden-Winkler Project Area is located in the Municipality of Stanley, Township 1, Range 4 west of the Principal Meridian. The area occupies a small portion of the western margin of the Agassiz Lake Basin, bordering the Pembina Escarpment to the west and the International Boundary to the south. The area, though apparently flat, slopes to the east-northeast at a uniform rate of approximately 10 feet per mile dropping from El. 975 to El. 900 in a distance of 7 to 8 miles.

Climate

In relation to world-wide climatic conditions, the Morden-Winkler area falls within the region designated Dfb by the Koeppen-Geiger Climatic Classification[3].

The D climates in this classification include the humid parts of the world that have a summer but that also have a long severe winter. By definition, this type of climate is one in which the mean temperature of the coldest month is below 26.6°F (-3°C) and that of the warmest month is above 50°F. It is thus characterized by wide seasonal ranges of temperature which are the result of continental heating and cooling. The members of the D group are differentiated in the Koeppen-Geiger Classification by the degree of summer warmth (a, b or c) and by the presence or absence of a winter dry season (w or f respectively). Hence the region is classified as humid continental with severe winters.

a. Temperature: The temperature data recorded at Morden shows a mean of 61°F for the summer months of May to September inclusive, and an annual mean of 38°F. The average duration of the frost-free period with a minimum of 33°F is 121 days. In the 60-year interval, this has ranged from 92 days in 1929 to 145 days in 1944. The maximum and minimum recorded temperatures at Morden for the same period are 111.2°F (July 11, 1936) and -42°F (January 20, 1943).

b. Precipitation: The annual precipitation at Morden during the 60-year period from 1914 to 1973 is 20.10 inches. This has varied from 12.44 inches in 1952 to 28.28 inches in 1968. The precipitation for the growing season of May to September has varied from a low of 6.0 inches in 1967 to a high of 19.1 inches in 1971 with a mean of 12.54 inches. This amounts to 62% of the mean annual precipitation for the area.

An examination of all the recorded meteorological data reveals that the temperatures during the growing season are generally favourable for the crops common to the latitude. It should also be noted that drought periods with durations from 1 to 2 consecutive years have occasionally occurred, but excessive wet periods have been rare. In the 53-year period from 1921-1974, there were 25 years in which moisture receipts were equal to or greater than the normal evapotranspiration of 21.4 inches. Another 15 years had between 17.5 and 21.5

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inches and 13 years had less than 17.5 inches. Indications are, then, that in less than half of the years, moisture will be adequate, that there will be a shortage of up to four inches in just over one quarter of the years and a critical shortage in slightly less than one quarter of the years. Therefore, the supply of artificial moisture for agriculture in the area is a primary necessity in over 50% of the time. Furthermore, records show that in the growing season of May to September, rainfall amounts have never exceeded evapotranspiration totals for the period, hence supplemental moisture would have to be made available every year to assure optimum crop production.

<u>Soils</u>

The soils in the project area are mainly fine sand and very fine sand, underlain at depths of from 12 to 15 feet by fine-textured lacustrine sediments. Surface texture is predominantly that of a loamy very fine sand on level to very gently sloping topography[4]. They are predominantly Class 1 soils[5], highly productive, with no serious limitations. They contain little or no salts and depths to water table are in excess of 7 feet. Permeability is rather high and water retention capacity is fairly low. These soils are highly suitable for irrigation. No special attention for soil management is required on these soils other than those practices necessary to maintain fertility and prevent erosion. Continuous crop production is recommended[6]. A variety of crops should be included in the cropping sequence to permit chemical and cultural weed control. Wheat, oats, barley, flax, rapeseed, peas, beans, potatoes, sugar beets, sunflowers and forage crops are suitable and do extremely well on the soils[6]. However, lack of sufficient moisture frequently limits crop production and yields.

Present Agricultural Economy

a. Farm Tenure: The Dominion Bureau of Statistics Census of Canada, Agriculture showed the status of operators of commercial farms in the Municipality of Stanley (which encompasses the project area) to be approximately as follows:

TABLE 1

Operator	% 1961 Census	% 1971 Census
Full Owners	61	61
Part Owners-Part Tenant	28	32
All Tenant	10	7
Managers	1	0

Private ownership of land by the people farming it, is the common pattern. Absentee ownership is not widespread although the amount of rented land indicates a considerable amount of land is owned by persons residing in and adjacent to the project, but is not farmed by them. Within the project area, there is no land owned by commercial lending institutions and no Crown land.

b. Farm size: The 1971 Census shows that the average size of farm in the project area is 351 acres, compared

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with 543 acres for the Province of Manitoba. Nearly 20% of the operators in the project area have farm sizes less than 70 acres and less than 10% of the operators farm areas greater than 760 acres. The smaller farm sizes in the project area are believed to be related to the more favorable physical characteristics of the area that makes more intensive crop production possible, and so reducing the land area required.

c. Land Use: The land in the project area is very arable and generally about 90% of it is improved and under cultivation or crop. In addition, a small percentage of the improved land is used for pasture to raise livestock, poultry and dairy. The following table presents the distribution of the land for the different uses as given by Census Canada for 1961 and 1971:

TABLE 2

Improved Land	Census Canada 1961	Census Canada 1971
Under Crops	76%	89%
Summer Fallow	18%	7%
Pasture	4%	2%
Other Uses	2%	2%
Total Improved Land	100%	100%

Several significant points in the land use distribution as given in the Census Canada 1971 should be mentioned:

(1) The amount of summer fallow is much lower than the usual one-third that is encountered on the prairie areas. However, even for the project area 7% is unusually low, the normal being around 10%. The reason for the decline in summer fallow in 1971 is that more land was placed under crops to offset

the losses incurred the previous year*.

(2) Wheat, oats, barley, flaxseed, rapeseed and potatoes which are predominantly cash crops, use the largest amount of land.

(3) Land use for pasture has decreased in the last 13 years, with more of the land being used intensively for cash crops.

d. Livestock: Generally, the high proportion of arable land on each farm and lack of readily accessible low cost pasture land has restricted grazing livestock. In general, cattle operations provide beef and dairy products mainly for home use. Census Canada 1971 shows that comparatively little variation since 1961 has taken place in livestock operations in the project area. In the future, livestock enterprises are not expected to increase much beyond present levels but will continue to meet farm-home requirements. Hence, this subject will not be pursued further herein.

e. Farm Net Income: Farm net income is the return to the capital and labour of the farm operator and the unpaid members of his family. It represents what is left after the cash and overhead expenses are deducted from gross income. Farm net income for the project area is not available, however, a good indication is given by the 1973 Manitoba Agriculture Yearbook. These are presented in the table below and are compared to the personal income of non-farm workers in Manitoba. The latter are obtained from the Manitoba Bureau of Statistics.

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* In 1970 serious flooding in the spring and bad weather throughout the growing season in Southern Manitoba reduced crop yields, thus substantially decreasing the cash income of the farmers in the district.

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TABLE 3

	Annual Income (dollars)		
	1971	1972	1973
Farm Net Income of Farm Operator	5,300	5,450	11,500
Personal Income of Non-Farm Workers	8,400	9,300	9,900

In general, farm incomes in Manitoba have always been lower than the personal income of non-farm workers. In 1973, this trend reversed with farm operators more than doubling their expected income. This was mainly the result of large increases in the farm cash receipts. It is not known whether these large increases in cash receipts will be maintained in the future.

PLAN OF DEVELOPMENT

General

The plan of development as presented herein involves a dam on the Pembina River in Canada (to be referred to as the Pembina Dam) and a pumping scheme to raise the water from the reservoir over the height of land into the adjoining Deadhorse Creek system from where it will flow by gravity into the Morden-Winkler project area.

The reservoir and pumping works will be adequate to irrigate 13,300 acres of land (11,975 productive acres) in the project area and as well, provide an annual dependable flow of 5,000 acre-feet for the present and future municipal and industrial requirements of the region.

This plan was chosen since it yields essentially the same benefits to Manitoba as the recommended I.J.C. plan of development while it eliminates some of its disadvantages.

The proposal to irrigate 11,975 productive acres of land is 825 acres short of the 12,800 acres recommended in the I.J.C. report for optimum irrigation development in southern Manitoba. This amount was chosen, however, because it corresponds to one of the five schemes (#3) studied in considerable detail by the I.J.C. Engineering Board, consequently a vast amount of useful information has already been gathered and is available for use.

Figure 1 presents the overall layout of the proposed plan of development.

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The remaining parts of this section present the results of investigations into (1) the irrigation water requirements of the region, (2) the size of the Pembina Dam, reservoir and ancillary structures, (3) the design of the conveyance system, (4) the design of the irrigation system.

Irrigation Water Requirements

Irrigation water requirements are the quantities of water that should be delivered in the field to produce optimum crop yields. These consist of all water used for irrigating the crops, seepage losses within and resulting from conveyance of water to the irrigated area and operational wastes.

The irrigation water requirements have been recalculated for this study to conform with the latest available records. The meteorological data as recorded at Morden for the period 1921 to 1973 was used.

The growing season from May 1st to September 30th has been assumed in the calculations. No irrigation has been allowed for the month of May, since the precipitation during May, plus the soil moisture available from the spring snow melt, is more than adequate to meet the consumptive use of crops without the need to apply artificial moisture.

In the following paragraphs, the general terminology and criteria to compute water requirements is briefly explained and the derived water quantities are presented. For more detailed information, the reader is referred to Appendix A.

a. Consumptive Use: The consumptive use is the actual quantity of water required for optimum plant growth. It includes water used directly in the building of plant tissues and water lost in evaporation and transpiration. The Lowry-Johnson method was used to establish annual consumptive use for the project area and the P-E Index method to obtain the monthly distribution of consumptive use. The following results were derived:

TABLE 4

MEAN CONSUMPTIVE USE IN ACRE-FEET PER ACRE

May	June	July	August	September	Total
0.29	0.37	0.47	0.40	0.24	1.77

b. Crop Irrigation Requirement: Crop irrigation requirement is the quantity of water, in addition to precipitation necessary to insure optimum crop production. It is obtained as the difference between the monthly consumptive use and that portion of the monthly precipitation which is effective in meeting consumptive use requirements of the crops. For the project, the following values were derived:

TABLE 5

MEAN CROP IRRIGATION REQUIREMENTS IN ACRE-FEET PER ACRE

May	June	July	August	September	Total
0.0	0.16	0.27	0.24	0.11	0.78

c. Farm Delivery Requirement: In practice, it is infeasible to supply crop irrigation requirements without

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loss and waste. In applying water by surface methods, losses will occur due to percolation below the root zone, breaking of farm ditches, etc. (Sprinkler irrigation would substantially reduce losses, however the system was considered too expensive*). These losses, plus the crop irrigation requirement, make up the farm delivery requirement. Farm irrigation efficiency is an indication of water losses. It represents the useful water portion of the total water delivered to the farm. For the project area, the farm efficiency is 60%. By dividing the crop irrigation by the farm efficiency, the farm delivery requirement is obtained for each month as shown below:

TABLE 6

MEAN FARM DELIVERY REQUIREMENTS IN ACRE-FEET PER ACRE

May	June	July	August	September	Total
0.0	0.27	0.45	0.40	0.18	1.30

d. Irrigation Diversion Requirement: Monthly irrigation diversion requirements were estimated by adding the conveyance losses (incurred in delivering the water from the Pembina Reservoir to the project area) to the farm delivery requirements and allowing 10% for operational wastes. Conveyance losses were taken to be distributed evenly for each full month of the operating season. The resulting diversion requirements are presented below:

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* Estimates are that the sprinkler system requires a capital outlay of $300 per acre.

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TABLE 7

MEAN IRRIGATION DIVERSION REQUIREMENTS IN ACRE-FEET PER ACRE:

May	June	July	August	September	Total
0.0	0.37	0.56	0.50	0.28	1.71

The above results show that on the average, the Pembina Reservoir must provide enough irrigation storage to supply an annual dependable flow, equivalent to 1.71 feet over each irrigated acre in the project area.

Engineering Works

a. Pembina Dam and Reservoir: The Pembina Damsite is located on the Pembina River in Sec. 31-1-7-W1 approximately 2 miles upstream of Manitoba Highway No. 31 as shown in Figure 2. This is the same damsite as used in the I.J.C. investigations.

Extensive water supply and reservoir operation studies have been carried out at this site to determine the reservoir size that will supply the project's water demands. Only a brief description on the more important aspects will be presented here. For more detailed information the reader is referred to Appendix B.

The mean annual runoff on the Pembina River at the damsite is 105,000 acre-feet and has ranged from 1,600 to 401,500 acre-feet. Runoff is mostly the result of spring snowmelt. The catchment area is 2,896 square miles of which 1,840 square miles (64%) are in Manitoba and 1,056 square miles (36%) are in North Dakota.

In the reservoir operation studies, it has been

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assumed that the total annual runoff at the damsite will be divided between Canada and the U.S. in the ratio of their respective gross drainage areas; that is, Canada can store and use up to 64% of the water and must release the remainder to the U.S. to satisfy their riparian rights to the water.

In sizing the reservoir, the criteria employed was that it should be capable of meeting the water needs of the project area during the most critical drought period on record*. Records show that the driest period occurred from 1931 to 1940. The computations have therefore been carried out to determine the required storage to satisfy the above needs, should this period reoccur.

Calculations have revealed that the Pembina Reservoir storing 147,000 acre-feet of water at a full supply level of El. 1241 will be able to supply the necessary water to irrigate 11,975 productive acres and in addition, provide 5,000 acre-feet annually for the municipal and industrial uses of the project area.

To accommodate this storage, requires a dam and ancillary structures such as a spillway and riparian conduits.

The dam will be a zoned earthfill structure, 4,000 feet long and 100 feet high. The cross-section consists of a 30 foot top width with 3:1 side slopes on the upper sections and 7:1 and 25:1 on the lower sections depending on whether the east or west banks of the river are involved.

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* The study did not consider the reservoir capacity necessary to meet particular draft rates during critical droughts having various recurrence intervals.

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The top of the dam is placed at elevation 1261, 20 feet above the full supply level. This allows 11 feet for surcharge storage and 9 feet for freeboard when passing the project design flood.

The spillway has been designed as an uncontrolled concrete chute, 208 feet wide and 460 feet long. This is adequate to safely pass the 1:1000 year project design flood.

The riparian flow will be passed through two 7-foot diameter gated concrete horseshoe conduits. When the reservoir is at the full supply level, the capacity of both conduits is such that the bankfull discharge of the channel downstream will not be exceeded.

At the full supply level, the reservoir will be 18 miles long and 3/4 of a mile wide. It will submerge 5,650 acres of land, 38% of which are agricultural. Two bridges will have to be abandoned. Four farmsteads, a telephone line and a hydro line will have to be relocated.

The capital cost of the dam and reservoir is estimated at $15,000,000 which will be spread over a three-year construction period.

b. Conveyance System: The conveyance system is designed to deliver the required flow from the Pembina reservoir to the project area. The table below presents the magnitude and distribution of these flows:

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TABLE 8

Diversion Requirements

Month	Irrigation (Acre-Feet)	Municipal & Industrial[20] (Acre-Feet)	Total (Acre-Feet)
April	– –	1530	1530
May	–	990	990
June	4430	–	4430
July	6710	–	6710
August	6000	–	6000
Sept.	3360	1900	5260
October	–	990	990

A glance at the above table indicates that the system operates for only seven months of each year. No deliveries will be made in the winter months from November to March.

To meet the continuous municipal and industrial demands for water, a 2,000 acre-foot dugout will be constructed near the Town of Winkler to serve as a distribution reservoir. Deliveries to the dugout are made only in the spring and fall so as not to interfere with the irrigation interests. Releases from the dugout are then made as required.

The criteria used in the design of the conveyance system requires that the capacity of the components be equal to the maximum monthly irrigation demand that could be expected to occur during the project life. From Table A-6 this amounts to 11,500 acre-feet per month, or roughly 1.7 times the average diversion requirement for the month of July.

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Five pumping units are needed to lift the flow over the height of land into the Deadhorse Creek system. The pumps and controls are installed in a pumphouse located near the toe of the downstream face of the dam.

The conduit that will carry the flow over the height of land is a 60-inch diameter concrete pressure pipe, approximately 19,000 feet long. The outflow at the upper end enters the Dead Pig Canal. This canal is designed to carry the flow for a distance of 11,000 feet into the Deadhorse Creek from where it will flow by gravity into the existing Morden reservoir.

The Morden reservoir is a 2,100* acre-foot man-made lake used mainly to supply the Town of Morden with its water needs. This reservoir will be used in the overall plan to provide some degree of pondage in order to smooth out the daily and weekly fluctuations in the irrigation demands. A spillway equipped with a radial gate located at the northeast corner of the dam will regulate releases into the main supply canal.

The main canal will have two branches. One branch will deliver water to the irrigation district a total distance of 15.2 miles and the other branch will deliver water to an existing watercourse 1 mile away which will deliver it to the

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* Latest surveys of the reservoir by PFRA indicate that the total storage at FSL 1075 is 2,100 acre-feet and not 2,500 acre-feet as previously believed.

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dugout near Winkler, a distance of 5.4 channel miles. Along the longer branch and on its high side, a drainage ditch will be constructed to intercept and re-direct the runoff from escarpmental streams.

A total of eleven timber bridges will be erected over the main supply canal to provide the necessary road crossings.

Right-of-way land totaling 310 acres, most of it cultivated, will be bought and cleared as required.

A service road along the conveyance route will be provided.

The capital cost of the system is estimated at $5,450,000 which will be spread over a two-year construction period.

For additional detailed information on the design and cost estimates of the conveyance system, the reader is referred to Appendix C.

c. Irrigation System: The I.J.C. Engineering Board, in their studies, investigated five separate irrigation schemes in the project area varying in size from 8,400 to 18,500 acres. For this report, scheme #3 has been adopted for the reasons described previously. The irrigated area is 13,300 acres, most of it confined in Township 1, Range 4, west of the Prime Meridian as shown in Figure 2.

This area meets all the land classification standards for irrigation. However, not all of it will be used for production. Some of it will be needed for such non-productive uses as farm roads, ditches, drains and buildings. A total of 10% has been deducted for these uses, bringing the total productive area to 11,975 acres.

Irrigation will be carried out using the border strip method. In this method, water will flow by gravity to the individual farmer's fields. To ensure efficient operation, land leveling in minor amounts will be carried out where needed. Not much of it will be undertaken however, since the topography is very flat with few undulations. Damage to land productivity is not expected from land leveling, since the topsoil layer is between 10 to 15 feet thick[4].

The existing east-west coulees transversing the project area will not be altered. These small creeks will be utilized as natural project drain outlets eliminating the need for costly collector drains.

For purposes of analysis, the system has been subdivided into one-quarter section units (160 acres). Distribution works will deliver the irrigation flows at the highest point in the quarter-section and drainage works will collect the residual flows at the lowest points.

The distribution works consist of laterals and sub-laterals. Four laterals with a combined length of 24 miles will convey the water from the main supply canal to the sub-laterals. These will then distribute it to the individual farmers' fields.

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The drainage works with a combined length of 34.5 miles are designed to remove irrigation waste water, to remove storm water and to control groundwater levels. Each drain is laid out to collect the flows at the lowest point of each quarter-section and discharge them to the nearest natural creek channel.

Other appurtenant works which ensure the efficient operation of the system include check structures, lateral turnouts, farm turnouts and measuring devices. For detailed information on these structures, the reader is referred to Appendix D.

Right-of-way land totalling 280 acres, all of it agricultural, will be bought and cleared as required.

The necessary crossings over the distribution canals will be provided so as not to disrupt the existing road network in the area.

The capital cost of the irrigation system has been estimated at $1,785,000 to be spread over a one-year construction period.

EVALUATION OF BENEFITS

General

The "with and without" principle has been employed in here in evaluating the potential irrigation benefits accruing from the implementation of this project.

Under this principle an attempt is made to forecast the future agricultural economy of the region with and without the irrigation development to determine by what amount production will increase with a view of estimating the change in net farm income. An increase in net farm income with the project results in net benefit which will be directly attributable to irrigation. No attempt is made in here to determine to whom these benefits will accrue.

The comparison of the irrigation benefits under "with and without" situations is made under the assumption that a mature irrigation economy is established. The development period for purposes of analysis is taken to be five years.

The benefits of providing a dependable source of potable water for Municipal and Industrial needs of the region are evaluated in here in terms of providing the same service by an alternative source.

Flood damage benefits due to peak reductions below the Pembina Dam have not been evaluated since these will only accrue to the Americans.

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The viewpoint taken in this analysis is Provincial. This viewpoint has implications affecting the validity of the secondary benefits that can be related to the project.

Anticipated Agricultural Economy Without Irrigation Development

a. Farm Size: The project area like other areas in Manitoba has experienced an upward trend in size of farms with a corresponding decrease in number, and this trend is expected to continue. In 1961 there were 838 farms in the project area and its immediate vicinity. In 1971 this number had dropped to 620. The distribution of farm sizes in the project area has changed as follows:

TABLE 9

Farm Size	No. of Operators 1961	No. of Operators 1971
Under 69 acres	175	111
70 - 399	500	309
400 - 759	142	142
760 - 1,599	19	55
Over 1,600	2	3

Clearly, the future trend will be towards larger farms and fewer operators.

b. Land Use: Land use in the future under dryland farming is not expected to change greatly from that at present. The percentage of land under summer fallow, however, is expected to increase from the present 7% to the long term normal of 10%. For purpose of economic analysis it has been assumed that the present proportions of crop production with the exception of summer fallow will continue in the future. These are as follows:

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TABLE 10

	Percent of Improved Land
Small Grains (1)	67.14
Forage (2)	9.50
Special Crops (3)	13.30
Horticultural Crops (4)	0.06
Summer fallow and waste	10.00

(1) Wheat, oats, barley, rye, flax, grain corn, etc.

(2) Legumes, silage corn, grasses,

(3) Sunflowers, rapeseed, sugar beets, mustard, etc.

(4) Canning crops, fresh and frozen vegetables, etc.

c. Dryland Crop Yields: Anticipated dryland crop yields are based on the analysis of historical data for Manitoba crops. For the major crops such as wheat, barley, oats and flax, this data is available since 1891.[6, 32] Analysis of this data shows that no real trend is evident that increased yields have occurred in recent years. Rather the data suggests that higher yields occur in those years when precipitation was adequate and lower yields corresponded to those years when precipitation was below normal. There was no evidence that increased yields have occurred due to better farming techniques. The use of fertilizer in recent years has helped to increase yields substantially only in those years when moisture was plentiful during the growing season.

For particular cases the writer is well aware that moisture is not the only factor which affects crop yields. Other factors such as disease, insects and weeds also play an important part. However, for this study it will be assumed that moisture is the main indicator of crop yields.

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To obtain a reasonable projection of crop yields under future dryland conditions for the project area the mean yields obtained from 1938 to 1973 have been computed as being representative of future conditions. The yields obtained in the dry years of the early 30's are neglected purposely in the analysis since it is believed that the probability of the reoccurrence of that dry period in the near future is small (less that 1%). Therefore, the inclusion of those yields in the analysis would tend to bias the results downwards. The following are the results obtained for all Manitoba:

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TABLE 11

MANITOBA CROP YIELD 1938 - 1973[32]

Crop	Yield per acre		
	Mean	Minimum	Maximum
Wheat	22.3 bushels	11.7 (1961)	29.4 (1971)
Oats	38.2 bushels	18.5 (1961)	54.5 (1971)
Barley	28.6 bushels	13.7 (1961)	45.8 (1971)
Flax	9.4 bushels	4.0 (1957)	12.2 (1968)
Rye	18.1 bushels	11.1 (1961)	25.5 (1971)
Mixed grains	31.7 bushels	18.2 (1961)	47.5 (1971)
Grain corn	28.9 bushels	6.0 (1951)	53.8 (1972)
Field peas	18.4 bushels	10.0 (1955)	25.0 (1942)
Tame hay	1.77 tons	0.90 (1961)	2.26 (1941)
Silage corn	5.06 tons	2.0 (1945)	8.0 (1963)
Sugar beets	9.45 tons	7.27 (1947)	12.36 (1963)
Potatoes	148 bushels	63 (1961)	218 (1969)
Buckwheat	14.7 bushels	10.0 (1959)	21.0 (1962)
Rapeseed	15.2 bushels	12.0 (1958)	20.9 (1968)
Mustard seed	719 lbs.	383 (1961)	900 (1958)
Sunflowers	637 lbs.	300 (1945)	950 (1963)

In the above table it is more evident that moisture availability affects crop yields. In 1961 record low yields were produced reflecting the lack of precipitation in the growing season of that year. In 1968 and 1971, recent years in our memories, record high yields were achieved corresponding to an adequate supply and distribution of precipitation in the growing seasons of those years.

Since the above mean yields are for all of Manitoba, it is imperative to compare them with recorded yields in the project area. Long term records for the area are lacking, however, records for the main crops are available for the agricultural district #3[32] which encompasses the project area. The mean yield for these crops were compiled and are as follows:

TABLE 12

Crop	Mean Yield Per Acre
Wheat	20.1 bushels
Oats	36.0 bushels
Barley	24.2 bushels
Flax	9.3 bushels

A comparison of Tables 11 and 12 show that the average yields for the project district are below those for the Province. For the economic analysis it will be assumed that the average yields for the Province in the past will prevail in the project area at the end of the five year development period.

Since 1964 approximately 3,600 acres per year in Manitoba have been employed for the production of commercial horticultural crops. The majority of these crops have been produced around the Winnipeg, Portage la Prairie and Winkler areas.

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Since approximately 18% of the productive acreage in the project area will be used to grow vegetable crops under irrigation, an estimate of the dryland yields of these crops is required for economic analysis.

Vegetable crop yields were the most difficult to predict because local experience and records for this type of crop are most limited.

Various agencies[33] and individuals[34] were contacted to provide information on potential dryland crop yields. This information supplemented with recorded yields since 1964 enabled a reasonable estimate to be made as shown on the table below:

TABLE 13

DRYLAND VEGETABLE YIELDS 1964 - 1973

Crop	Estimated Dry-land Vegetable Yields (lbs.)	Maximum Recorded	Minimum Recorded
Asparagus	2,000	3,000 (1968)	1,100 (1972)
Beans	4,700	---	---
Beets	10,000	16,400 (1972)	3,500 (1969)
Cabbage	14,500	16,900 (1973)	10,000 (1969)
Carrots	24,000	37,400 (1971)	17,500 (1969)
Cauliflower	7,500	10,000 (1970)	5,000 (1969)
Celery	32,300	50,000 (1971)	16,000 (1969)
Cucumbers	7,700	10,000 (1965)	4,000 (1964)
Green peas	1,800	---	---
Lettuce	6,900	14,000 (1967)	2,700 (1966)
Onions	12,000	20,000 (1973)	10,500 (1966)
Parsnips	12,500	14,500 (1971)	8,000 (1973)
Sweet corn	3,500	4,400 (1972)	2,400 (1968)
Tomatoes	14,200	21,000 (1966)	9,600 (1968)
Turnips	22,000	29,000 (1967)	18,500 (1968)

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Anticipated Agricultural Economy With Irrigation Development

a. Farm Size: Farm sizes after irrigation development are expected to range from small farms with less than normal family labor requirements, and little or no hired labor, to large farms on which the operator makes full use of family labor and considerable use of hired labor. The trend towards larger farms and fewer operators is expected to continue.

b. Land Use: The approximate distribution of cropland on irrigated land is assumed to be as follows:

TABLE 14

	% of improved land
Small grains	45
Forage	12
Special crops	15
Horticultural crops	18
Summer fallow and waste	10

The above table shows that under irrigation development, the production of principal crops will remain more or less as at present levels, however, there will be an appreciable increase in the production of horticultural and special crops.

c. Irrigated Crop Yields: Potential crop yields under irrigation development are difficult to determine, as there is no comparable project nearby. Yields of irrigated crops were, therefore, estimated on the basis of present yields the better farmers are obtaining from irrigated lands

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in the Portage la Prairie and Winkler areas and also in consultations with many agencies[33] and individuals.[34] Considerable judgement was employed.

TABLE 15

ESTIMATED IRRIGATED CROP YIELDS

Crop	Unit	Yield per Acre
Small Grains:		
Wheat	bushels	45.0
Barley	bushels	50.0
Oats	bushels	75.0
Flax	bushels	17.0
Forage:		
Tame Hay	tons	3.5
Special Crops:		
Sunflowers	lbs.	1,200
Rapeseed	bushels	25
Potato	bushels	400
Sugar beets	tons	15
Horticultural Crops		
Asparagus	lbs.	4,000
Beans	lbs.	8,000
Beets	lbs.	18,000
Cabbage	lbs.	20,000
Carrots	lbs.	40,000
Cauliflower	lbs.	12,000
Celery	lbs.	55,000
Cucumbers	lbs.	12,000
Green peas	lbs.	3,000
Lettuce	lbs.	15,000
Onions	lbs.	30,000
Parsnips	lbs.	15,000
Sweet Corn	lbs.	6,000
Tomatoes	lbs.	25,000
Turnips	lbs.	30,000

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Irrigation Benefits

In the analysis it has been assumed that the irrigation benefits are wholly derived from the increase in future production yields. Benefits due to future increases in the value of the output or due to quality improvement have been neglected. It has also been assumed that in the future a market will always exist to sell the crops and that these will be sold at the 1973 prices paid to farmers. Prices were obtained from the Economics Branch of the Provincial Department of Agriculture.

No attempt has been made here to predicting changes in commodity prices over the lifetime of the project or the effect of continuing inflation on these prices. However, it should be noted, that it is the opinion of some agricultural economists that the trend of price increases witnessed today will continue in the future.

The table below shows the distribution, yields, prices and total value of crops with and without irrigation development for the Morden-Winkler irrigation district. The difference in total values with and without irrigation shown in the last column is indicative of the potential gross benefits. These benefits at the end of the development period amount to $3,334,000 annually.

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TABLE 16

CROPS, YIELDS, PRICES WITH & WITHOUT IRRIGATION FOR THE PROJECT AREA

Crop	WITHOUT IRRIGATION % Of Crop Area (Acres)	WITHOUT IRRIGATION Actual Crop Area (Acres)	WITHOUT IRRIGATION Yield Per Acre	WITHOUT IRRIGATION Unit Price ($)	WITHOUT IRRIGATION Total Value ($000)	WITH IRRIGATION % Of Crop Area (Acres)	WITH IRRIGATION Actual Crop Area (Acres)	WITH IRRIGATION Yield Per Acre	WITH IRRIGATION Unit Price ($)	WITH IRRIGATION Total Value ($000)	Benefits ($000)
SMALL GRAINS											
Wheat	23.70	2840	22.3 bus./acre	4.50	285.0	25.0	3000	45.0	4.50	607.5	+322.5
Barley	11.30	1350	28.6 "	2.35	90.7	10.0	1200	50.0	2.35	141.0	+ 50.3
Oats for Grain	13.60	1630	38.2 "	1.35	84.1	5.0	600	75.0	1.35	60.8	- 23.3
Flax	9.00	1080	9.4 "	9.75	99.0	5.0	600	17.0	9.75	99.5	+ 0.5
Mixed Grains	4.70	560	31.7 "	1.00	17.8						- 17.8
Rye	0.14	17	18.1 "	1.30	0.4						- 0.4
Buckwheat	3.80	455	14.7 "	3.25	21.7						- 21.7
Corn for Grain	0.40	48	28.9 "	3.00	4.2						- 4.2
Corn for Ensilage	0.50	60	5.06 tons/acre	12.00	3.6						- 3.6
FORAGE											
Tame Hay	9.50	1140	1.77 tons/acre	30.00	60.5	12.0	1420	3.5	30.00	149.1	+ 88.6
SPECIAL CROPS											
Sunflowers	6.40	766	637 lbs./acre	0.09	43.9	3.0	360	1200	0.09	38.9	- 5.0
Rapeseed	5.90	707	15.2 bus./acre	5.65	60.7	5.0	600	25.0	5.65	84.8	+ 24.1
Potato	0.68	81	148 "	1.26	15.1	2.0	240	400	1.26	121.0	+105.9
Sugar Beets	0.32	38	9.45 tons/acre	25.00	9.0	5.0	600	15.0	25.00	225.0	+216.0
AGRICULTURAL CROPS											
Beans			4,700 lbs./acre	0.19		5.0	600	8,000	0.19	912.0	+912.0
Cabbage			14,500 "	0.06		1.0	120	20,000	0.06	144.0	+144.0
Carrots			24,000 "	0.05		1.0	120	40,000	0.05	240.0	+240.0
Cauliflower			7,500 "	0.12		0.5	60	12,000	0.12	86.4	+ 86.4
Celery			32,300 "	0.10		0.2	24	55,000	0.10	132.0	+132.0
Asparagus			2,000 "	0.30		0.5	60	4,000	0.30	72.0	+ 72.0
Cucumber			7,700 "	0.10		0.1	12	12,000	0.10	14.4	+ 14.4
Beets			10,000 "	0.05		0.1	12	18,000	0.05	10.8	+ 10.8
Green Peas	0.02	2	1,800 "	0.19	0.7	5.0	600	3,000	0.19	342.0	+341.3
Lettuce			6,900 "	0.08		0.1	12	15,000	0.08	14.4	+ 14.4
Onions	0.03	4	12,000 "	0.08	3.8	0.5	60	30,000	0.08	144.0	+140.2
Parsnips			12,500 "	0.12		0.2	24	15,000	0.12	43.2	+ 43.2
Sweet Corn			3,500 "	0.06		3.0	360	6,000	0.06	129.6	+129.6
Tomatoes			14,200 "	0.16		0.6	70	25,000	0.16	280.0	+280.0
Turnips	0.01	1	22,000 "	0.06	1.3	0.2	24	30,000	0.06	43.2	+ 41.9
Fallow & Waste	10.00	1200				10.0	1200				
TOTAL	100%					100%					3,334.1

Municipal and Industrial Water Supply Benefits

The future Pembina triangle's Municipal and Industrial water requirements have been estimated at 5,000 acre-feet per year. Storage in the Pembina Reservoir has been allowed for this purpose. The water will be pumped over the Escarpment and will be stored in the Morden Reservoir and also in a proposed dugout one mile west of Winkler. The purpose of the dugout will be to store water for short carry-over periods during the summer and winter months. Water will be delivered to the dugout by means of the Main Irrigation canal for a short distance and then by an existing natural watercourse. Water will be delivered as follows:

TABLE 17

Date	Water Delivered in Acre-feet
First week in April	1,530
Last week in May	990
First week in September	1,900
Last week in October	990

No water will be delivered in June, July and August since at these times the full amount will be required for irrigation.

The benefits of providing water for Industrial and Municipal needs are expressed in terms of the cost of providing the same service by an alternative source. This source must be the most economic alternative, i.e., the one which would be constructed in the absence of the project.[36]

The nearest source that can be depended upon to supply this large amount of good quality water will have to be the Pembina River. This involves the construction of a stoplog dam across the stream near Highway No. 31 bridge to store an amount of water that will yield 5,400 acre-feet annually. In addition, a pumping plant near the dam, 8,000 feet of 10-inch pressure pipe from the dam to the top of the valley, and a canal from the top of the valley to Dead Horse Creek will have to be provided.

Details of this alternative for only 1,000 acre-feet storage have been examined in a recent PFRA report.[37] This scheme will be operated during the summer months only with winter storage provided in the dugout near Winkler. The cost of these works including the capitalized cost of pumping over 50 years has been estimated at $1,200,000. This then will be taken to represent the present value of the benefits of providing Industrial and Municipal water for the project area. Amortization over 50 years at 8% gives an annual benefit value of $98,000.

Flood Control Benefits

The creation of a reservoir on any river will usually reduce flood flows downstream due to the dampening effect of storage on flood peaks. For any given flood the degree of peak reduction is directly related to the size of the reservoir.

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Evaluation of flood control benefits depends on measurement of the physical problem, mainly the extent and frequency of flooding and the resulting average annual damages. Herein only the frequencies of flood peaks with and without the reservoir have been evaluated. (See Appendix B). The resulting natural and modified frequency curves of peak flows are presented on Figure 9.

Since most of the flood control benefits would accrue along that part of the river reach located in the U.S. no attempt has been made to evaluate the reduction in average annual damages to the Americans. Hence, no cost item will be included in the economic analysis for this benefit.

Secondary Benefits

The evaluation of secondary benefits includes estimation of their total magnitude, their division between those regional and those local in character and analysis of their implication towards achieving regional goals rather than economic efficiency. The U.S. Senate Document 97 states that "such benefits, combined with primary benefits shall be included in the computation of the benefit-cost ratio."

Secondary benefits will normally accrue in the general areas of processing, marketing, handling of goods and servicing of facilities.

The increase in vegetable crops, potatoes and sugar beets will be processed almost exclusively in or near the project

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area giving rise to increased employment. A large portion of the gross value of factory shipments of the finished commodities will remain within the communities in the project area as payments to labour, payments for raw material, payments for industrial services and professional services, and as real property taxes. Additional substantial amounts will be paid as corporate and income taxes to senior governments.

One example of the potential of the area to attract processing industries will be cited. Both Campbell's and Green Giant have in the past exhibited considerable interest in the project area as a source of supply for their soup-making and vegetable canning operations. Neither have located, however, giving as their main reason the lack of assured supply of water, first for their plant requirements, and secondly for supplemental use in agriculture to overcome hazards of dependence upon natural rainfall only.

Because of the enormous difficulty in estimating the magnitude of secondary benefits, the Bureau of Reclamation (U.S.B.R.) estimates secondary benefits associated with the production of agricultural crops as a percentage of primary benefits. Typical percentages used for stemming from benefits are summarized in Table 18 as follows:[35]

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TABLE 18

	% of Primary Benefits
Grain (wheat, oats, corn, barley	53%
Oil crops (flax, cotton seed, soy beans)	35%
Sugar beets	31%
Fruits and Vegetables	29%
Dry beans	28%

For the Morden-Winkler project area it will be assumed that secondary benefits will be approximately 30% of primary benefits or roughly $1,000,000 annually.

ECONOMIC EVALUATION

Capital Cost of Project

The capital cost of a project may be defined as the sum of all expenditures required to bring the project to completion. It includes direct items of construction components and indirect items such as contingencies, engineering and interest during construction. The definitions given by Kuiper[38] for these items have been adhered to in the detailed cost estimates presented in Appendices B, C and D.

The table below summarizes the capital cost of the various components of the project and also the overall capital cost.

TABLE 19

Capital Cost Summary

Project Component	Capital Cost $
Pembina Dam	15,000,000
Conveyance System	5,450,000
Irrigation System	1,785,000
Overall Project Capital Cost:	$22,235,000
Initial capital cost per irrigable acre =	$ 1,858.00

Operating Costs

The operating costs of the project include the operation and maintenance (O+M)* of the project components, the pumping charges and the labor costs. The (O+M) and pumping charges are determined in Appendices B, C and D. Here a brief description on farm labor requirements and its costs is presented.

* (O+M) cost percentages were obtained from Reference (38).

Establishment of total and seasonal distribution of labor on the proposed irrigation farms is subject to considerable estimation due to the lack of available data. It is generally accepted that under dryland farming, one operator for one-quarter section of land is adequate. However, under irrigation farming, more extensive use of farm labor is needed especially during seeding, weeding and harvesting. No information could be found on the number of farm laborers required under irrigation farming. The author has conjectured that each quarter section would require each year the equivalent of two laborers over a period of five months at $400.00 per month. This results in a yearly farm labor expenditure for the total area of $300,000.00. Whether this outlay is adequate to cover labor costs under the new system the author does not fully know.

The farmer residents in the project area have had a long history of fairly extensive use of family labor under dryland farming. This, however, is not expected to continue in the future since in recent times there has been an exodus of young people from the farms to the nearby industrial centres of Winkler, Morden and even Winnipeg. This was very evident in the 15 farms visited by the author where only the middle-aged husband-wife operators remained. The 15-farm random survey also revealed that operators are not overly enthusiastic

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about the use of hired labor on their farms. Their experience has been that hired labor is not dependable and also is not available at critical times when most needed.

The table below summarizes the annual costs to operate the project.

TABLE 20

Operating Costs Summary

Type of Operation	Annual Operating Cost $
Labor	300,000
Pumping	185,000
Maintenance	
Pembina Dam	15,000
Conveyance System	82,000
Irrigation System	54,000
Overall annual operating cost:	$636,000

Annual operating cost per irrigable acre = $53.00

Annual Costs Summary

The table below summarizes the annual costs of the project components and also the overall annual cost. The useful life of the project is 50 years* and the interest rate for discount purposes is 8%**.

*This is consistent with Water Projects Studies carried out in the U.S. See Reference (39) "Benefit-Cost Evaluations as Applied to Water Projects", U.S. Dept. of State, Agency for International Development 1963.

**This is the current interest rate used in Federal Government Projects.

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TABLE 21

Annual Costs Summary

Component	Annual Cost $
Pembina Dam	1,235,000
Conveyance System Including Pumping	719,000
Irrigation System	204,000
Farm Labor	300,000
Overall annual cost:	$2,458,000

Annual cost per irrigable acre = $205.00

Annual Benefits Summary

The annual tangible benefits of the project accrue from water supply, irrigation and flood control. The irrigation benefits are not fully realized until some time after the project has been developed. For purposes of this analysis it has been assumed that five years will have to elapse in order to realize the full irrigation benefits of $3,334,000 per year. Within the five years the benefits are taken to vary uniformly from zero the first year to the full value at the end of the development period.

Below is a summary of the equivalent annual primary and secondary benefits that will be realized over a 50-year period at a discount rate of 8%.

TABLE 22

Annual Benefits Summary

Project Purpose	Annual Primary Benefits $	Annual Secondary Benefits $
Irrigation	2,776,000	833,000
Water Supply	98,000	undetermined
Flood Control	undetermined	undetermined

Annual primary benefits per irrigable acre = $240.00

Annual secondary benefits per irrigable acre = $70.00

Economic Soundness of Project

In economic analysis three parameters are employed to measure the economic soundness of a project. These are the benefit-cost ratio, the net benefits and the rate of return.

The benefit-cost ratio is the most popular. If this ratio is greater than one (i.e. the benefits exceed the costs) then the project is desirable and can be recommended for implementation.

The net benefits is the second parameter that indicates the economic merits of a project. It is defined as the sum of all benefits minus the sum of all costs. If the result is positive then the project is desirable.

The rate of return is the third parameter used. It is defined as the discount rate which makes the total costs equal to the total benefits. In other words it is the "internal interest rate" of the project.

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The table below shows the results of the evaluation of all three parameters for the Morden-Winkler project.

TABLE 23

Parameter	Only Primary Benefits Included	Primary and Secondary Benefits Included
B/C	1.2	1.5
B-C	$416,000	$1,249,000
R.R.	10 1/2%	14%

A glance at the above table indicates that the proposal as presented is economically feasible. The net primary benefits accruing to irrigation only are $30.00 per productive acre. The total net benefits accruing to the region as a whole are $104.00 per productive acre.

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SOCIAL CONSIDERATIONS

It is difficult to visualize the sociological effects that the provision of irrigation water will have upon any agricultural area not previously accustomed to it. Herein an effort will be made to outline some of the more important advantages and disadvantages of the project for the people residing in the project area and also for the people of Manitoba. It is the author's contention that the utmost consideration should be given to these items in the evaluation of the project's overall feasibility.

Advantages

1. The project offers stabilization of agricultural production, increase in farm family income, and an assured supply of potable water for Morden and Winkler. All of this resulting in a general increase in the standard of living of the region.

2. With the project, there will be substantial increases in freight traffic and public utilities.

3. With the project, water distributed for irrigation might also be channeled through a system which could be used for the distribution of water to other smaller urban centres nearby such as Altona, Plum Coulee, Gretna, Rosenfeld and Horndean with substantial savings in "write-offs".

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4. With the project, increased farm employment will result. This could sharply reduce the migration of young people from the area thus alleviating a situation of concern to Manitobans.

5. Implementation of irrigation will probably initiate abandonment of the presently grown grain crops thus emphasizing canning crops (which already are common to the nearby areas) and also horticultural products for freezing, and to satisfy the fresh-produce markets of Winkler, Morden and Winnipeg. This in the long-run will substantially reduce Manitoba's dependability on imported fresh and canned products.

6. Implementation of the project will create new seasonal employment opportunities within the area throughout the duration of its construction.

7. The development of the Pembina reservoir will offer an additional source of recreation for Manitobans. This, if fully exploited, could result in re-imbursable benefits which upon analysis could be capable of bearing a portion of the capital cost of the project.

8. The partial control and reduction of flood flows by the Pembina Dam will result in a greater security of life for those Manitobans living downstream of the dam.

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Disadvantages

1. The brief survey conducted by the author showed that many farmers were dubious about implementing such a scheme. They were concerned about capital costs, increased taxation, labor supply, and market stability for the proposed special crops.

2. Undoubtedly, the implementation of irrigation will mean additional expenses to the individual farmer. In general, the acquisition of capital for the incurred expenses will be easier for the larger farmer to whom wide avenues of credit are open than to the smaller farmer to whom capital savings is limited. It is possible then that the smaller farmer will become disillusioned and will sell out to the larger farmer. This could well see the removal of some middle-aged unadaptable farmers. Some of these will set up farming elsewhere, but others with inadequate resources and few skills will find their way into the unskilled labor market of Manitoba. This could possibly be avoided by the installation of regulations similar to those in effect in the U. S. where one man may irrigate one-quarter section and no more.

3. Favorable consideration of the project by government officials will undoubtedly bring in land speculators in the area which will drive up the price of land in anticipation of irrigation and thus inducing small farmers to sell

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their farm prematurely in favor of early retirement.

4. Implementation of the project will bring a sudden influx of large numbers of temporary workers in the area giving rise to housing and law-enforcement problems in the small communities.

5. Construction of the various phases of the project will result in a statistically ascertainable rate of death and injury. On projects of this type one fatality per ten million worth of construction is not unlikely.

6. Implementation of any large scale water resources project will cause community disruption and the flooding out of settled land areas. For the project area it is estimated that four farmsteads will have to be relocated due to the reservoir flooding.

ENVIRONMENTAL AND ECOLOGICAL CONSIDERATIONS

In this section the potential environmental and ecological impacts of the proposed project will be considered. The three main areas where the natural state will be altered are the area of impoundment, the area along the conveyance route and the irrigation district. Only a broad outline of the potential impacts in qualitative terms will be presented. Before implementing the proposal, detailed studies should be undertaken by the appropriate disciplines to evaluate the impacts in a more quantitative manner where it is possible.

Area of Impoundment

1. The initial action of the proposed Pembina Dam will be the abrupt transformation from terrestrial and riverine conditions to aquatic and lacustrine conditions. Approximately 30 miles of natural free-flowing stream will be converted into an 18 mile long 3/4 of a mile wide man-made lake.

2. The proposed impoundment will submerge 5650 acres of land, drastically altering the present land forms and vegetation in the area.

3. The resulting reservoir ecosystem may trigger an explosive growth of aquatic and semiaquatic shoreline vegetation which may have various effects on man and his actions in the vicinity of the created lake.

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4. In the flooding process there will be mass mortality and migration of terrestrial organisms.

5. The flooding of vegetation may contribute to oxygen deficits in the reservoir as the plant material decays under water. This could retard the natural creation of new life forms in the reservoir.

6. The proposed Pembina Dam will alter the present habitat of fish and wildlife in the upstream reach of the river but in time it will create conditions for new life forms, plants, insects, fish and other wildlife.

7. The reservoir will alter the micro-climate of the nearby region. Evaporation from the reservoir surface will increase. Air temperatures will be likely cooler in the summer and warmer in the fall. No temperature changes are expected in the winter months.

8. The reservoir will disrupt the sedimentation process of the stream. Most of the upstream sediment will be deposited in the reservoir. This will result in increased carrying capacity of the river downstream thus changing its regime from a presently equilibrium condition to an unstable condition where degradation of the channel bottom and sloughing of its banks will occur until such time that a new stable channel is established.

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9. The temperature of the water will be altered. The reservoir being 100 feet deep at the damsite will probably stratify into the three main layers known technically as the Epilimnion (top layer), Thermocline (middle layer), and Hypolimnium (lower layer). In the summer the water in the reservoir decreases in temperature and increases in density with depth. Since the riparian conduit is located in the Hypolimnium layer, riparian water released during this period will be cooler than would be the case under natural flow conditions. In the winter months the reverse happens where warmer temperatures are found in the bottom layer than in the two layers above. Riparian releases during these months will generally mean higher water temperatures downstream than would occur under natural conditions. The implications of these temperature changes on the downstream ecosystem is not too well understood at the present time.

10. With the proposed reservoir there is the danger of severe ice problems upstream of the dam. Ice jams on the upstream reach of the river in the spring will occur more frequently causing flooding in the adjacent valley areas and possibly endangering man-made structures such as existing bridges and buildings. Detailed investigations should be undertaken to determine the extents of the problem and whether the village of La Riviere will be affected.

11. During the construction stage of the dam, the following temporary adverse environmental effects will occur.

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(a) Landscape - The abutment on the north side of the dam will be converted into a borrow area to provide construction material for the embankment.

(b) Air - Pollution of the surrounding air at the damsite will occur from exhaust fumes of the construction equipment and from fine earth particles which will be driven into suspension during the construction process.

(c) Water - The turbidity of the stream will increase downstream of the damsite. This could cause some disruption of the aquatic ecosystem.

(d) Noise - There will be a pronounced increase in the surrounding noise level emanating from the operation of the heavy construction equipment at the site. This could have adverse effects on the wildlife nearby.

<u>Conveyance Route</u>

1. The proposed conveyance route will require the clearing of 10 acres of natural vegetation.

2. The proposed conveyance system could act as an artery for possible introduction into the Morden-Winkler area of new plant, animal and insect species. These could introduce new waterborne diseases in the region.

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3. There will be an increase in aquatic weed growth along the canal section of the route. This could possibly reduce the capacity of the channels.

4. Possible erosion of the existing steep slopes in the concrete conduit section of the route could result from the land being stripped of its natural vegetative cover.

5. The increased flows proposed for the Deadhorse Creek will degrade the existing channel resulting in deposition of sediments into the existing Morden Reservoir. The increased sedimentation could cause considerable disruption to the bottom fauna in the reservoir.

Irrigation District

1. The proposed system of canals could serve as a breeding place for the development of insects and other aquatic organisms.

2. The proposed system of canals will increase the rate of groundwater recharge which could result in higher water tables than that at present.

3. There will be an increase in aquatic weed growth in the irrigation channels possibly resulting in reduced channel capacities.

4. The irrigation return flows could become heavily polluted with agricultural chemicals and plant and animal wastes. This pollution could percolate into the groundwater

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system and/or be carried by the existing natural drainage courses to low areas further east. No allowance has been made herein for the treatment of these flows.

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this thesis has been to present a plan of development of the Pembina River to supply the Morden-Winkler district in Southern Manitoba with large amounts of water for irrigation, municipal and industrial water supply purposes.

The proposal consists of a dam on the Pembina River to store 147,000 acre-feet of water, a conveyance system to transport the water to the district and an irrigation scheme in the district comprising 11,975 productive acres.

From an engineering and economic viewpoint this plan of development appears to be feasible. With an initial capital expenditure of $22,235,000 it is possible to realize annual direct benefits amounting to $2,874,000 throughout the life of the project. The ratio of direct benefits to costs of this plan of development for a discount rate of 8% is 1.2.

This proposal is an alternative to the joint plan of development of the Pembina River Basin recommended by the I.J.C. Engineering Board in its 1964 report. The advantages to Manitoba of this proposal over the joint venture are:

1. Manitoba will have full control over the source of supply.

2. A savings of 650 acres of agricultural land due to a smaller reservoir on the Pembina River.

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3. A savings roughly equal to $8,000,000 while providing essentially the same benefits as the joint venture.

Although the engineering and economic viability of the Pembina River as a source of supply has been established, the large expenditures involved require that other sources be assiduously sought. Two of these, Lake Manitoba and Shellmouth Reservoir, are briefly described in Appendix E. It is recommended that detailed investigations be undertaken on these two sources to determine their feasibility to supply water to the project area and compare them with the Pembina River source.

Before a decision is made to proceed with construction, the social environmental and ecological impacts of the project should be thoroughly assessed. In particular, detailed studies should be undertaken to determine:

1. The farmers' willingness to adapt to irrigation farming.

2. Market availability for the crops grown.

3. The extent Americans are willing to co-operate towards financing the project in view of the potential flood control benefits that could accrue to them.

4. The recreation potential of the Pembina reservoir.

5. The quantity, the nutrient content, and the means of disposal of irrigation return flows.

Finally, no project of this magnitude can ever be made to operate effectively without the co-operation and support of the residents of the affected areas. Therefore, it is suggested that the residents be kept well-informed at all times; their views on the project sought at an early stage and, above all, they should be encouraged to participate in the overall implementation of this plan.

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Manitoba Vegetable Board
Morden Experimental Farm
Agriculture Canada - Fruit and Vegetable Division
University of Manitoba - Agricultural Economics
University of Manitoba - Plant Science

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John Kuhl from Southern Potato Co. - Winkler
John Dumay from Mulder Farms - Portage la Prairie
Ed Connery from Connery Farms - Portage la Prairie

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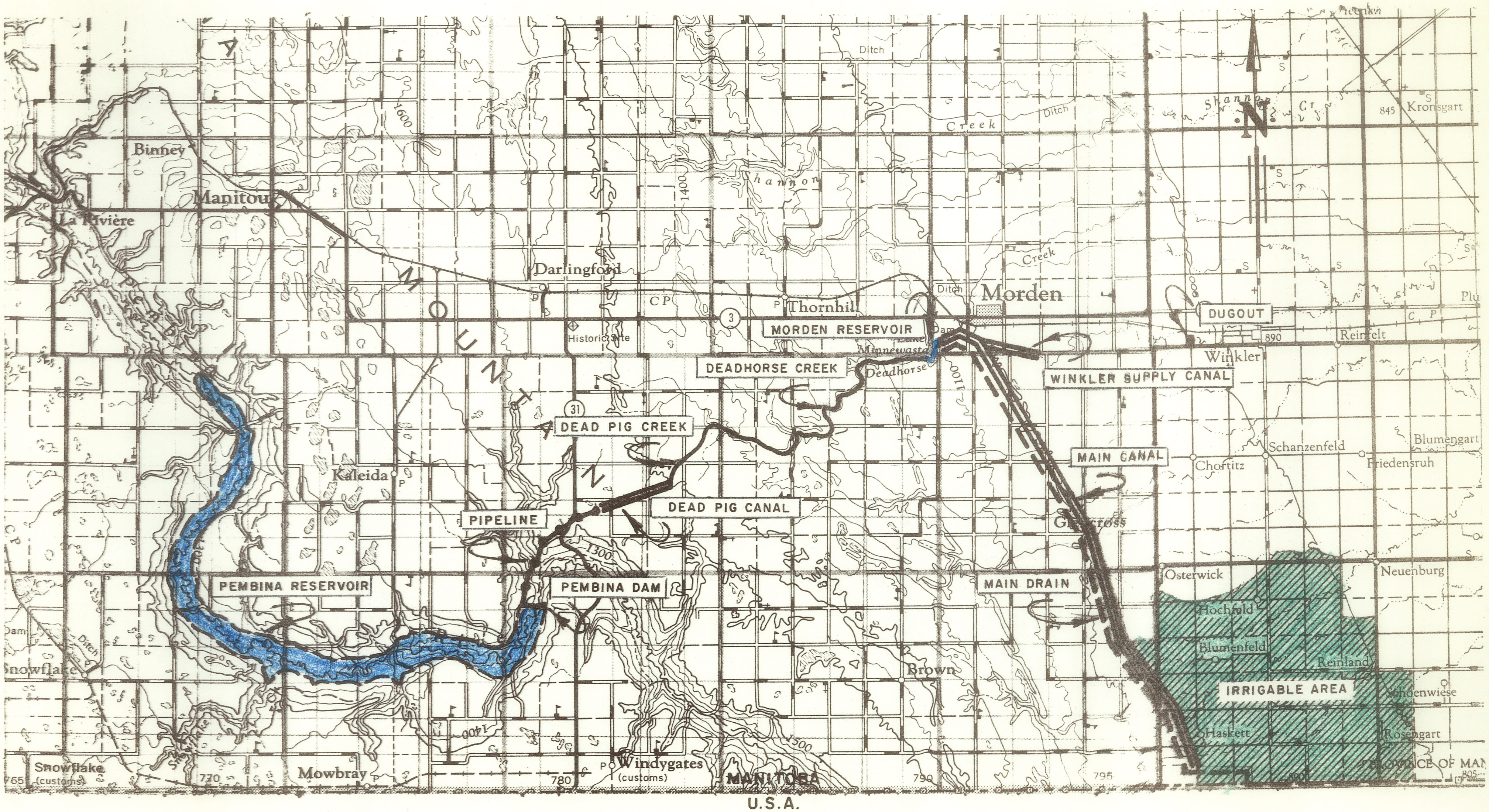
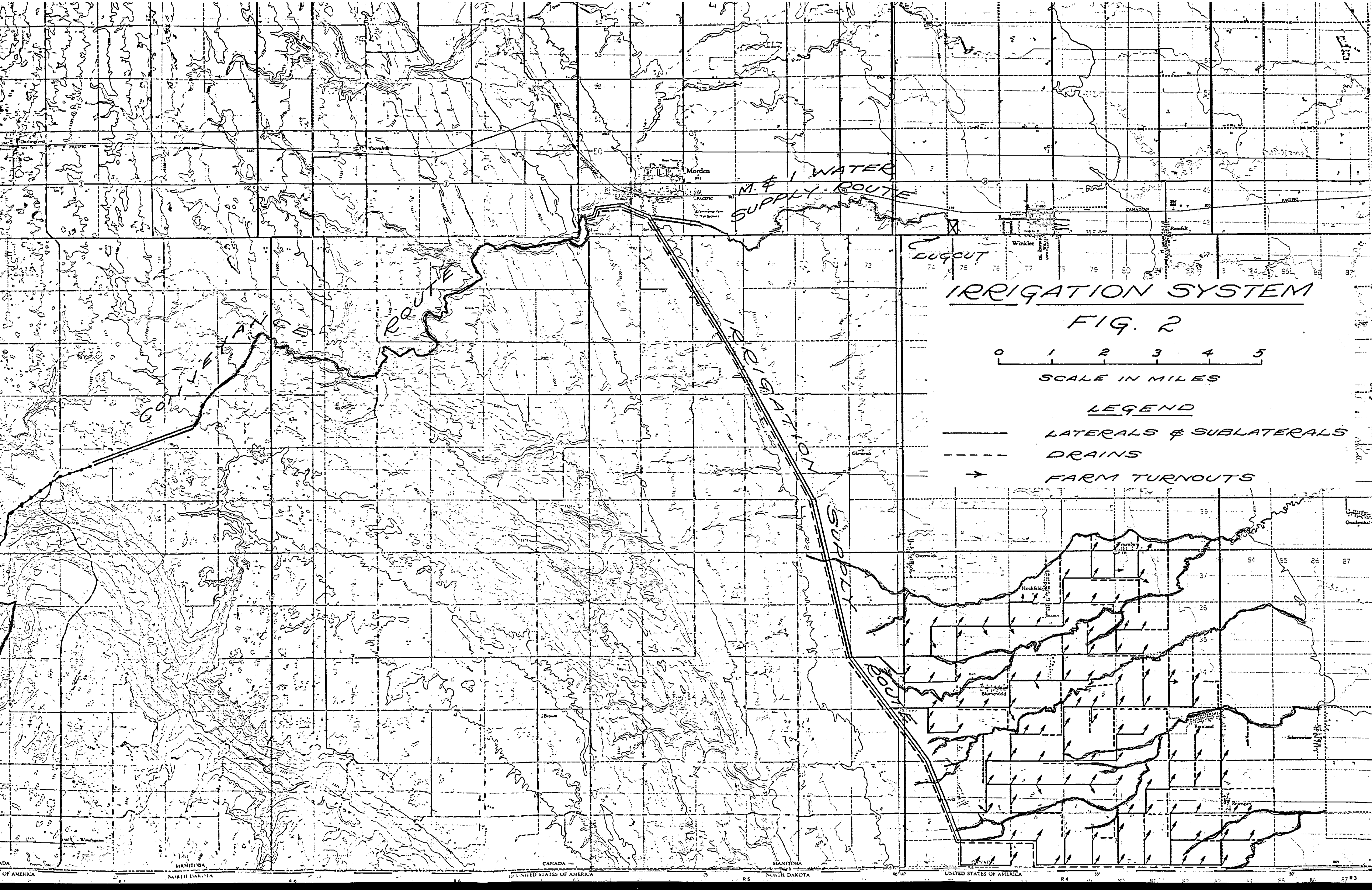
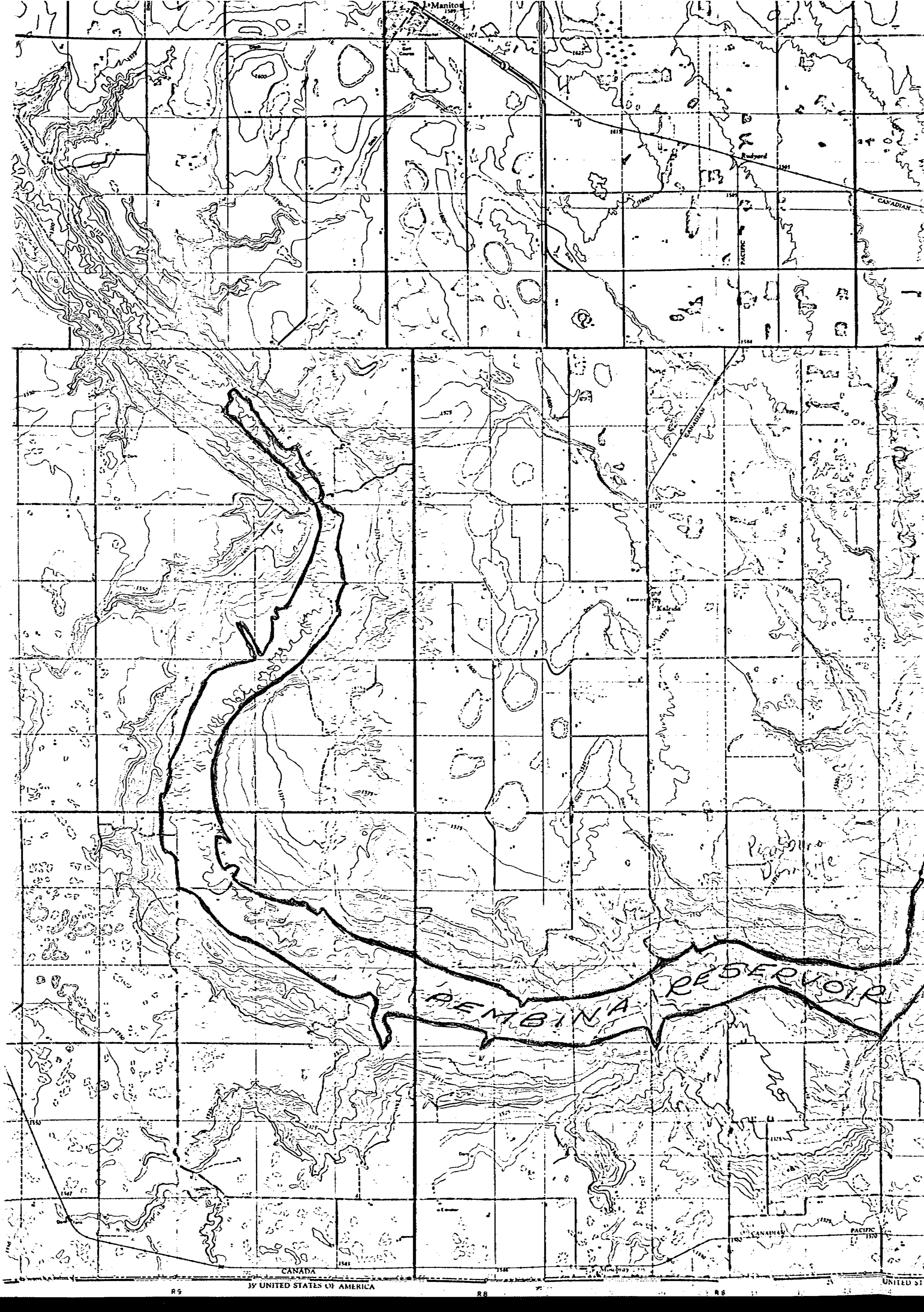


FIG. 1
LOCATION PLAN
OCT 1974


IRRIGATION SYSTEM
FIG. 2
0 1 2 3 4 5
SCALE IN MILES
LEGEND
LATERALS & SUBLATERALS
DRAINS
FARM TURNOUTS
M. & I. WATER SUPPLY ROUTE
IRRIGATION SUPPLY ROUTE
GOLIE LAKE ROUTE
DUGOUT
Morden
Winkler
Reinfeld
Darlingford
Thornhill
Hochfeld
Blumenfeld
Reinland
Brown
Windygates
MANITOBA
NORTH DAKOTA
CANADA
UNITED STATES OF AMERICA


Manitou
PACIFIC
Rudyard
CANADIAN
PEMBINA RESERVOIR
CANADA
UNITED STATES OF AMERICA
R9
R8
Mowbray

APPENDIX A

WATER IRRIGATION REQUIREMENTS

INDEX: PAGE:

IRRIGATION WATER REQUIREMENTS

The depth of water required to produce satisfactory crop yields varies with the soil texture and composition, kinds of crops grown, preparation of field surfaces, methods and frequency of irrigation, rainfall characteristics and general climatic conditions. Other things being equal, the amount of water that must be artificially applied depends on the deficiency in rainfall during the growing season.

In the following discussions irrigation water requirement is used to mean the total quantity of water per unit area that must be applied artificially, in addition to natural precipitation, to produce satisfactory crop yields. It consists of all water used for irrigation of crop lands, seepage losses within and resulting from conveyance of water to irrigated areas and operational wastes. General hydrologic criteria for estimating the irrigation water requirements are presented in the paragraphs to follow.

Consumptive Use

The consumptive use of water is the actual quantity of water required for plant growth. It includes water used directly in the building of plant tissue and water lost in evaporation and transpiration.

There are many methods of estimating consumptive use, but no one method can be applied generally for all purposes. Several methods widely used in engineering investigations are: tank and lysimeter experiments, field experimental plots, soil moisture studies, integration, and inflow-outflow for large areas. These methods measure consumptive use directly.

Because of the difficulties in measurement required in the above field methods and the lack of basic data available, great efforts have been made to develop evapotranspiration equations that relate consumptive use with some readily available climatic data. The more successful of these equations relate consumptive use to temperature, humidity, wind velocity, vapor pressure and solar radiation.

In this study the Lowry-Johnson equation has been employed to estimate annual consumptive use and a "revised" P-E Index Method to estimate monthly consumptive use.

a. Lowry-Johnson Method

This is essentially an empirical method based upon data collected from irrigated areas near the Rocky Mountains where humidities are generally low. The method applies to a valley not to an individual farm, and has been used by the Bureau of Reclamation in the arid western portion of the United States with good results.

The method assumes a linear relationship between "effective heat" and consumptive use. Effective heat, as defined for the method, is the accumulated maximum daily temperatures in degrees Fahrenheit above a base of $32^{O}F$ during the effective growing season.

The approximate relationship is:[7]

$$U = 0.8 + 0.156F$$

where: U = consumptive use in acre-feet per acre

F = effective heat in thousands of day-degrees

The nearest meteorological station to the project area where temperatures have been recorded for a long period of time is the Morden Research station. Monthly maximum temperatures at this station were tabulated for the period 1921 to 1973 and the corresponding monthly effective heats were computed for the growing season. These latter were then accumulated for each year and using the Lowry-Johnson formula the annual consumptive use was determined. Table A-1 shows the results of the calculations.

The mean annual day-degrees of heat in the area is 6,300 indicating an average annual consumptive use of 1.78 acre-feet per acre. In the above calculations it has been assumed that the winter season consumptive use is satisfied entirely by winter precipitation, therefore it does not need to be included in the analysis. The effective growing season

TABLE A-1

EFFECTIVE HEAT AT MORDEN IN DAY-DEGREES FAHRENHEIT* & CONSUMPTIVE USE IN FEET DEPTH

Year	May	June	July	August	Sept.	Total Annual	Consumptive Use In Feet Depth V= 0.8+0.156 F
1921	1057	1359	1559	1395	1185	6555	1.82
1922	958	1341	1401	1590	1167	6457	1.81
1923	1091	1536	1655	1333	1185	6800	1.86
1924	725	1119	1426	1364	1034	5669	1.68
1925	989	1095	1392	1454	1065	5995	1.74
1926	1194	1092	1445	1321	798	5850	1.71
1927	589	1176	1339	1277	1080	5461	1.65
1928	1218	1074	1367	1324	1011	5994	1.74
1929	772	1263	1572	1448	918	5973	1.73
1930	899	1317	1587	1615	1080	6498	1.81
1931	958	1449	1569	1516	1224	6716	1.85
1932	1138	1521	1538	1578	1176	6951	1.88
1933	1147	1560	1668	1584	1107	7066	1.90
1934	1311	1275	1702	1411	843	6542	1.82
1935	1014	1149	1655	1389	1017	6224	1.77
1936	1358	1326	1916	1535	1164	7299	1.94
1937	1088	1326	1550	1578	1077	6619	1.83
1938	992	1293	1522	1575	1302	6684	1.84
1939	1178	1167	1730	1575	1128	6778	1.86
1940	1051	1254	1584	1438	1284	6611	1.83
1941	1119	1248	1646	1457	975	6445	1.81
1942	893	1227	1445	1392	999	5956	1.73
1943	890	1146	1587	1401	1035	6059	1.75
1944	1194	1185	1516	1358	1026	6279	1.78
1945	750	1173	1466	1454	939	5782	1.70
1946	964	1308	1525	1392	1044	6227	1.77
1947	896	1173	1573	1513	1005	6165	1.76
1948	1113	1257	1423	1488	1347	6628	1.83
1949	1085	1314	1500	1615	1062	6576	1.83
1950	806	1257	1358	1302	1104	5827	1.71
1951	1240	1173	1535	1234	894	6076	1.75
1952	1116	1302	1491	1438	1239	6586	1.83
1953	946	1224	1457	1535	1041	6203	1.77
1954	831	1356	1504	1352	927	5970	1.73
1955	1057	1251	1559	1578	1047	6492	1.81
1956	871	1401	1342	1417	936	5967	1.73
1957	1116	1104	1569	1361	963	6113	1.75
1958	1194	1185	1373	1398	1056	6206	1.77
1959	899	1335	1544	1516	960	6254	1.78
1960	1107	1233	1584	1497	1164	6585	1.83
1961	1088	1530	1491	1733	900	6742	1.85
1962	884	1308	1389	1414	1005	6000	1.74
1963	939	1317	1547	1485	1233	6521	1.82
1964	1156	1191	1525	1287	975	6134	1.76
1965	949	1278	1435	1386	708	5756	1.70
1966	865	1296	1504	1373	1152	6190	1.77
1967	840	1278	1525	1473	1272	6388	1.80
1968	896	1194	1401	1178	1062	5731	1.69
1969	1060	1023	1383	1615	1089	6170	1.76
1970	862	1401	1525	1491	1056	6335	1.79
1971	1023	1278	1308	1482	1059	6150	1.76
1972	1200	1371	1345	1482	936	6334	1.79
1973	1088	1272	1389	1494	1011	6254	1.78
MEAN	1013	1270	1508	1451	1058	6300	1.78

* Number of degrees F. by which maximum daily temperature exceeded 32°F during the growing season. It is assumed the growing season is from May 1st until September 30th of each year.

at Morden is 145 days[8] usually starting second week in May and ending first week in October. By comparison the irrigation season has been assumed to commence June 1 and end September 30.

The Lowry-Johnson method was not developed to estimate monthly use. Occasionally, however, it has been applied[9] successfully for this purpose by using simple proportions of monthly heat units to annual heat units in those areas where consumptive use of crops does not vary greatly throughout the growing season.

This method of proportions was tried for the project area but the results were not acceptable since the values did not reflect the actual extremes in monthly consumptive use between the months of May and July and between the months of July and September.

b. P-E Index Method

Based on studies of weather and crop data from irrigated areas over the Western United States W. C. Munson[10] found that the following monthly P/E ratios (precipitation-evaporation ratios) hold adequately for normal plant growth:

Months	Jan.	Feb.	March	April	May	June
P/E	1.0	1.8	3.2	4.4	5.8	6.0
Months	July	Aug.	Sept.	Oct.	Nov.	Dec.
P/E	6.8	6.1	4.6	3.5	2.3	1.5

For a given month, the corresponding value of P/E ratio and the average monthly temperature t in ^{o}F can be substituted in the following equation to solve for P.

$$P = 0.014(t-10)(\frac{P}{E})^{n}$$

This equation is based on the formula derived by Thornthwaite[11] in which P is the monthly consumptive use requirement in inches for crop production on an area basis and n is an exponent (n = 0.9 in the original equation).

The monthly and hence annual consumptive use for the project area were computed by this method using the average monthly temperatures recorded at the Morden Research station. With an n-value of 1.0 in the above equation the resulting annual values agreed very closely to those found by the Lowry and Johnson method as can be seen from Table A-2. The monthly distribution of consumptive use in Table A-2 was judged much better than that given by the method of proportioning effective heats hence these values were employed in the analysis.

Effective Precipitation

Only a part of the precipitation falling to the ground is effective in meeting consumptive use requirements. The effectiveness of the precipitation depends upon several factors such as amount and intensity, character of soil

TABLE A-2

THE MONTHLY & YEARLY CONSUMPTIVE USE AT MORDEN, USING THE P-E INDEX METHOD

YEAR	MAY (P/E)= 5.8	JUNE (P/E)= 6.0	JULY (P/E)= 6.8	AUGUST (P/E)= 6.1	SEPT. (P/E)= 4.6	TOTAL(P-E INDEX METHOD) (Ft)	TOTAL (FROM LOWRY-JOHNSON METHOD) (Ft)
1921	0.28	0.40	0.48	0.39	0.26	1.81	1.82
1922	0.29	0.37	0.44	0.42	0.26	1.78	1.81
1923	0.29	0.40	0.49	0.37	0.31	1.86	1.86
1924	0.24	0.33	0.44	0.38	0.23	1.62	1.68
1925	0.28	0.35	0.44	0.41	0.25	1.73	1.74
1926	0.32	0.34	0.45	0.38	0.21	1.70	1.71
1927	0.24	0.36	0.44	0.37	0.25	1.66	1.65
1928	0.31	0.34	0.45	0.38	0.23	1.71	1.74
1929	0.24	0.36	0.47	0.40	0.23	1.70	1.73
1930	0.27	0.38	0.48	0.42	0.24	1.79	1.81
1931	0.28	0.40	0.47	0.41	0.27	1.83	1.85
1932	0.31	0.42	0.47	0.42	0.26	1.88	1.88
1933	0.31	0.42	0.49	0.42	0.26	1.90	1.90
1934	0.33	0.37	0.48	0.39	0.21	1.78	1.82
1935	0.28	0.31	0.51	0.39	0.24	1.73	1.77
1936	0.29	0.37	0.54	0.41	0.26	1.87	1.94
1937	0.30	0.40	0.48	0.43	0.25	1.86	1.83
1938	0.29	0.37	0.48	0.42	0.28	1.84	1.84
1939	0.32	0.35	0.48	0.41	0.26	1.83	1.86
1940	0.29	0.36	0.48	0.41	0.28	1.82	1.83
1941	0.32	0.37	0.50	0.40	0.24	1.83	1.81
1942	0.27	0.36	0.48	0.39	0.23	1.73	1.73
1943	0.27	0.35	0.49	0.39	0.24	1.74	1.75
1944	0.32	0.36	0.45	0.39	0.25	1.77	1.78
1945	0.24	0.35	0.50	0.40	0.23	1.72	1.70
1946	0.27	0.37	0.46	0.39	0.24	1.73	1.77
1947	0.26	0.36	0.45	0.41	0.24	1.72	1.76
1948	0.30	0.37	0.45	0.41	0.28	1.81	1.83
1949	0.30	0.38	0.48	0.44	0.24	1.84	1.83
1950	0.26	0.36	0.46	0.36	0.26	1.70	1.71
1951	0.32	0.35	0.47	0.37	0.23	1.74	1.75
1952	0.30	0.38	0.46	0.40	0.27	1.81	1.83
1953	0.29	0.37	0.46	0.42	0.24	1.78	1.77
1954	0.26	0.36	0.47	0.39	0.24	1.72	1.73
1955	0.31	0.37	0.48	0.42	0.24	1.82	1.81
1956	0.26	0.40	0.43	0.40	0.23	1.72	1.73
1957	0.30	0.34	0.48	0.39	0.24	1.75	1.75
1958	0.31	0.34	0.44	0.39	0.25	1.73	1.77
1959	0.27	0.38	0.47	0.42	0.24	1.78	1.78
1960	0.30	0.36	0.47	0.41	0.26	1.80	1.83
1961	0.29	0.41	0.46	0.45	0.23	1.84	1.85
1962	0.28	0.38	0.44	0.40	0.23	1.73	1.74
1963	0.27	0.39	0.47	0.41	0.27	1.81	1.82
1964	0.32	0.38	0.46	0.37	0.24	1.77	1.76
1965	0.28	0.37	0.45	0.39	0.20	1.69	1.70
1966	0.26	0.38	0.48	0.39	0.26	1.77	1.77
1967	0.26	0.37	0.46	0.40	0.28	1.77	1.80
1968	0.27	0.36	0.45	0.37	0.25	1.70	1.69
1969	0.30	0.32	0.45	0.44	0.26	1.77	1.76
1970	0.27	0.41	0.48	0.41	0.25	1.82	1.79
1971	0.29	0.38	0.43	0.41	0.25	1.76	1.76
1972	0.33	0.39	0.44	0.41	0.23	1.80	1.79
1973	0.30	0.38	0.45	0.42	0.24	1.79	1.78
MEAN	0.29	0.37	0.47	0.40	0.24	1.77	1.78

surface, permeability, storage capacity and the rate of consumptive use. The Bureau of Reclamation treats effective precipitation as a percentage of the monthly totals. These range from over 90% effectiveness for the first inch to zero effectiveness for amounts in excess of 6 inches per month. The following ranges are suggested[12] and have been adopted for this study.

Precipitation Increment Inches	Effective Precipitation Percent	Effective Precipitation Inches Accumulated
1	90-100	0.90-1.00
2	85-95	1.75-1.95
3	75-90	2.50-2.85
4	50-80	3.00-3.65
5	30-60	3.30-4.25
6	10-40	3.40-4.65
over 6 inches	0-10	3.40-4.75

Using the monthly precipitation totals recorded at the Morden Research station from 1921 to 1973 enabled the calculation of the effective precipitation for the same period by the method outlined above. The results are tabulated on Table A-3.

Crop Irrigation Requirements

The crop irrigation requirement is the quantity of water, in addition to precipitation, necessary to insure optimum crop production. It is obtained as the difference between the monthly consumptive use and the monthly effective

TABLE A-3

EFFECTIVE PRECIPITATION AT MORDEN, MANITOBA

YEAR	MAY	JUNE	JULY	AUGUST	SEPT.	TOTAL
1921	0.16	0.13	0.34	0.24	0.22	1.09
1922	0.30	0.17	0.23	0.09	0.30	1.09
1923	0.11	0.08	0.12	0.18	0.18	0.67
1924	0.04	0.13	0.22	0.09	0.30	0.78
1925	0.11	0.32	0.07	0.10	0.24	0.84
1926	0.12	0.29	0.20	0.14	0.28	1.03
1927	0.34	0.23	0.15	0.16	0.11	0.99
1928	0.11	0.34	0.34	0.12	0.01	0.92
1929	0.07	0.04	0.10	0.06	0.19	0.46
1930	0.28	0.29	0.15	0.04	0.10	0.86
1931	0.10	0.08	0.14	0.15	0.21	0.68
1932	0.12	0.18	0.18	0.08	0.11	0.67
1933	0.34	0.07	0.07	0.11	0.18	0.77
1934	0.05	0.26	0.13	0.16	0.09	0.69
1935	0.12	0.33	0.21	0.26	0.11	1.03
1936	0.04	0.20	0.06	0.17	0.12	0.59
1937	0.13	0.33	0.34	0.03	0.11	0.94
1938	0.11	0.17	0.29	0.14	0.00	0.71
1939	0.14	0.28	0.05	0.28	0.09	0.84
1940	0.13	0.20	0.31	0.17	0.17	0.98
1941	0.24	0.21	0.08	0.12	0.34	0.99
1942	0.24	0.14	0.27	0.14	0.06	0.85
1943	0.21	0.19	0.17	0.29	0.05	0.91
1944	0.17	0.33	0.18	0.34	0.10	1.12
1945	0.18	0.16	0.24	0.13	0.25	0.96
1946	0.07	0.15	0.23	0.15	0.22	0.82
1947	0.03	0.31	0.11	0.34	0.12	0.91
1948	0.19	0.13	0.33	0.07	0.01	0.73
1949	0.19	0.15	0.17	0.13	0.06	0.70
1950	0.32	0.26	0.25	0.06	0.20	1.09
1951	0.02	0.16	0.08	0.34	0.16	0.76
1952	0.04	0.28	0.16	0.19	0.03	0.70
1953	0.30	0.28	0.25	0.18	0.12	1.13
1954	0.18	0.30	0.13	0.16	0.27	1.04
1955	0.13	0.29	0.19	0.06	0.18	0.85
1956	0.19	0.19	0.28	0.32	0.04	1.02
1957	0.14	0.28	0.33	0.21	0.18	1.14
1958	0.03	0.17	0.27	0.08	0.12	0.67
1959	0.30	0.20	0.15	0.26	0.15	1.06
1960	0.10	0.17	0.09	0.26	0.04	0.66
1961	0.07	0.07	0.14	0.03	0.26	0.57
1962	0.34	0.16	0.28	0.22	0.05	1.05
1963	0.26	0.33	0.33	0.06	0.04	1.02
1964	0.10	0.31	0.24	0.32	0.17	1.14
1965	0.29	0.11	0.19	0.25	0.23	0.87
1966	0.06	0.11	0.33	0.23	0.03	0.76
1967	0.08	0.10	0.13	0.11	0.04	0.46
1968	0.28	0.21	0.32	0.34	0.16	1.31
1969	0.11	0.26	0.16	0.08	0.14	0.75
1970	0.28	0.30	0.15	0.10	0.21	1.04
1971	0.09	0.32	0.24	0.11	0.15	0.91
1972	0.19	0.11	0.12	0.19	0.17	0.78
1973	0.15	0.24	0.24	0.18	0.32	1.13
MEAN	0.15	0.21	0.20	0.17	0.15	0.88

precipitation. In periods when effective precipitation exceeds the consumptive use, the irrigation requirement will be set at zero. For the month of May it has been assumed that no irrigation is needed since the precipitation during the month plus the soil moisture available from the spring snow melt will be more than adequate to meet the consumptive use for that month.

The monthly crop irrigation requirements for the project area during the period 1921 - 1973 are shown as Table A-4.

Farm Delivery Requirements

In practice it is infeasible to supply crop irrigation requirements without loss and waste. In applying water by surface methods, the soil at the upper end of the run receives more water than it can retain before that at the lower end of the run is served and the excess percolates below the root zone. Any excess, reaching the lower end of the run, drains off into waste ditches and drains, or onto waste non-productive land unless it can be diverted onto other irrigable lands. Other wastes may occur as a result of the breaking of farm ditches. These losses plus the crop irrigation requirement make up the farm delivery requirement.

Farm irrigation efficiency is an indication of water losses. It represents the useful water portion of the

TABLE A-4

CROP IRRIGATION REQUIREMENT

YEAR	MAY	JUNE	JULY	AUGUST	SEPT.	TOTAL
1921	0.00	0.27	0.14	0.15	0.04	0.60
1922	0.00	0.20	0.21	0.33	0.00	0.74
1923	0.00	0.32	0.37	0.19	0.13	1.01
1924	0.00	0.20	0.22	0.29	0.00	0.71
1925	0.00	0.03	0.37	0.31	0.01	0.72
1926	0.00	0.05	0.25	0.24	0.00	0.54
1927	0.00	0.13	0.29	0.21	0.14	0.77
1923	0.00	0.00	0.11	0.26	0.22	0.59
1929	0.00	0.32	0.37	0.34	0.04	1.07
1930	0.00	0.09	0.33	0.38	0.14	0.94
1931	0.00	0.32	0.33	0.26	0.06	0.97
1932	0.00	0.24	0.29	0.34	0.15	1.02
1933	0.00	0.35	0.42	0.31	0.08	1.16
1934	0.00	0.11	0.35	0.23	0.12	0.81
1935	0.00	0.00	0.30	0.13	0.33	0.76
1936	0.00	0.17	0.48	0.24	0.14	1.03
1937	0.00	0.07	0.14	0.40	0.14	0.75
1938	0.00	0.20	0.19	0.28	0.28	0.95
1939	0.00	0.07	0.43	0.14	0.17	0.81
1940	0.00	0.16	0.17	0.24	0.11	0.68
1941	0.00	0.16	0.42	0.28	0.00	0.86
1942	0.00	0.22	0.21	0.25	0.17	0.85
1943	0.00	0.16	0.32	0.10	0.19	0.77
1944	0.00	0.03	0.27	0.05	0.15	0.50
1945	0.00	0.19	0.26	0.27	0.00	0.72
1946	0.00	0.22	0.23	0.24	0.02	0.71
1947	0.00	0.05	0.34	0.07	0.12	0.58
1948	0.00	0.24	0.12	0.34	0.27	0.97
1949	0.00	0.23	0.31	0.31	0.18	1.03
1950	0.00	0.10	0.21	0.30	0.06	0.67
1951	0.00	0.19	0.39	0.03	0.07	0.67
1952	0.00	0.10	0.30	0.21	0.24	0.85
1953	0.00	0.09	0.21	0.24	0.12	0.66
1954	0.00	0.06	0.34	0.23	0.00	0.63
1955	0.00	0.08	0.29	0.36	0.06	0.79
1956	0.00	0.21	0.15	0.08	0.19	0.63
1957	0.00	0.06	0.15	0.18	0.06	0.45
1958	0.00	0.17	0.17	0.31	0.13	0.78
1959	0.00	0.18	0.32	0.16	0.09	0.75
1960	0.00	0.19	0.38	0.15	0.22	0.94
1961	0.00	0.34	0.32	0.42	0.00	1.08
1962	0.00	0.22	0.16	0.18	0.18	0.74
1963	0.00	0.06	0.14	0.35	0.23	0.78
1964	0.00	0.07	0.22	0.05	0.07	0.41
1965	0.00	0.26	0.26	0.14	0.00	0.66
1966	0.00	0.27	0.15	0.16	0.23	0.81
1967	0.00	0.27	0.33	0.29	0.24	1.13
1968	0.00	0.15	0.13	0.03	0.09	0.40
1969	0.00	0.06	0.29	0.36	0.12	0.83
1970	0.00	0.11	0.33	0.31	0.04	0.79
1971	0.00	0.06	0.19	0.30	0.10	0.65
1972	0.00	0.28	0.32	0.22	0.06	0.88
1973	0.00	0.14	0.21	0.24	0.00	0.59
MEAN	0.00	0.16	0.27	0.24	0.11	0.78

total water delivered to the farm. Typical water application losses and irrigation efficiencies for different soil conditions are given below[13].

Item	General Soil Type		
	Open Porous %	Medium Loam %	Heavy Clay %
Farm Lateral Loss*	15	10	5
Surface-Runoff Loss	5	10	25
Deep Percolation Loss	35	15	10
Field Irrigation Efficiency	60	75	65
Farm Irrigation Efficiency	45	65	60

* Unlined ditches

The soil type in the Morden-Winkler area can be classified as a medium clay loam. Using some judgement the following losses have been derived:

Percolation loss	-20%
Surface-runoff loss	-10%
TOTAL FIELD LOSS	-30%
Field Efficiency	-70%
Farm Ditch loss	-15%

THEREFORE - Farm Efficiency = 70% x 0.85 = 60%

For each month the farm delivery requirement was computed by dividing the crop irrigation requirement by the farm efficiency. Monthly farm delivery requirements, in acre-feet per acre, for the project area during the period 1921 - 1973 are shown on Table A-5.

Conveyance Losses

Conveyance losses are those losses of water in transit from the source of supply to the point of service whether in natural channels or in artificial ones such as canals, ditches and laterals. They comprise evaporation from the water surface, and incidental transpiration by water-loving vegetation growing in the water or along the banks of the conveyance works. Operational wastes are those losses due to lack of efficiency in management and breaks in conduits and ditches. In estimating diversion requirements, all conveyance losses and waste are ordinarily lumped together into a single estimate.

Conveyance losses in the project area will be incurred from the proposed Pembina Reservoir to the irrigation district. Most of these will occur in the gravity canal system. All canals will have clay lining thus reducing seepage losses.

Based on other projects experience[14] and using some judgement the following loss figures were adopted:

TABLE A-5

FARM DELIVERY REQUIREMENT

YEAR	MAY	JUNE	JULY	AUGUST	SEPT.	TOTAL
1921	0.00	0.45	0.23	0.25	0.07	1.00
1922	0.00	0.33	0.35	0.55	0.00	1.23
1923	0.00	0.53	0.62	0.32	0.22	1.69
1924	0.00	0.33	0.37	0.48	0.00	1.18
1925	0.00	0.05	0.62	0.52	0.02	1.21
1926	0.00	0.08	0.42	0.40	0.00	0.90
1927	0.00	0.22	0.48	0.35	0.23	1.28
1928	0.00	0.00	0.18	0.43	0.37	0.98
1929	0.00	0.53	0.62	0.57	0.07	1.79
1930	0.00	0.15	0.55	0.63	0.23	1.56
1931	0.00	0.53	0.55	0.43	0.10	1.61
1932	0.00	0.40	0.48	0.57	0.25	1.70
1933	0.00	0.58	0.70	0.52	0.13	1.93
1934	0.00	0.18	0.58	0.38	0.20	1.34
1935	0.00	0.00	0.50	0.22	0.55	1.27
1936	0.00	0.28	0.80	0.40	0.23	1.71
1937	0.00	0.12	0.23	0.67	0.23	1.25
1938	0.00	0.33	0.32	0.47	0.47	1.59
1939	0.00	0.12	0.72	0.23	0.28	1.35
1940	0.00	0.27	0.28	0.40	0.18	1.13
1941	0.00	0.27	0.70	0.47	0.00	1.44
1942	0.00	0.37	0.35	0.42	0.28	1.42
1943	0.00	0.27	0.53	0.17	0.32	1.29
1944	0.00	0.05	0.45	0.08	0.25	0.83
1945	0.00	0.32	0.43	0.45	0.00	1.20
1946	0.00	0.37	0.38	0.40	0.03	1.18
1947	0.00	0.08	0.57	0.12	0.20	0.97
1948	0.00	0.40	0.20	0.57	0.45	1.62
1949	0.00	0.38	0.52	0.52	0.30	1.72
1950	0.00	0.17	0.35	0.50	0.10	1.12
1951	0.00	0.32	0.65	0.05	0.12	1.14
1952	0.00	0.17	0.50	0.35	0.40	1.42
1953	0.00	0.15	0.35	0.40	0.20	1.10
1954	0.00	0.10	0.57	0.38	0.00	1.05
1955	0.00	0.13	0.48	0.60	0.10	1.31
1956	0.00	0.35	0.25	0.13	0.32	1.05
1957	0.00	0.10	0.25	0.30	0.10	0.75
1958	0.00	0.28	0.28	0.52	0.22	1.30
1959	0.00	0.30	0.53	0.27	0.15	1.25
1960	0.00	0.32	0.63	0.25	0.37	1.57
1961	0.00	0.57	0.53	0.70	0.00	1.80
1962	0.00	0.37	0.27	0.30	0.30	1.24
1963	0.00	0.10	0.23	0.58	0.38	1.29
1964	0.00	0.12	0.37	0.08	0.12	0.69
1965	0.00	0.43	0.43	0.23	0.00	1.09
1966	0.00	0.45	0.25	0.27	0.38	1.35
1967	0.00	0.45	0.55	0.48	0.40	1.88
1968	0.00	0.25	0.22	0.05	0.15	0.67
1969	0.00	0.10	0.48	0.60	0.20	1.38
1970	0.00	0.18	0.55	0.52	0.07	1.32
1971	0.00	0.10	0.32	0.50	0.17	1.09
1972	0.00	0.47	0.53	0.37	0.10	1.47
1973	0.00	0.23	0.35	0.40	0.00	0.98
MEAN	0.00	0.27	0.45	0.40	0.18	1.30

Canal losses	- 5%
Lateral and sub-lateral losses	-10%
Waste	-10%
TOTAL CONVEYANCE AND WASTE LOSS	-25%

THEREFORE - Project efficiency = 60% x 0.75 = 45%

Irrigation Diversion Requirements

Monthly irrigation diversion requirements, were estimated by adding the conveyance losses to the farm delivery requirements, and dividing the sum by 0.90 to provide an allowance of 10% for operational wastes. These conveyance losses were taken to be distributed evenly for each full month of the operating season. The monthly and annual irrigation diversion requirements for the Pembina River supply source are shown on Table A-6. The mean annual diversion requirement for the recorded period 1921 - 1973 is 1.71 acre-feet per productive acre.

Irrigation Return Flow

Return flow is water which is not consumed in evapo-transpiration and returns to a surface stream, drain, or body of water.

When a project is first operated, most of the water absorbed by the soil, not used by plant growth or lost by

TABLE A-6

IRRIGATION DIVERSION REQUIREMENT - PEMBINA DAM

YEAR	MAY	JUNE	JULY	AUGUST	SEPT.	TOTAL
1921	0.00	0.57	0.32	0.34	0.14	1.37
1922	0.00	0.43	0.46	0.68	0.07	1.64
1923	0.00	0.66	0.76	0.42	0.31	2.15
1924	0.00	0.43	0.48	0.60	0.07	1.58
1925	0.00	0.12	0.76	0.64	0.09	1.61
1926	0.00	0.16	0.53	0.51	0.07	1.27
1927	0.00	0.31	0.60	0.46	0.32	1.69
1928	0.00	0.07	0.27	0.54	0.48	1.36
1929	0.00	0.66	0.76	0.70	0.14	2.26
1930	0.00	0.23	0.68	0.77	0.32	2.00
1931	0.00	0.66	0.68	0.54	0.18	2.06
1932	0.00	0.51	0.59	0.70	0.34	2.14
1933	0.00	0.71	0.84	0.64	0.21	2.40
1934	0.00	0.27	0.70	0.49	0.29	1.75
1935	0.00	0.07	0.62	0.31	0.68	1.68
1936	0.00	0.38	0.96	0.51	0.32	2.17
1937	0.00	0.20	0.32	0.81	0.32	1.65
1938	0.00	0.43	0.42	0.59	0.59	2.03
1939	0.00	0.20	0.87	0.32	0.38	1.77
1940	0.00	0.37	0.38	0.51	0.27	1.53
1941	0.00	0.37	0.84	0.59	0.07	1.87
1942	0.00	0.48	0.46	0.53	0.38	1.85
1943	0.00	0.37	0.66	0.26	0.42	1.71
1944	0.00	0.12	0.57	0.16	0.34	1.19
1945	0.00	0.42	0.54	0.57	0.07	1.60
1946	0.00	0.48	0.49	0.51	0.10	1.58
1947	0.00	0.16	0.70	0.20	0.29	1.35
1948	0.00	0.51	0.29	0.70	0.57	2.07
1949	0.00	0.49	0.64	0.64	0.40	2.17
1950	0.00	0.26	0.46	0.62	0.18	1.52
1951	0.00	0.42	0.79	0.12	0.20	1.53
1952	0.00	0.26	0.62	0.46	0.51	1.85
1953	0.00	0.23	0.46	0.51	0.29	1.49
1954	0.00	0.18	0.70	0.49	0.07	1.44
1955	0.00	0.21	0.60	0.73	0.18	1.72
1956	0.00	0.46	0.34	0.21	0.42	1.43
1957	0.00	0.18	0.34	0.40	0.18	1.10
1958	0.00	0.38	0.38	0.64	0.31	1.71
1959	0.00	0.40	0.66	0.37	0.23	1.66
1960	0.00	0.41	0.77	0.34	0.48	2.01
1961	0.00	0.70	0.66	0.84	0.07	2.27
1962	0.00	0.48	0.37	0.40	0.40	1.65
1963	0.00	0.18	0.32	0.71	0.49	1.70
1964	0.00	0.20	0.48	0.16	0.20	1.04
1965	0.00	0.54	0.54	0.32	0.07	1.47
1966	0.00	0.57	0.34	0.37	0.49	1.77
1967	0.00	0.57	0.68	0.60	0.51	2.36
1968	0.00	0.34	0.31	0.12	0.23	1.00
1969	0.00	0.18	0.60	0.73	0.29	1.80
1970	0.00	0.27	0.68	0.64	0.14	1.73
1971	0.00	0.18	0.42	0.62	0.26	1.48
1972	0.00	0.59	0.59	0.48	0.18	1.84
1973	0.00	0.32	0.46	0.51	0.07	1.36
MEAN	0.00	0.37	0.56	0.50	0.28	1.71

soil moisture evaporation, percolates into the deeper sub-soil strata. Later as the surface of the groundwater storage rises, much of the deeper percolation returns to the natural stream channels. This could amount to between 30 to 60% of the diverted supply after 20 to 30 years of operation[15]. Forecasting where and at what time in the future return flows become available in the above quantities is somewhat speculative hence the subject will not be pursued further.

APPENDIX B

PEMBINA DAM

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PEMBINA DAM

Introduction

This section is concerned with the engineering feasibility of providing a reservoir on the Pembina River in Manitoba large enough to supply the irrigation, municipal and industrial water needs of the Morden-Winkler project area. The proposed dam will be located approximately 2 miles upstream of Highway No. 31 as shown on Figure B-1.

Description of Basin

The Pembina River has its source in the Turtle Mountains about 10 miles south of Boissevain, Manitoba at about elevation 2,000 feet. Its total length is about 310 miles. The river runs in an easterly direction until it reaches the Pembina Valley at the east end of Pelican Lake and continues east through 4 more lakes before turning southeast to the United States Border (see Figure B-1). It continues into North Dakota, on a southeast course until it passes the Town of Walhalla, where it turns eastward and parallels the International boundary to a point 1 mile south of Emerson where it empties into the Red River. The valley through the lakes has a bottom approximately 1 mile wide with steep side slopes, while below the lakes, the valley narrows to a u-shape. The Pembina Escarpment ends near Walhalla, so that east of this point, the channel meanders across the flat Red River Valley.

The drainage basin can be divided into two main sections at the Pembina Escarpment. To the east, the topography is flat with a gentle slope to the Red River. West of the Escarpment, the uplands area is rolling, undulating plain dotted with flat areas due to glacial action. The general altitude is 1,400 to 1,600 feet above sea level except in the Turtle Mountains which are more than 1,900 feet above sea level.

Hydrology

The climate of the Pembina River Basin is characterized by wide variations in temperature and rainfall. The mean annual precipitation over the basin for the last 53 years is approximately 18 inches; the eastern region having a slightly higher annual precipitation than the western. About 75% of the annual precipitation occurs during the summer months. Snowfall is moderate at about 35 inches of which a portion is evaporated. However, snow drifts into the Pembina River Valley and tributary valleys to give a runoff higher than would be expected from the average snow cover.

The average annual runoff of the Pembina River at the dam site for the 53 year period 1921 - 1973 is 105,000 acre-feet, or only 4% of the average annual precipitation over the basin, with 85% occurring from April to June. The runoff has varied from a minimum of 1,600 acre-feet (1938 - 1939) to a maximum of 401,500 acre-feet (1968 - 1969).

a. Drainage Areas

The gross drainage area of the Pembina River above its confluence with the Red River is 3,950 square miles, of this total area, 1,989 square miles, or slightly over 50% are in Canada while the remaining 1,961 square miles are in the United States.

At the Pembina dam site the gross drainage area is 2,896 square miles of which 1,840 square miles (64%) are in Manitoba and 1,056 square miles (36%) are in North Dakota.

It is believed[16] that at some post-glacial time a significant event occurred to the Pembina River drainage area. Headward erosion by a tributary of the Assiniboine River encroached on the Pembina Valley at a point 10 miles upstream of Ninette, and eventually robbed the valley of all upstream flow and formed what is now the Souris River.

By this event, the area drained by the Pembina River was reduced from 22,500 square miles to 3,950 square miles. Flow down the valley between the point of piracy and La Riviere has been insufficient to carry away fan debris deposited by side tributaries, and such lakes as Pelican lake, Rock lake and Swan lake were formed along the valley bottom. Throughout this reach the bottom gradient is in the order of one foot per mile, but downstream of La Riviere it steepens and at the dam site it is five feet per mile.

It has long been recognized that prairie watersheds are characterized by large areas of depressional storage which may or may not contribute to streamflow depending on antecedent precipitation. Shallow depressions are usually dry and the water surface in deeper depressions may be several feet below their outlet level. To include such areas as a portion of the basin contributing to stream flow, except in the very wettest of years, would be in error.

To assist in the determination of runoff and in the analysis of hydrometric records, the drainage basin above the Pembina dam site has been separated into effective, contributing and gross areas.

Herein the following definitions suggested by Stichling and Blackwell will apply:[17]

1. Effective Drainage Area - That area which might conceivably contribute to peak flow in an average run-off year. Marshes and sloughs with no connecting channels to the stream are excluded, as are areas upstream from lakes which have sufficient storage to detain runoff entirely or until after the peak flow has been observed at the gauging point.

2. Contributing Drainage Area - That area, including a portion of the basin affected by depressional storage which would probably contribute to large flood peaks (10% flood peak or better). Generally speaking, the criterion used when outlining this area on a map is that any portion of the basin which is connected to the main stream by a channel or an indication of a channel, lies within the contributing drainage area boundaries.

3. Gross Drainage Area - That area enclosed within its divide (height of land between watersheds) which would, through natural and artificial processes entirely contribute to the flood peak under extremely wet conditions.

With these definitions in mind the following table has been prepared.

TABLE B-1

Description	Gross Drainage Area Square Miles	Contributing Drainage Area Square Miles	Effective Drainage Area Square Miles
Pembina River @ Manitou	2090	1825	134
Pembina River @ Kaleida	2870	2272	200
Pembina River @ Pembina Dam Site	2896	2296	210
Pembina River @ Windygates	3016	2413	225
Pembina River @ Walhalla	3331	2711	---

b. Streamflow Records

There are numerous stream-gauging stations in operation in the Pembina River Basin. For the purpose of this study, only stations with long periods of records on the main stem of the river have been utilized. The approximate location of these stations along with the period of records at each station are shown on the table below.

TABLE B-2

	Gross Drainage Area Square Miles	Period of Record	
		From	To
Pembina River			
@ Manitou	2090	Oct. 1921	Sept. 1957
@ Kaleida	2870	Oct. 1957	Dec. 1969
@ Windygates	3016	Apr. 1962	present
@ Walhalla	3331	Oct. 1921	present

The maximum streamflow during a year on the Pembina River usually occurs in the latter part of March or in April, following the spring snow melt. Occasionally, these high flows are increased and frequently prolonged by accompanying rains. Runoff from the basin decreases during the summer months and flow in the winter months is very low. In some winters no flow has occured for many months.

c. <u>Analysis of Pembina River Flows</u>

Pembina River flows at the four gauging stations were analyzed to determine the monthly flows at the proposed Pembina Dam Site from 1921 to 1973. Due to the discontinuities in recorded flows three periods were studied separately.

1. From 1921 to 1957 - Monthly flow records for this period are available at both Walhalla and Manitou stations.* The following procedure was employed to obtain the monthly flows at the dam site. First, the difference in contributing drainage areas was computed between Walhalla and Manitou. For each month on record, the difference in runoff volume between Walhalla and Manitou was also calculated. By multiplying this volume difference by the ratio of contributing drainage areas between Manitou and the dam site (471 sq. mi.) and Manitou and Walhalla (886 sq. mi.) the monthly runoff

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* Records at Manitou are available for the open water year only. Estimates of winter flows at this station were obtained from the following PFRA publication: "Compilation of Run-Off Records for the Canadian Prairies" prepared by PFRA Hydrology Div. 1967.

from the uncontrolled area between Manitou and the dam site was obtained. This value was then added to the corresponding monthly flow at Manitou to yield an array of monthly runoffs at the dam site.

2. From 1958 to 1969 - Because the contributing drainage area at Kaleida is nearly equal to the contributing drainage area at the dam site, the recorded flows for this period at Kaleida were taken to represent the flows at the dam site.

3. From 1969 to 1973 - For this period the monthly flows at Kaleida and Windygates were compared. For some reason unknown to the author, the recorded monthly flows at Windygates were consistently less than the recorded flows at Kaleida even though the Windygates station is downstream of Kaleida. This seems to imply a loss in volume somewhere. Because of this anomaly, the records at Windygates for this period were not altered but were taken to represent the flows at the dam site.

All the computed monthly flow values at the dam site by the above methods are presented in Table B-3 and also are plotted in Figure B-2.

d. <u>Magnitude & Frequency of Floods</u>

The purpose of this section is to provide information on the magnitude and frequency of floods which may be expected to occur on the Pembina River.

TABLE B-3

MONTHLY AND ANNUAL RUNOFF IN ACRE-FEET: PEMBINA RIVER AT DAM SITE

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	ANNUAL
1921	6200	3800	2550	1600	1000	1350	16550	8750	3550	5350	700	700	52100
1922	3050	1550	1500	350	200	2550	21100	11300	4800	900	500	1150	48950
1923	2900	3300	1400	1150	500	700	56900	62300	13700	4100	4800	5200	156950
1924	5200	3450	900	200	200	600	10900	7050	4400	1550	450	750	35650
1925	8100	4550	900	100	100	23050	20250	9750	9200	4100	1600	2600	84300
1926	6800	2600	1950	550	150	3150	5250	3600	2800	2650	650	2100	32250
1927	2650	1700	1250	700	200	17800	49300	47950	25900	15650	11900	16100	191100
1928	11150	5400	1150	1900	1200	20650	17000	9950	7000	2700	2200	3250	83550
1929	5800	1900	1000	850	650	9300	9400	5450	2600	1550	150	150	37800
1930	500	1050	500	100	50	50	43950	23000	9000	3000	850	800	82850
1931	1300	450	100	350	300	2000	17400	4500	1100	1300	50	20	27870
1932	50	200	50	50	150	900	19150	8450	2700	1000	200	50	32950
1933	200	350	100	0	0	1050	35750	28450	13700	3200	1300	1850	85950
1934	1300	1150	450	200	200	4800	15750	7400	2750	650	50	0	34700
1935	50	25	0	0	0	450	5600	2750	3400	2300	1500	800	16875
1936	600	350	150	150	0	0	29300	22750	9400	2700	950	1150	67400
1937	1200	400	150	50	0	0	4050	2650	2200	400	250	0	11350
1938	20	12	0	0	0	10100	5100	3800	1450	400	50	0	20950
1939	20	0	0	0	0	50	900	350	250	20	0	0	1600
1940	0	0	0	0	0	0	3200	650	100	20	350	0	4320
1941	0	0	0	0	0	0	43500	18750	6650	1900	1650	5200	77650
1942	4100	1700	900	400	250	3700	84000	47900	14850	4950	4400	2850	170000
1943	2200	1450	500	600	250	6400	23300	15250	11600	9400	2900	2800	76650
1944	6700	3500	1600	300	200	100	11050	10900	12650	42950	17600	21950	129500
1945	10050	10000	4350	2050	1950	26500	55200	37150	19150	13000	38400	4250	222050
1946	3000	1650	850	500	350	28100	32000	12950	4300	2600	1150	750	88200
1947	1100	900	450	200	100	500	26150	14350	7450	3200	5350	3000	62750
1948	2350	1350	900	750	400	350	37800	43400	18450	13200	10050	5850	134850
1949	3100	1850	1150	850	500	350	140200	76600	31850	13050	6900	3300	279700
1950	2300	1500	950	700	500	700	81200	132400	58650	31200	20550	11150	341800

Continued ....

TABLE B-3 cont...

MONTHLY AND ANNUAL RUNOFF IN ACRE-FEET: PEMBINA RIVER AT DAM SITE

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	ANNUAL
1951	7250	3700	1750	1200	800	3000	37950	26750	13300	5600	2750	1500	105550
1952	800	500	200	150	150	1200	14350	25400	5550	2450	650	50	51450
1953	50	100	50	0	0	150	3250	2150	7150	4100	2200	400	19600
1954	150	200	150	50	50	500	3500	2600	21950	40750	22200	9250	101350
1955	5650	3050	1450	850	650	1000	78400	42300	24500	13100	4150	1800	176900
1956	1600	950	500	350	300	350	52500	119200	38400	17100	8750	6300	246300
1957	5200	2300	400	200	100	6000	14000	9000	5100	1800	3000	6000	53100
1958	8500	3650	4450	2200	950	1200	9200	4900	1150	700	50	20	36970
1959	50	550	200	50	0	550	11500	4600	2450	550	450	250	21200
1960	2050	5900	6650	3350	2500	1250	97550	72250	21800	9100	4350	1850	228600
1961	1100	400	250	250	100	1300	15100	8600	1650	150	50	50	29000
1962	0	0	0	0	0	0	17150	13000	9450	3850	5000	5600	54050
1963	2450	1300	1000	450	0	1900	8200	13500	13200	5650	6350	3450	57450
1964	1650	900	100	0	0	0	13100	20900	6750	1450	1550	1700	48100
1965	1100	450	0	0	0	0	29150	39300	22450	7850	3700	5650	109550
1966	4200	2700	1500	550	0	10850	63050	43100	17150	7750	3550	1200	155600
1967	400	350	100	200	250	1750	30250	42850	14750	3800	800	200	95700
1968	1000	300	150	0	0	6750	6800	3500	1500	1550	6350	23800	51700
1969	24800	10000	2900	1050	800	900	200000	103000	28100	16300	8250	5400	401500
1970	3500	2000	1550	900	700	750	65200	115000	64000	38900	16000	7800	316300
1971	4700	2550	900	600	550	700	121000	79900	27700	21100	18000	8400	286100
1972	5000	3400	2300	1150	800	16600	71700	47600	18700	12100	10100	5800	195250
1973	4400	1700	300	200	150	3450	4450	3050	1950	2800	3150	2700	28400

MEAN ANNUAL = 104950

say 105000

From the mean daily peak flows recorded at Manitou, Kaleida and Windygates, the annual maximum mean daily peaks were selected at each location for the recorded period and these were transposed to the dam site using the ratio of effective drainage areas to the 0.65 power.[18]

$$\frac{Q}{Q_{\circ}} = \left(\frac{A}{A_{\circ}}\right)^{0.65}$$

where: Q = computed peak flow at dam site

$Q_{\circ}$ = recorded peak flow at station

A = effective drainage area at dam site

$A_{\circ}$ = effective drainage area at recording station

In order to arrive at a frequency curve of peakflows at the dam site the annual maximum mean daily peaks were arranged in descending order of magnitude and the corresponding frequencies were computed using the following plotting position:

$$P = \frac{M}{N+1}$$

where: P = probability of occurrence

N = number of years on record

M = order of magnitude of flood peak

The results are presented on Table B-4.

The peakflows were plotted at their frequencies on Gumbel's probability paper and a curve was drawn through the plotted points. To extend the curve beyond the available data, a straight line extrapolation was used (see Figure B-3).

TABLE B-4

PEMBINA RIVER

MAGNITUDE AND FREQUENCIES OF PEAK FLOWS

YEAR	DATE	PEAK FLOW @ MANITOU (CFS)	PEAK FLOW @ DAM SITE (CFS)	PEAK FLOW @ DAM SITE IN ORDER OF MAGNITUDE	ORDER NO. M	$\frac{M}{N+1}$ % N=53
1921	July 4	755	1010	9700	1	1.85
1922	April 5	477	639	6730	2	3.70
1923	April 19	1620	2170	5650	3	5.56
1924	May 2	187	250	3560	4	7.40
1925	April 2	393	527	3510	5	9.26
1926	Apr. 24-26	54	72	3330	6	11.11
1927	April 13	889	1190	2720	7	12.96
1928	Mar. 24-26	451	603	2220	8	14.81
1929	April 18	185	248	2170	9	16.67
1930	Apr. 6,10	581	778	2140	10	18.52
1931	Apr. 6,7	161	216	2120	11	20.37
1932	Apr. 8,13	303	406	2050	12	22.22
1933	May 25	884	1180	1980	13	24.07
				1600	14	25.93
1934	Apr.7,9,12	369	495	1550	15	27.78
1935	April 13	131	176	1490	16	29.63
1936	Apr. 14,16	634	850	1480	17	31.48
1937	Apr. 14,17	68	91	1280	18	33.33
1938	March 22	223	300	1280	19	35.19
1939	April 15	22	30	1260	20	37.04
1940	April 20	150	200	1190	21	38.89
1941	April 11	1530	2050	1180	22	40.74
1942	Apr. 4,5	1600	2140	1150	23	42.59
1943	April 7	500	670	1010	24	44.44
1944	July 20	1110	1490	862	25	46.30
1945	March 27	1480	1980	850	26	48.15
1946	Mar. 21,23	863	1150	778	27	50.00
1947	April 4	516	690	745	28	51.85
1948	April 1	1190	1600	690	29	53.70
1949	April 17	5030	6730	670	30	55.56
1950	April 17	2660	3560	639	31	57.41
1951	April 5	642	862	604	32	59.26
1952	April 1	556	745	603	33	61.11
1953	June 5	286	383	555	34	62.96
1954	July 1	955	1280	527	35	64.81
1955	April 3	1660	2220	519	36	66.67
1956	May 1	2480	3330	495	37	68.52
1957	March 23	450	604	426	38	70.37
		@ Kaleida				
1958	April 6	303	314	406	39	72.22
1959	April 5	501	519	383	40	74.07
1960	April 24	2620	2720	325	41	75.93
1961	April 18	314	325	314	42	77.78
1962	April 20	1220	1260	308	43	79.63
1963	June 5	298	308	300	44	81.48
1964	May 10	412	426	250	45	83.33
1965	April 14	1240	1280	248	46	85.19
1966	April 3	2050	2120	216	47	87.04
1967	April 23	1430	1480	200	48	88.89
1968	Sept. 27	535	555	176	49	90.74
1969	April 19	9400	9700	100	50	92.59
		@ Windygates				
1970	April 28	3680	3510	91	51	94.44
1971	April 10	5910	5650	72	52	96.30
1972	April 12	1620	1550	30	53	98.15
1973	July 12	104	100			

A value of 30,000 cfs was obtained for the 1 in 1000 year flood peak. This is 8000 cfs higher than the value used in the 1964 report.[19]

Design hydrographs at the dam site were obtained using the basic hydrograph concept. A basic hydrograph is a synthetic hydrograph derived from the best estimate of the slopes of the rising and recession limbs of actual recorded hydrographs plotted on semi-logarithmic paper. With the representative slopes of the rising and recession limbs determined the basic hydrograph can be drawn simply by knowing the peak discharge at any frequency.

The main difference between the basic hydrograph and the conventional unit hydrograph is that the basic hydrograph has a varying base width depending on peak discharge whereas the unit hydrograph has a fixed base width. Examination of recorded streamflow hydrographs on the prairie streams indicate that the base width does vary with the peak discharge and therefore the basic hydrograph gives a better estimate of actual streamflow conditions at design frequencies.

Design flood hydrographs at the dam site were derived by first plotting on semi-logarithmic paper the largest observed flood hydrographs at the three recording gauging stations for the period 1921 to 1973. Typical plots are given in Figure B-4. The characteristic double peak is due to the series of lakes in the Pembina Valley which modify the upstream flow by lagging it with respect to the flow from the drainage area below the lakes.

The steepest portions of the rising and recession limbs were selected to obtain the shape of the basic hydrographs as shown in Figure B-5. For recurrence intervals of 25, 100, 500 and 1000 years, peak discharge values were selected from the frequency curve and combined with the representative basic hydrograph shape to give design flood hydrographs at the dam site as shown in Figure B-6.

Water Supply

This study was undertaken primarily to determine the storage requirement at the Pembina dam site to supply the irrigation, municipal and industrial requirements of the Morden-Winkler project area.

Streamflow data at the Pembina Dam site show that the most critical runoff period occured from 1931 to 1940. Storage-yield calculations are based on this period on the assumptions that no shortages are to be allowed and that at the end of the critical period the reservoir will be at the dead-storage level.

a. Municipal & Industrial Water Requirement Storage

The future Pembina Triangle municipal and industrial water requirement has been estimated to be 5000 acre-feet per year.[20]

The proposal is to build a dugout-type reservoir one mile west of Winkler, in order to store water for short carry-over periods, during the summer and winter months. A short diversion from the main irrigation canal will carry the needed flows to a natural stream which will take it to the proposed dugout as shown in Figure 2 in the main report. Delivery will be as follows:

TABLE B-5

DATE		WATER DELIVERED IN ACRE-FEET
First week in April		1,530
Last week in May		990
First week in September		1,900
Last week in October		990
	TOTAL:	5,410

The 410 acre-feet surplus is the additional storage water required to offset transmission losses, etc.

No water will be delivered in June, July, and August since at these times, the full amount will be needed for irrigation.

b. Sediment Storage

Suspended sediment data obtained at the Windygates gauging station from 1962 to 1969 inclusive, was evaluated to determine the dead storage allowance in the proposed Pembina reservoir.

The mean annual suspended sediment carried during the 8 year period was 67,160 tons. The particle size distribution of the sediment shows that it can be classified as a silty-clay. The sediment density was determined using a procedure developed by Koelzer et al.[21] The density equation is:

$$W = W_1 + K \log_{10} t$$

where: W = density after t years lb/cu.ft.

W_1 = density after 1 year lb/cu.ft.

K = a constant for each sediment class & operation condition, to reflect consolidation

t = number of years of consolidation

The values of W_1 and K vary with the method of operation and the size of sediment material.

For a moderate reservoir drawdown, K has been estimated at 6.0

For a silty-clay W_1 has been estimated at 60 lbs/cu.ft.

Assuming a reservoir life of 100 years:

$$W = 60 + 6 \log_{10} 100$$

$$W = 72 \text{ lbs/cu.ft.}$$

Over 100 years, the total suspended sediment transport will be 1.34×10^{10} lbs.

The volume of suspended sediment $= \dfrac{1.34 \times 10^{10}}{(72)\ (4.36 \times 10^{4})}$

= 4,300 acre-feet

Allowing 10% for bed load transport, the total reservoir volume required for dead storage is 5,000 acre-feet.

c. Reservoir Evaporation & Seepage Loss Rates

Since no recorded data on evaporation in the Pembina River Basin is available for the critical period used in this study, the monthly gross evaporation rates recorded at Winnipeg have been used. These were obtained from the "Nelson River Basin Board Report on Hydrology, Appendix 4, Volume 2".

To obtain net evaporation rates, the monthly precipitation has to be subtracted from the gross evaporation. For the project, the precipitation data used was recorded at Ninette. This station located on the Pembina Valley is considered to be representative of the climatic conditions found at the dam site.

Seepage losses through the proposed reservoir were arbitrarily assumed at 2.5 inches per year to be distributed evenly for each month.

d. Reservoir Operation Computations

The operation studies were computed in reverse, starting with the Pembina Reservoir fully depleted of useful storage at the end of the drought period in October 1940. The computations were continued backwards for 10 years through the controlling critical period. The demands on the reservoir storage were the irrigation diversion requirement that would have been in demand during the period, the annual municipal and industrial requirement of 5,000 acre-feet, the net reservoir evaporation losses that were estimated for the period and the seepage losses. The inflows into the reservoir were the estimated monthly flows less that portion of the flow allotted to the U.S. This was computed to be 36 per cent of the inflow using the ratio of gross drainage areas at the dam site. Thus the monthly accretion or depletion to storage was obtained. The procedure was continued until the maximum storage requirement was reached. These calculations are set out in Table B-6. The reservoir storage required from the storage-elevation curve of Figure B-7 is 147,000 acre-feet at a full supply level of 1241. On the average, this storage will supply a dependable annual yield of 28,000 acre-feet.

Flood Control

A review of historical records on the Pembina River indicate that major flooding occurs regularly due to spring snow melt primarily east of the Pembina Escarpment. West of the Escarpment, flood flows are localized and confined to the valley floor.

In order to assess the effect of the Pembina dam on reducing flooding downstream, hypothetical flood hydrographs were routed through the reservoir.

For the purpose of this study, the following assumptions were made:

Length of Spillway = 200 feet
Elevation of Spillway Crest = 1241
Two 7 foot ∅ conduits with inverts at El. 1168

TABLE B-6

PEMBINA DAM: STORAGE-YIELD CALCULATIONS
PRODUCTIVE ACRES: 11,975
UNIT: 1,000 Acre Feet

	DATE	RUNOFF AT DAM SITE (Acre-Feet)	RUNOFF ALLOTTED FOR MANITOBA USE (Acre-Feet)	STORAGE (Acre-Feet)	EVAPORATION + SEEPAGE - PRECIPITATION (Feet)	E + S - P LOSS (Acre-Feet)	MUNICIPAL & INDUSTRIAL USE (Acre-Feet)	IRRIGATION REQUIREMENT (Acre-Feet)	TOTAL DRAFT (Acre-Feet)	TOTAL LOSS (Acre-Feet)	CARRY OVER STORAGE (Acre-Feet)
1931	JAN	0.35	0.22	134.33	0.10	0.04	0	0	0	0.04	134.59
	FEB	0.30	0.19	134.59	0.35	0.15	0	0	0	0.15	134.63
	MAR	2.00	1.28	134.63	-0.37	-0.16	0	0	0	-0.16	136.07
	APR	17.40	11.14	136.07	0.91	0.42	1.53	0	1.53	1.95	145.26
	MAY	4.50	2.88	145.26	1.09	0.51	0.99	0	0.99	1.50	146.64
	JUN	1.10	0.70	146.64*	1.37	0.62	0	7.90	7.90	8.52	138.82
	JUL	0.30	0.19	138.82	3.85	1.65	0	8.15	8.15	9.80	129.21
	AUG	0.05	0.03	129.21	2.81	1.10	0	6.46	6.46	7.56	121.68
	SEP	0.02	0.01	121.68	0.66	0.23	1.90	2.16	4.06	4.29	117.40
	OCT	0.05	0.03	117.40	2.14	0.84	0.99	0	0.99	1.83	119.20
	NOV	0.20	0.13	119.20	0.58	0.23	0	0	0	0.23	119.10
	DEC	0.05	0.03	119.10	0.36	0.14	0	0	0	0.14	118.99
1932	JAN	0.05	0.03	118.99	-0.70	-0.27	0	0	0	-0.27	119.29
	FEB	0.15	0.10	119.29	0.18	0.07	0	0	0	0.07	119.32
	MAR	0.90	0.58	119.32	-0.38	-0.15	0	0	0	-0.15	120.05
	APR	19.15	12.26	120.05	0.04	0.02	1.53	0	1.53	1.55	130.76
	MAY	8.45	5.41	130.76	0.70	0.31	0.99	0	0.99	1.30	134.87
	JUN	2.70	1.73	134.87	-1.06	-0.46	0	6.10	6.10	5.64	130.96
	JUL	1.00	0.64	130.96	2.90	1.18	0	7.06	7.06	8.24	123.36
	AUG	0.20	0.13	123.36	2.58	0.97	0	8.37	8.37	9.34	114.15
	SEP	0.05	0.03	114.15	5.58	1.95	1.90	4.07	5.97	7.92	106.26
	OCT	0.20	0.13	106.26	-0.11	-0.04	0.99	0	0.99	0.95	105.44
	NOV	0.35	0.22	105.44	-0.47	-0.16	0	0	0	-0.16	105.82
	DEC	0.10	0.06	105.82	-0.02	-0.07	0	0	0	-0.07	105.95
1933	JAN	0.00	0.00	105.95	-0.47	-0.16	0	0	0	-0.16	106.11
	FEB	0.00	0.00	106.11	0.20	0.07	0	0	0	0.07	106.04
	MAR	1.05	0.67	106.04	0.43	0.15	0	0	0	0.15	106.56
	APR	35.75	22.88	106.56	-1.42	-0.59	1.53	0	1.53	0.94	128.50
	MAY	28.45	18.24	128.50	-1.83	-0.86	0.99	0	0.99	0.13	146.61
	JUN	13.70	8.77	146.61*	4.85	2.26	0	8.50	8.50	10.76	144.62
	JUL	3.20	2.05	144.62	5.75	2.50	0	10.01	10.01	12.51	134.16
	AUG	1.30	0.83	134.16	5.79	2.40	0	7.67	7.67	10.07	124.92
	SEP	1.85	1.18	124.92	2.67	1.07	1.90	2.52	4.42	5.49	120.61
	OCT	1.30	0.83	120.61	2.40	0.96	0.99	0	0.99	1.95	119.49
	NOV	1.15	0.74	119.49	-0.45	-0.18	0	0	0	-0.18	120.41
	DEC	0.45	0.29	120.41	-1.47	-0.59	0	0	0	-0.59	121.29

* Maximum Storage Requirement

TABLE B-6

DATE		RUNOFF AT DAM SITE (Acre-Feet)	RUNOFF ALLOTTED FOR MANITORA USE (Acre-Feet)	STORAGE (Acre-Feet)	EVAPORATION + SEEPAGE - PRECIPITATION (Feet)	E + S - P LOSS (Acre-Feet)	MUNICIPAL AND INDUSTRIAL USE (Acre-Feet)	IRRIGATION REQM'T (Acre-Feet)	TOTAL DRAFT (Acre-Feet)	TOTAL LOSS (Acre-Feet)	CARRY OVER STORAGE (Acre-Feet)
1934	JAN	0.20	0.13	121.29	-0.09	-0.04	0	0	0	-0.04	121.46
	FEB	0.20	0.13	121.46	0.42	0.17	0	0	0	0.17	121.42
	MAR	4.80	3.07	121.42	0.30	0.12	0	0	0	0.12	124.37
	APR	15.75	10.08	124.37	1.07	0.46	1.53	0	1.53	1.99	132.46
	MAY	7.40	4.76	132.46	2.00	0.88	0.99	0	0.99	1.87	135.35
	JUN	2.75	1.76	135.35	2.52	1.10	0	3.24	3.24	4.34	132.77
	JUL	0.65	0.42	132.77	5.81	2.33	0	8.38	8.38	10.71	122.48
	AUG	0.05	0.03	122.48	3.29	1.26	0	5.87	5.87	7.13	115.38
	SEP	0.00	0.00	115.38	3.84	1.38	1.90	3.47	5.37	6.75	108.63
	OCT	0.05	0.03	108.63	3.13	1.12	0.99	0	0.99	2.11	106.58
	NOV	0.03	0.02	106.58	-0.13	-0.05	0	0	0	-0.05	106.65
	DEC	0.00	0.00	106.65	-0.46	-0.16	0	0	0	-0.16	106.81
1935	JAN	0.00	0.00	106.81	-1.15	-0.41	0	0	0	-0.41	107.22
	FEB	0.00	0.00	107.22	0.53	0.19	0	0	0	0.19	107.03
	MAR	0.45	0.29	107.03	-0.87	-0.31	0	0	0	-0.31	107.63
	APR	5.60	3.58	107.63	-0.04	-0.01	1.53	0	1.53	1.52	109.69
	MAY	2.75	1.76	109.69	0.54	0.20	0.99	0	0.99	1.19	110.26
	JUN	3.40	2.18	110.26	-3.08	-1.15	0	0.84	0.84	-0.31	112.75
	JUL	2.30	1.47	112.75	-0.45	-0.16	0	7.42	7.42	7.26	106.00
	AUG	1.50	0.96	106.00	3.05	1.03	0	3.71	3.71	4.74	102.22
	SEP	0.80	0.51	102.22	4.01	1.23	1.90	8.15	10.05	11.28	91.45
	OCT	0.60	0.38	91.45	3.31	1.02	0.99	0	0.99	2.01	89.82
	NOV	0.35	0.22	89.82	-0.54	-0.17	0	0	0	-0.17	90.21
	DEC	0.15	0.10	90.21	-0.32	-0.10	0	0	0	-0.10	90.41
1936	JAN	0.05	0.03	90.41	-0.59	-0.18	0	0	0	-0.18	90.62
	FEB	0.00	0.00	90.62	-0.67	-0.25	0	0	0	-0.25	90.87
	MAR	0.00	0.00	90.87	-0.32	-0.10	0	0	0	-0.10	90.97
	APR	29.30	18.75	90.97	1.70	0.61	1.53	0	1.53	2.14	107.58
	MAY	22.75	14.56	107.58	1.12	0.45	0.99	0	0.99	1.44	120.70
	JUN	9.40	6.02	120.70	2.43	0.98	0	4.55	4.55	5.53	121.19
	JUL	2.70	1.73	121.19	6.21	2.25	0	11.50	11.50	13.75	109.17
	AUG	0.95	0.61	109.17	5.64	1.92	0	6.12	6.12	8.04	101.84
	SEP	1.15	0.74	101.84	3.43	1.09	1.90	3.83	5.73	6.82	95.76
	OCT	1.20	0.77	95.76	3.80	1.20	0.99	0	0.99	2.19	94.34
	NOV	0.40	0.26	94.34	0.40	0.13	0	0	0	0.13	94.47
	DEC	0.15	0.10	94.47	-0.55	-0.17	0	0	0	-0.17	94.74
1937	JAN	0.05	0.03	94.74	-0.04	-0.01	0	0	0	-0.01	94.78
	FEB	0.00	0.00	94.78	-1.00	-0.30	0	0	0	-0.30	95.08
	MAR	0.00	0.00	95.08	0.39	0.12	0	0	0	0.12	94.96
	APR	4.05	2.59	94.96	-1.49	-0.48	1.53	0	1.53	1.05	96.50
	MAY	2.65	1.70	96.50	-0.13	-0.04	0.99	0	0.99	0.95	97.25
	JUN	2.20	1.41	97.25	0.59	0.19	0	2.40	2.40	2.59	96.07
	JUL	0.40	0.26	96.07	4.70	1.45	0	3.84	3.84	5.29	91.04
	AUG	0.25	0.16	91.04	2.87	0.79	0	9.70	9.70	10.49	80.71

TABLE B-6

	DATE	RUNOFF AT DAM SITE (Acre-Feet)	RUNOFF ALLOTTED FOR MANITOBA USE (Acre-Feet)	STORAGE (Acre-Feet)	EVAPORATION + SEEPAGE - PRECIPITATION (Feet)	E + S - P LOSS (Acre-Feet)	MUNICIPAL AND INDUSTRIAL USE (Acre-Feet)	IRRIGATION REQM'T (Acre-Feet)	TOTAL DRAFT (Acre-Feet)	TOTAL LOSS (Acre-Feet)	CARRY OVER STORAGE (Acre-Feet)
1937	SEP	0.00	0.00	80.71	3.74	0.93	1.90	3.84	5.74	6.67	74.04
	OCT	0.02	0.01	74.04	1.83	0.46	0.99	0	0.99	1.45	73.60
	NOV	0.01	0.01	73.60	-0.36	-0.09	0	0	0	-0.09	73.69
	DEC	0.00	0.00	73.69	-0.48	-0.12	0	0	0	-0.12	73.81
1938	JAN	0.00	0.00	73.81	-0.13	-0.03	0	0	0	-0.03	73.84
	FEB	0.00	0.00	73.84	-1.91	-0.50	0	0	0	-0.50	73.84
	MAR	10.10	6.46	73.84	0.38	0.10	0	0	0	0.10	80.20
	APR	5.10	3.26	80.20	0.17	0.05	1.53	0	1.53	1.58	81.88
	MAY	3.80	2.43	81.88	0.29	0.08	0.99	0	0.99	1.07	83.24
	JUN	1.45	0.93	83.24	3.28	0.87	0	5.15	5.15	6.02	78.15
	JUL	0.40	0.26	78.15	2.96	0.74	0	5.03	5.03	5.77	72.64
	AUG	0.05	0.03	72.64	3.73	0.86	0	7.06	7.06	7.92	64.75
	SEP	0.00	0.00	64.75	5.02	1.00	1.90	7.06	8.96	9.96	54.79
	OCT	0.02	0.01	54.79	3.17	0.63	0.99	0	0.99	1.62	53.18
	NOV	0.00	0.00	53.18	0.23	0.05	0	0	0	0.05	53.13
	DEC	0.00	0.00	53.13	-1.42	-0.28	0	0	0	-0.28	53.41
1939	JAN	0.00	0.00	53.41	-0.05	-0.01	0	0	0	-0.01	53.42
	FEB	0.00	0.00	53.42	-1.09	-0.22	0	0	0	-0.22	53.64
	MAR	0.05	0.03	53.64	-0.54	-0.11	0	0	0	-0.11	54.08
	APR	0.90	0.58	54.08	0.53	0.10	1.53	0	1.53	1.63	53.03
	MAY	0.35	0.22	53.03	-0.68	-0.13	0.99	0	0.99	0.86	52.39
	JUN	0.25	0.16	52.39	1.39	0.26	0	2.40	2.40	2.66	49.89
	JUL	0.02	0.01	49.89	5.06	0.80	0	10.42	10.42	11.22	38.68
	AUG	0.00	0.00	38.68	3.30	0.48	0	3.83	3.83	4.31	34.37
	SEP	0.00	0.00	34.37	3.51	0.45	1.90	4.55	6.45	6.90	27.47
	OCT	0.00	0.00	27.47	2.83	0.35	0.99	0	0.99	1.34	26.13
	NOV	0.00	0.00	26.13	1.13	0.14	0	0	0	0.14	25.99
	DEC	0.00	0.00	25.99	0.37	0.05	0	0	0	0.05	25.94
1940	JAN	0.00	0.00	25.94	-0.04	-0.01	0	0	0	-0.01	25.95
	FEB	0.00	0.00	25.95	-1.26	-0.16	0	0	0	-0.16	26.11
	MAR	0.00	0.00	26.11	-0.48	-0.06	0	0	0	-0.06	26.17
	APR	3.20	2.05	26.17	-1.00	-0.12	1.53	0	1.53	1.41	26.81
	MAY	0.65	0.42	26.81	-0.24	-0.03	0.99	0	0.99	0.96	26.27
	JUN	0.10	0.06	26.27	0.88	0.10	0	4.43	4.43	4.53	21.80
	JUL	0.02	0.01	21.80	-0.42	-0.04	0	4.55	4.55	4.51	17.30
	AUG	0.35	0.22	17.30	0.53	+0.04	0	6.12	6.12	6.16	11.36
	SEP	0.00	0.00	11.36	3.11	+0.13	1.90	3.23	5.13	5.26	6.10
	OCT	0.00	0.00	6.10	2.93	+0.11	0.99	0	0.99	1.10	5.00**
	NOV	0.00	0.00	5.00	-0.48	-0.02	0	0	0	0	5.00
	DEC	0.00	0.00	5.00	-0.18	-0.01	0	0	0	0	5.00
1941	JAN	0.00	0.00	5.00	-1.20	-0.04	0	0	0	0	5.00
	FEB	0.00	0.00	5.00	-0.12	-0.01	0	0	0	0	5.00
	MAR	0.00	0.00	5.00	-0.13	-0.01	0	0	0	0.00	5.00
	APR	43.50	27.84	5.00	-1.11		1.53	0	1.53		
	MAY	18.70	12.00		-1.93	-0.07	0.99	0	0.99	0.92	5.00

** Dead Storage Requirement

The Goodrich method was applied to route through the reservoir floods having recurrence intervals of 25, 100, 500 and 1000 years. Only one method of operation was analyzed. For each routing the initial condition of the reservoir was assumed at 100,000 acre-feet storage and both conduits wide open. This is considered a good assumption since in most years storage-yield calculations show that the reservoir can be expected at this storage volume prior to the spring snowmelt.

The results of flood routing calculations show that peak reductions from 13% to 50% can be realized downstream for peak flows of 30,000 cfs to 6,000 cfs respectively. Also results show that for the 4% design flood of 6,000 cfs the spillway was not used. Typical flood routing calculations are set out in Table B-7. Figure B-8 shows the developed natural and modified frequency curves at the dam site.

Design

a. General

This section is concerned with the design of the Pembina Dam. The dam site is located on the south boundary of Sec. 31-1-7W1 about 2 miles upstream of Manitoba Highway No. 31. The Geologic and Soils Investigations at the dam site were carried out by the PFRA in 1962 in conjunction with the Pembina River Basin Report to the International Joint Commission.

TABLE B-7

PEMBINA DAM - FLOOD ROUTING CALCULATIONS

1% FLOOD

ROUTING EQ. $S_1 + I_1 + I_2 - O_1 = O_2 + S_2$

TIME DAYS	I_1 FOR 1% FLOOD:	I_1+I_2	O_1	S_1	$S_2 + O_2$	O_2
1	400	1,900	2,750	0	100,000	2,750
2	1,500	7,500	2,500	97,250	102,000	2,800
3	6,000	10,200	2,800	99,200	106,600	2,800
4	4,200	7,200	2,800	103,800	108,200	2,850
5	3,000	5,200	2,850	105,350	107,700	2,850
6	2,200	6,200	2,850	104,850	108,200	2,850
7	4,000	11,000	2,850	105,350	113,500	2,850
8	7,000	19,000	2,850	110,650	126,800	2,900
9	12,000	23,400	2,900	123,900	144,400	2,950
10	11,400	22,400	2,950	141,450	160,900	4,200
11	11,000	21,300	4,200	156,700	173,800	7,400*
12	10,300	20,300	7,400	166,400	169,300	6,200
13	10,000	19,400	6,200	163,100	166,900	5,600
14	9,400					

* Maximum Outflow

The results and recommendations of the investigations have been adopted herein in the design of the various components.

b. Embankments

The embankment design submitted by the Soil Mechanics and Materials Division of the PFRA has a 30-foot top width and 3:1 side slopes on the upper section and slopes of 7:1 and 25:1 on the lower section depending on whether the east or west banks of the river are involved. A 3-foot thick filter on a 1:1 slope is placed on the downstream side of the core and a 3-foot thick horizontal filter connects it to the downstream toe of the dam. It is recommended that 2 feet of 15-inch riprap over 1.5 feet of coarse gravel be placed on the upstream 3:1 slope to resist wave action. These details are depicted on Figures B-9 and B-10.

The results of storage-yield calculations place the full supply level at elevation 1241. The maximum water level was found by routing the 0.1% design hydrograph through the reservoir. Results show an increase of 11 feet above the full supply level. To obtain the height of dam an allowance for freeboard must be considered.

The freeboard of a dam may be defined[22] as the difference in elevation between the top of the dam and the maximum reservoir level that would be obtained during the passing of the spillway design flood through the reservoir. The first problem in determining the freeboard of a dam is to establish the criteria. This is mostly a matter of selecting the wind velocity that may prevail during the passing of the spillway design flood.

A wind velocity of 50 miles per hour for a duration of one hour and a fetch of 17 miles has been adopted. These values were also adopted to design the riprap. With the wind velocity decided upon, the consequent wind set up, wave height and uprush are computed.

1. Wind Set-Up - The following equation was used to compute wind set-up:

$$S = \frac{V^2 \cdot F}{C \cdot D}$$

where: S = wind set-up in feet above still water

C = coefficient. A value of 1400 has been used[22].

V = wind velocity in mph

F = effective fetch in miles

D = average depth in feet.

With an effective fetch of 10 miles and an average depth of 50 feet the wind set-up S is 0.4 feet.

2. Wave Height and Uprush - The wave height and wave uprush were computed by the method found in Kuiper's

"Water Resources Development." The calculations will not be reproduced herein. An all inclusive value of 5.6 feet was determined.

The total freeboard requirement is found by adding to the wind set-up and wave height an allowance of 2 feet for settlement and 1 foot for frost action on the embankment. This yields a total of 9 feet for freeboard requirement.

The results of these calculations place the top of the dam at elevation 1,261.0.

c. Spillway

The spillway was designed as an uncontrolled concrete chute, 208 feet wide with a 5:1 slope on the chute section. A bridge, 24 feet wide, across the spillway is supported on 4 concrete piers each 2 feet thick giving an effective spillway opening of 200 feet. The opening width was compared with the PFRA criterion of width equal to $1.1\ Q^{1/2}$ which gives 192 feet for the spillway design discharge of 30,000 cfs. The spillway rating curve shown in Figure B-11 was computed assuming an ogee weir. The equation is:

$$Q = 3.9\ LH^{3/2}$$

where Q = design discharge in cfs

L = length of weir in feet

H = head on weir in feet

Flood routing to pass the spillway design flood as shown on Figure B-12, give the maximum head on the weir to be 11 feet.

A normal backwater calculation, using Bernoulli's theorem was made to compute the water surface down the chute and the hydraulic jump height, in order to set the stilling basin floor elevation and height of walls. The roughness coefficient of the concrete surface used is 0.012 giving a stilling basin floor elevation of 1154. A type III[23] stilling basin is provided to dissipate the energy from the hydraulic jump. Details are shown on Figure B-13.

d. Riparian Works

The size and number of conduits required was controlled by the downstream bankfull stage of approximately 2500 cfs. To pass at least this flow with the reservoir at F.S.L. requires two 7-foot diameter Boston Horsehoe concrete conduits which have a capacity of 3000 cfs. Each conduit length is 850 feet and is placed at a slope of 0.015. These pipes are each divided into 2 at the gatewell and each smaller pipe is fitted with 2 gates, one gate being available for emergency use in each case. The discharge through each conduit when flowing full is found from the following formula[24]:

$$H = \frac{2.52\ (1 + k)}{D^4} + \frac{466.18\ n^2\ L}{D^{16/3}} \quad \left(\frac{Q}{10}\right)^2$$

where H = hydraulic head in feet

D = effective diameter of pipe in feet

n = Manning's roughness coefficient

Q = discharge in cfs

L = length of pipe in feet

k = entrance coefficient

With an entrance coefficient of 0.2 and a Manning's "n" of 0.012 the formula can be simplified to:

$$Q = 175\ H^{\frac{1}{2}}$$

The computed rating curve is found on Figure B-14. A type III[23] basin with no basin blocks was chosen as the outlet structure. The structure length was computed at 133 feet and is detailed on Figure B-15.

Damages

The areas and present uses of the land in the reservoir were taken from 1 inch = 1 mile map showing 25 feet contour intervals.

Land up to elevation 1252, at the spillway design flood level is to be bought and cleared. The total acreage involved is 6500 acres including 4000 acres of bush and 2500 acres of cultivation and pasture. The purchase price of the land is $300 per acre for cultivation and pasture and $150 per acre for bush, while $300 an acre was allowed for clearing the bush, which is quite heavy in places.

Some farm buildings must be relocated, therefore allowance was made in the land costs to cover this.

Two bridges will be flooded out by the reservoir. Since the estimated costs to replace them is felt to be far greater than the benefits that would be realized, these crossings should be abandoned.

Several power and telephone lines require relocation from the valley bottom. The cost of moving these services is estimated at $60,000 for telephone and $20,000 for power lines. These estimates were prepared by the agencies involved.

DETAILED COST ESTIMATE

	Unit	Unit Cost	Quantity	Cost
Land Costs:				
Purchase				
Cultivated	acre	$300.00	2,500	$ 750,000
bush, hay	acre	150.00	4,000	600,000
				1,350,000
Acquisition and Contingencies			20%	270,000
				1,620,000
Direct Items				
Reservoir Clearing :	acre	300.00	4,000	1,200,000
River Diversion:	lump sum			40,000
Embankment:				
Core trench excavation	cu.yd.	1.25	110,000	137,500
Compacted embankment	cu. yd.	0.30	2,300,000	690,000
Borrow excavation (+ 20%)	cu. yd.	0.70	2,875,000	2,012,500
Stripping	cu. yd.	0.60	250,000	150,000
Gravel bedding	cu. yd.	4.00	26,000	104,000
Rock riprap	cu. yd.	12.00	35,000	420,000
Select pervious	cu. yd.	4.00	150,000	600,000
Topsoil	cu. yd.	2.00	4,000	8,000
Seeding	acre	100.00	7	700

DETAILED COST ESTIMATE

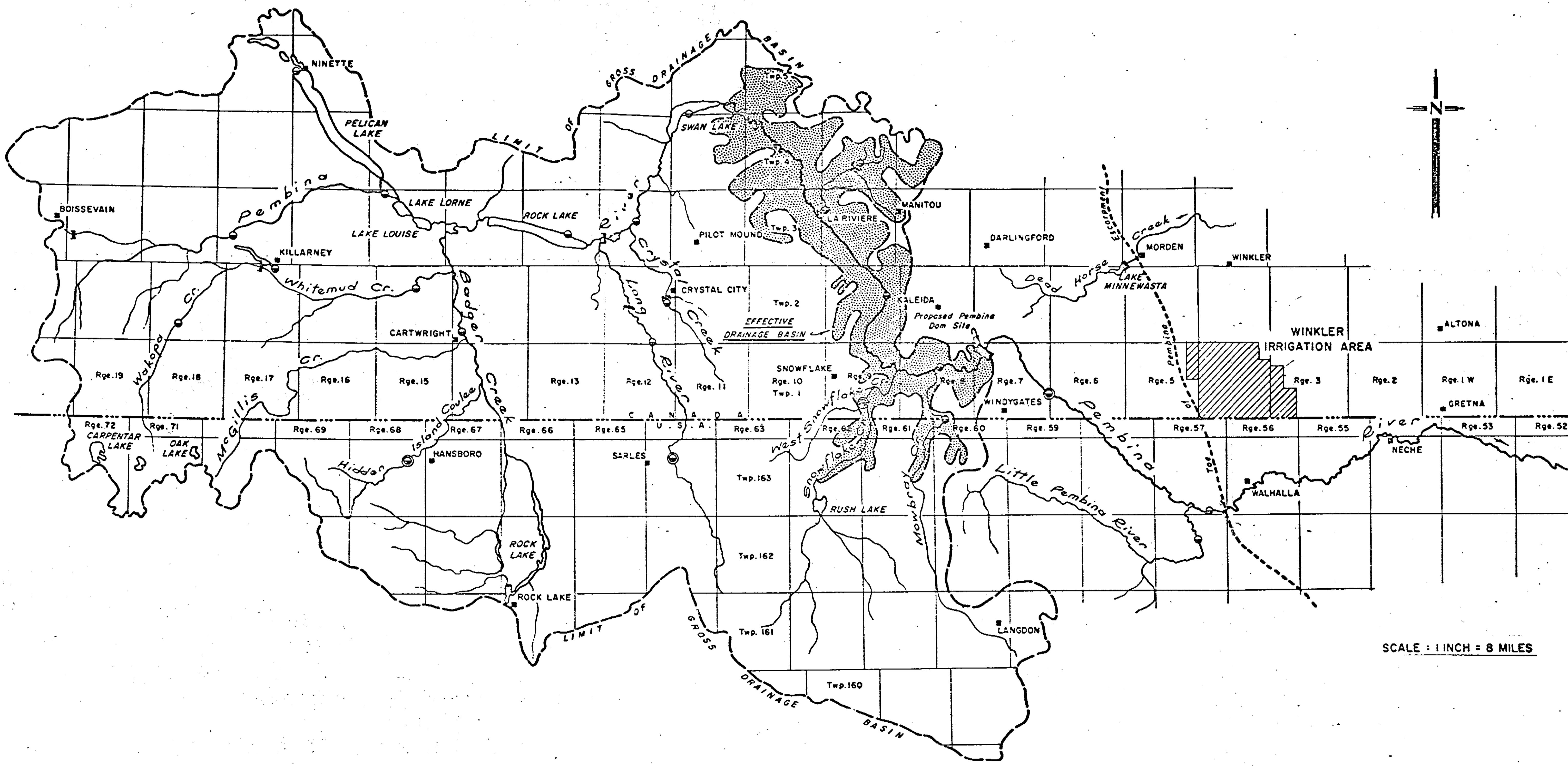
	Unit	Unit Cost	Quantity	Cost
Spillway:				
Excavation	cu. yd.	$ 0.70	$570,000	$ 399,000
Reinforced concrete	cu. yd.	125.00	10,500	1,312,500
Gravel back-fill	cu. yd.	4.00	13,800	55,200
Gravel blanket	cu. yd.	4.00	1,100	4,400
Rock riprap	cu. yd.	12.00	1,700	20,400
Tamped back-fill	cu. yd.	10.00	900	9,000
Trench ex-cavation	cu. yd.	10.00	960	9,600
Bridge con-crete	cu. yd.	200.00	100	20,000
Bridge steel	lbs.	0.50	42,000	21,000
Riparian Works:				
Excavation	cu. yd.	1.00	21,000	21,000
Reinforced concrete	cu. yd.	150.00	5,600	840,000
Gravel back-fill	cu. yd.	4.00	2,200	8,800
Gravel blanket	cu. yd.	4.00	320	1,300
Rock riprap	cu. yd.	12.00	460	5,500
Tamped backfill	cu. yd.	10.00	4,700	47,000
Trench ex-cavation	cu. yd.	10.00	100	1,000
Gates & hoists	unit	50,000.00	8	400,000
Vent pipe, 10-inch	feet	12.00	360	4,300
Waterstop	feet	5.00	700	3,500

DETAILED COST ESTIMATE

	Unit	Unit Cost	Quantity	Cost
Land Damages:				
Relocation Hydropower lines		lump sum		$ 20,000
Telephone lines		lump sum		60,000
				$10,246,200
Indirect Items:				
Contingencies: 20% of direct items				$ 1,753,800
				$12,000,000
Engineering: 10% of direct items				800,000
Interest during construction: 8% for 3 years				2,200,000
CAPITAL COST:				$15,000,000

Annual Charges

Interest: 8% x $15,000,000	1,200,000
Depreciation: 50 year life	20,000
Operation & Maintenance: 0.1% of capital cost	15,000
ANNUAL COST:	$ 1,235,000



LEGEND

- STREAM GAUGING STATIONS
- INTERNATIONAL STREAM GAUGING STATIONS
- EXISTING DAMS

FIG. B

PEMBINA RIVE

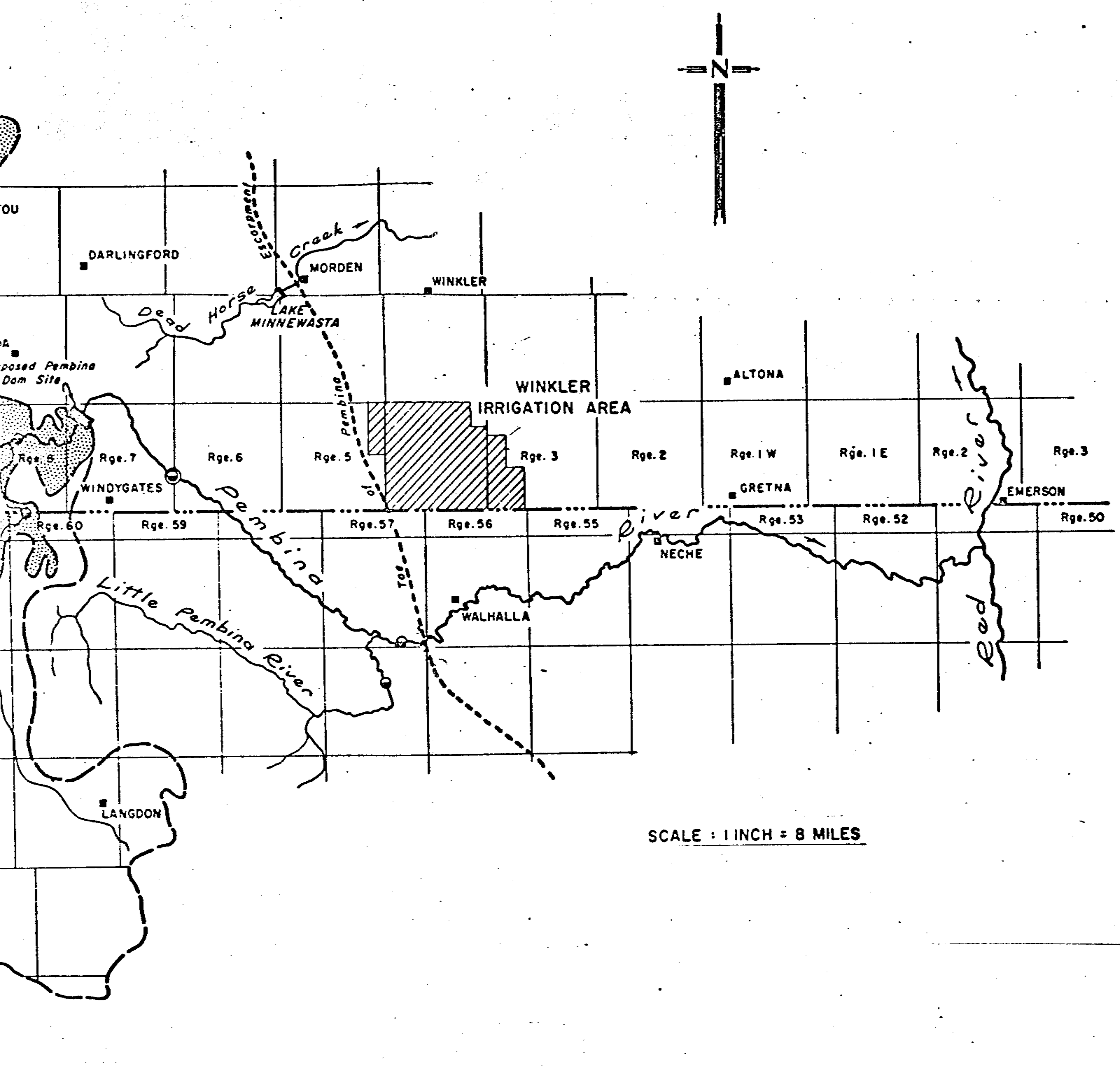


FIG. B-1

PEMBINA RIVER BASIN

OCT. 1974

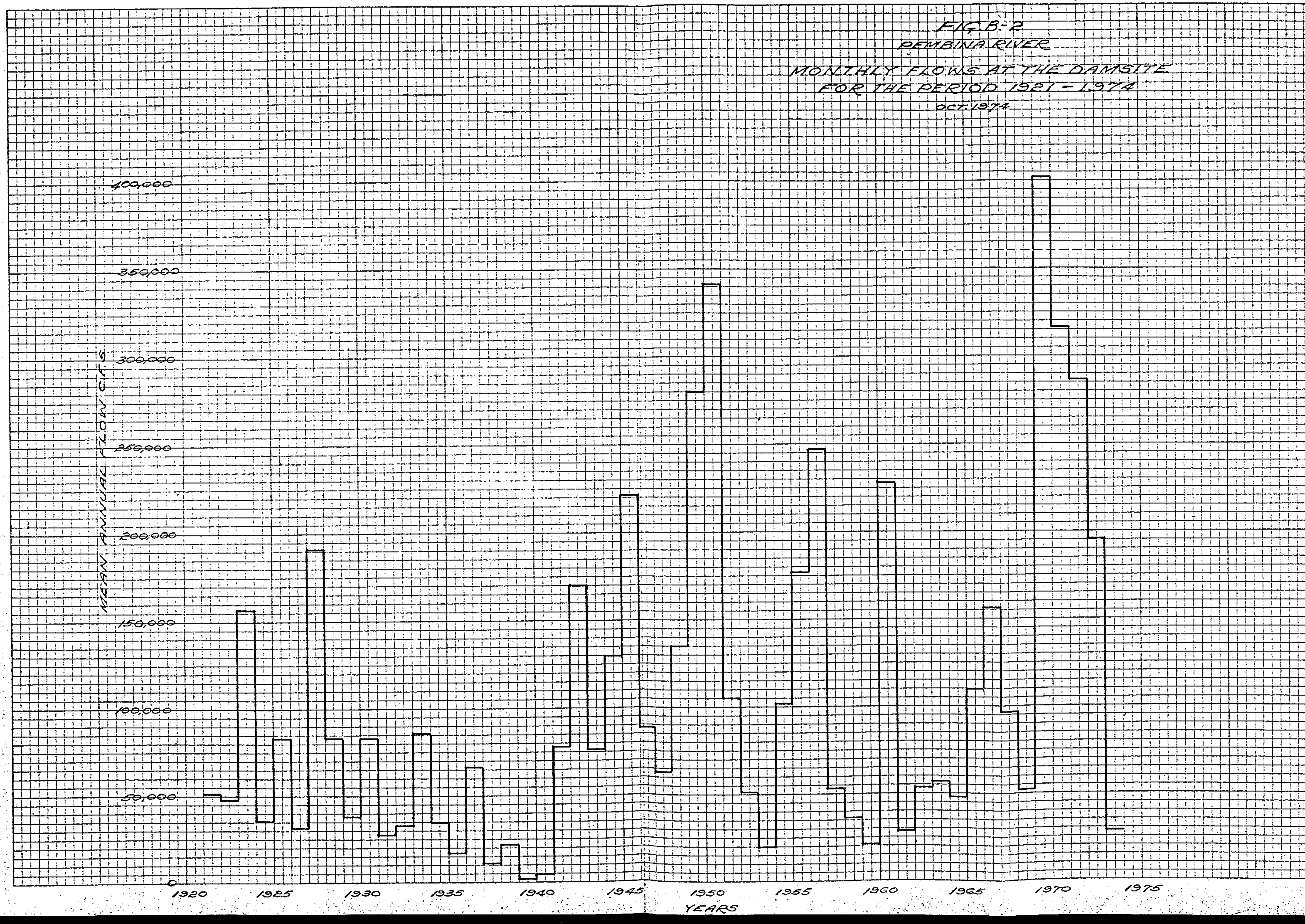


FIG. B-2
PEMBINA RIVER
MONTHLY FLOWS AT THE DAMSITE
FOR THE PERIOD 1921 - 1974
OCT. 1974

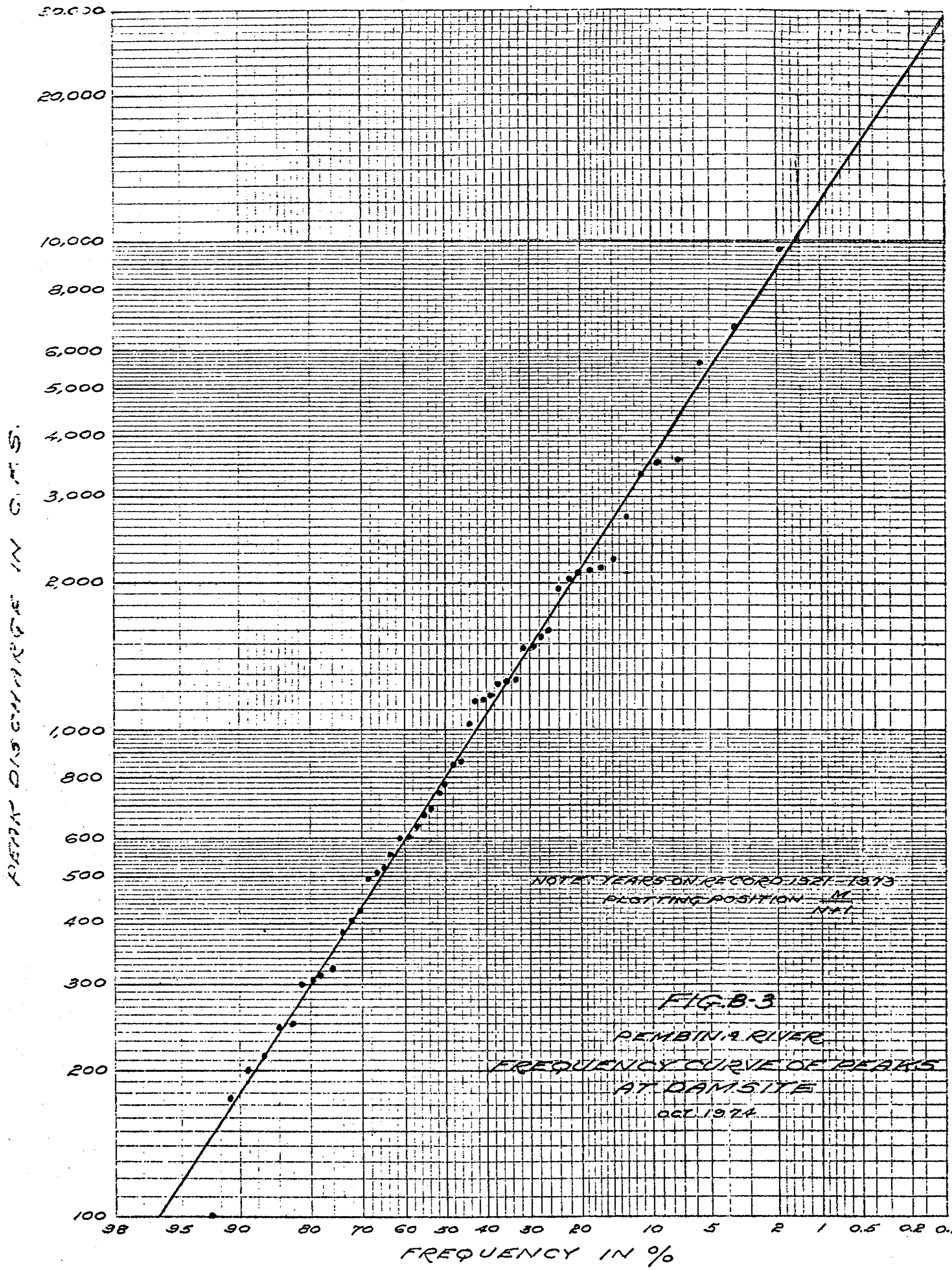


FIG. B-3

PEMBINA RIVER
FREQUENCY CURVE OF PEAKS
AT DAMSITE
OCT. 1974

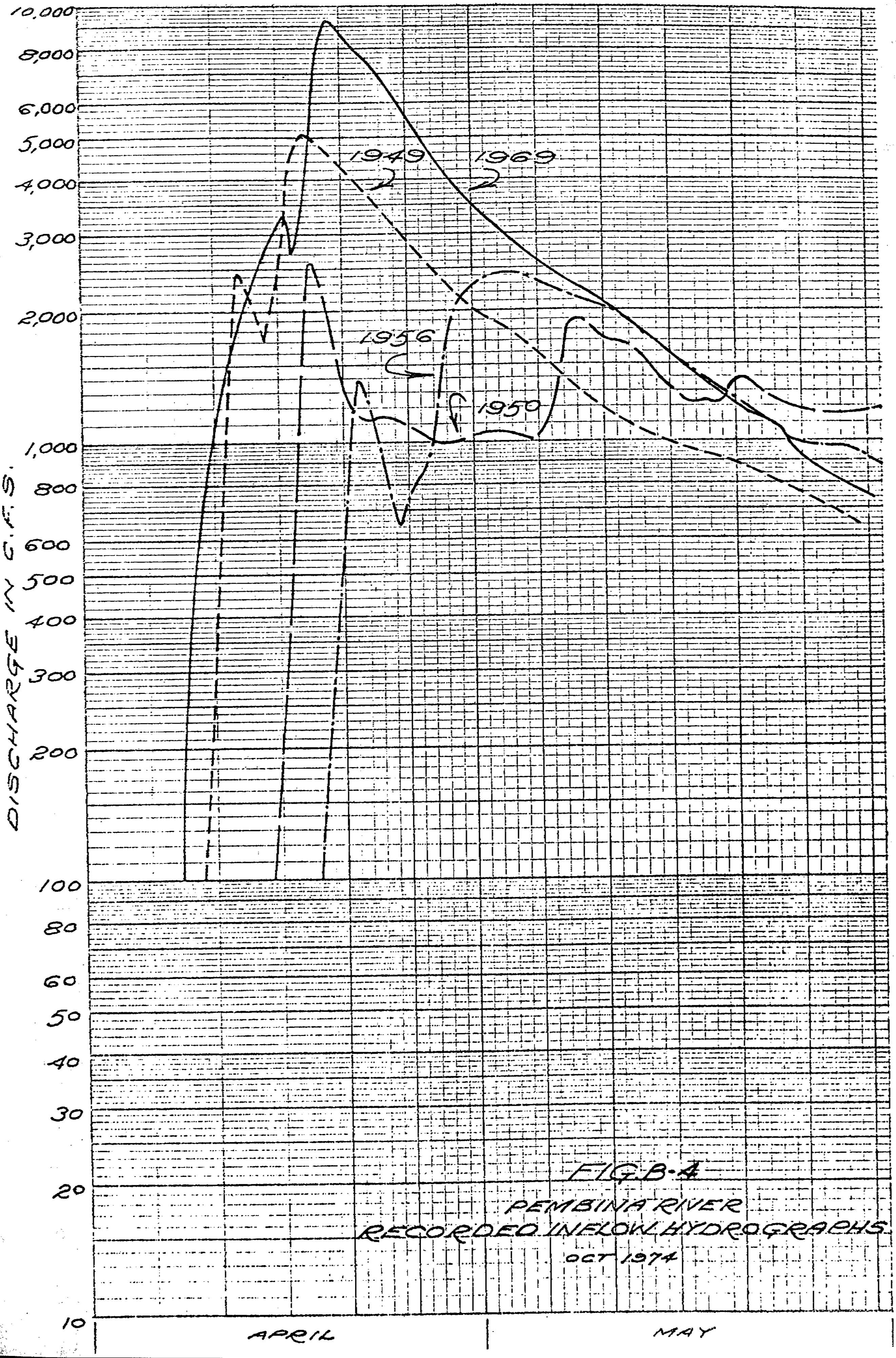


FIG.B-4
PEMBINA RIVER
RECORDED INFLOW HYDROGRAPHS
OCT 1974

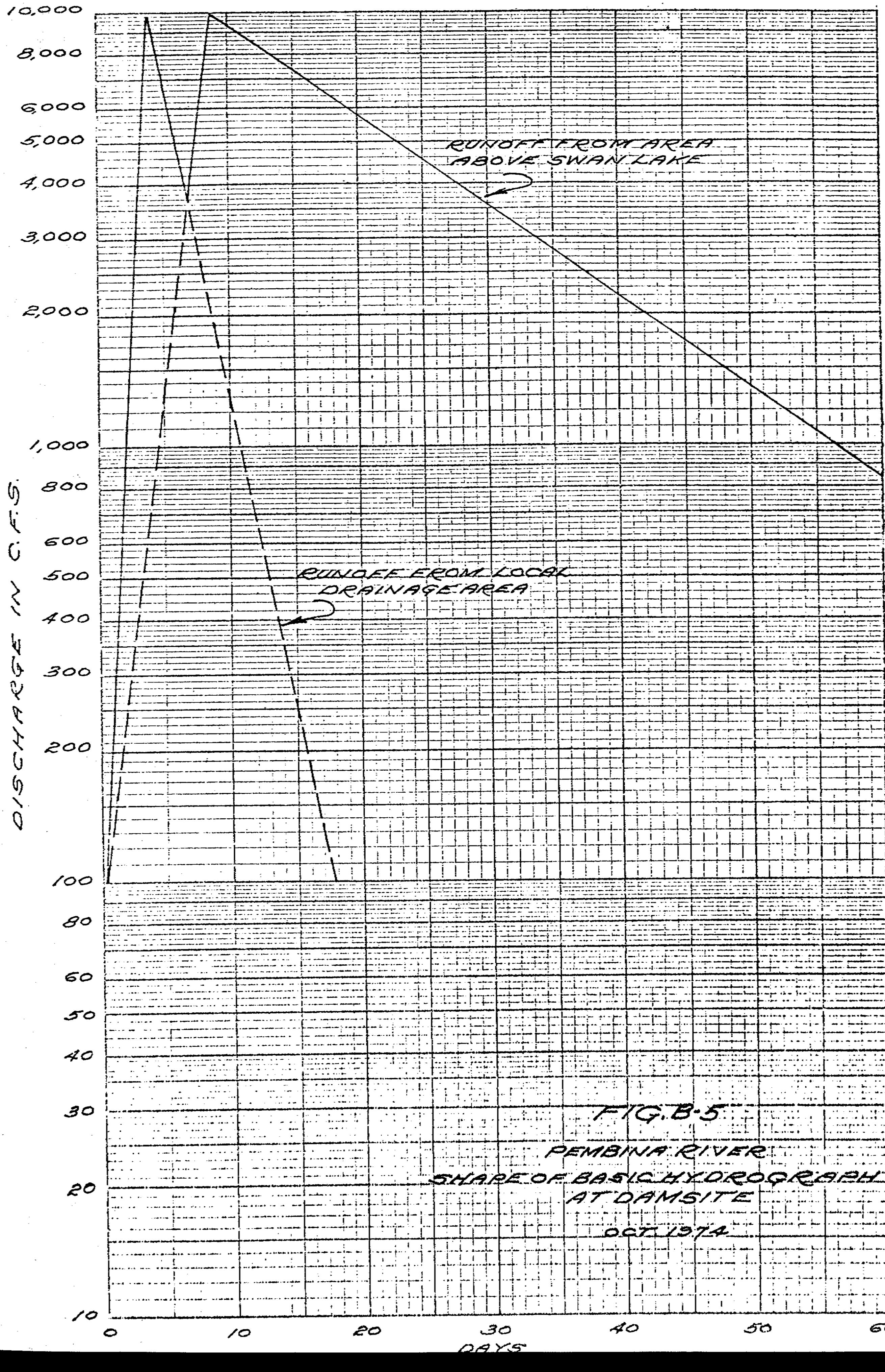
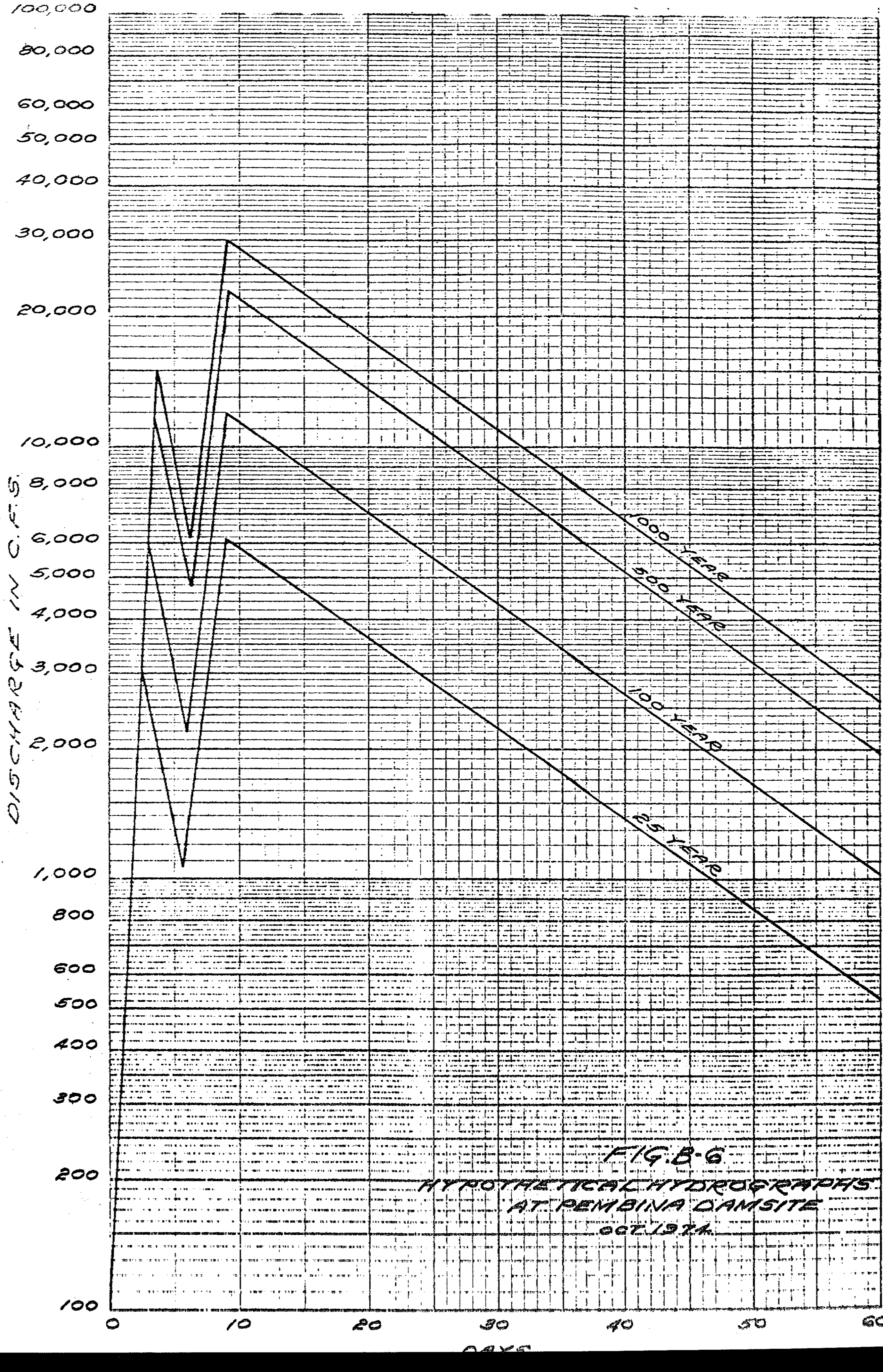


FIG. B-5

PEMBINA RIVER

SHAPE OF BASIC HYDROGRAPH AT DAMSITE

OCT. 1974


100,000
80,000
60,000
50,000
40,000
30,000
20,000
10,000
8,000
6,000
5,000
4,000
3,000
2,000
1,000
800
600
500
400
300
200
100
DISCHARGE IN C.F.S.
0
10
20
30
40
50
60
DAYS
1000 YEAR
500 YEAR
100 YEAR
25 YEAR
FIG. B-6
HYPOTHETICAL HYDROGRAPHS
AT PEMBINA DAMSITE
OCT. 1974

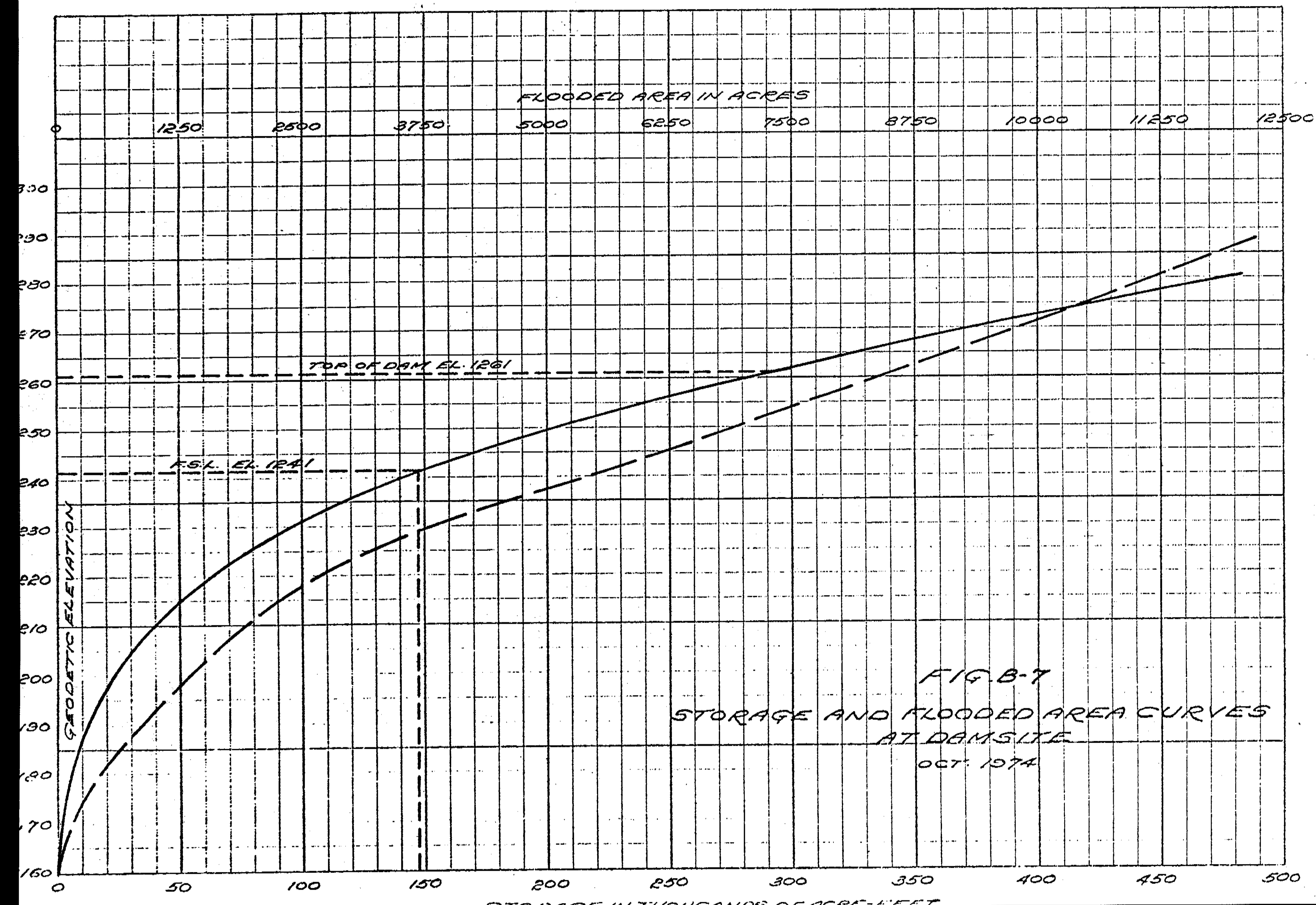


FIG. B-7
STORAGE AND FLOODED AREA CURVES
AT DAMSITE
OCT. 1974

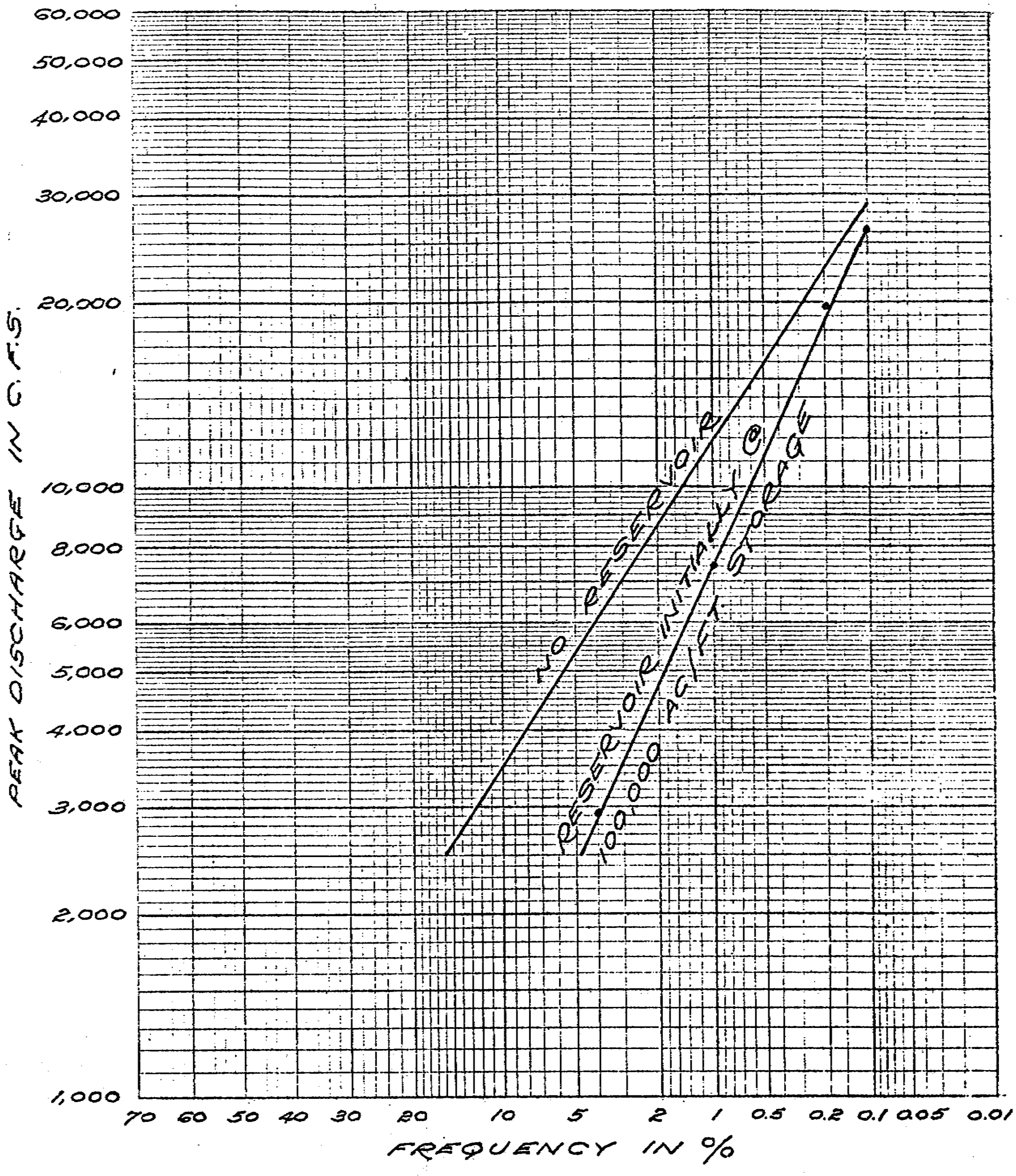


FIG. B-8
PEMBINA DAM
NATURAL AND MODIFIED
FREQUENCY CURVES OF
PEAK DISCHARGE
OCT. 1974

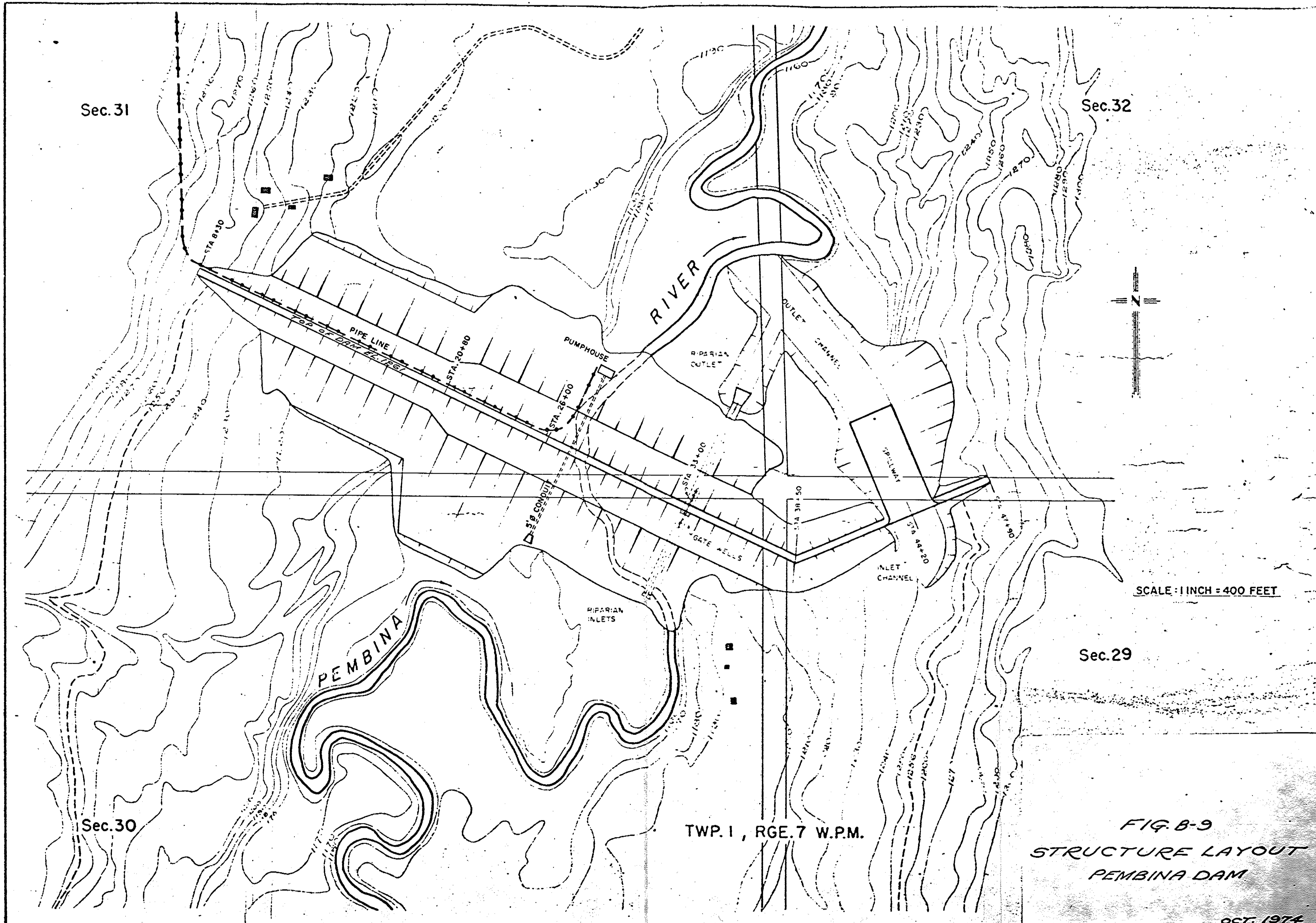
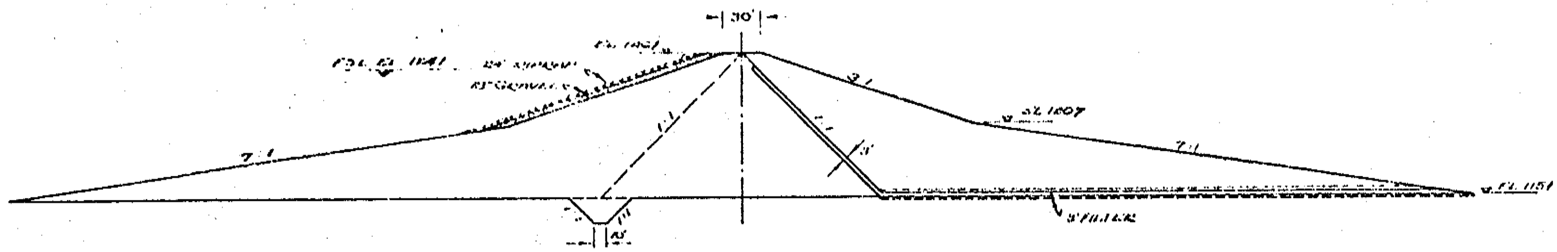
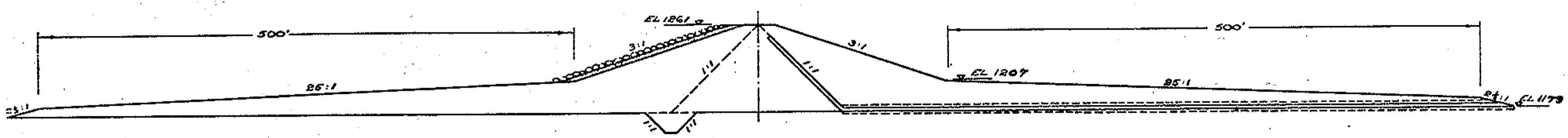


FIG. B-9
STRUCTURE LAYOUT
PEMBINA DAM

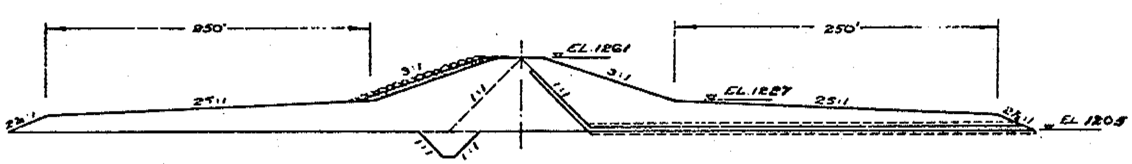
OCT. 1974



STATION 26+00 TO 47+90



STATION 20+80 TO 26+00



STATION 8+30 TO 20+80

FIG. B-10

TYPICAL X-SECTIONS OF DAM

OCT. 1974

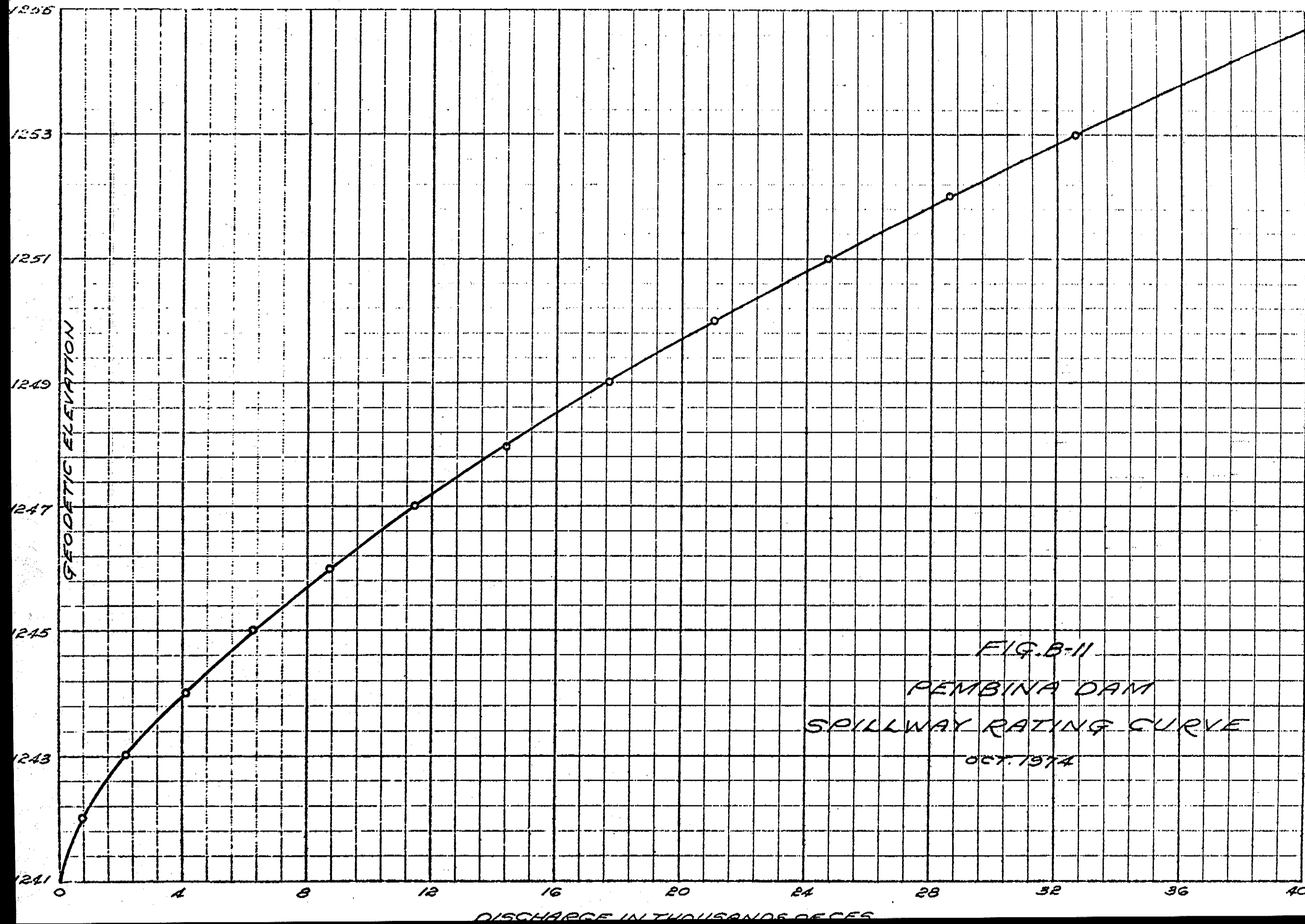


FIG. B-11
PEMBINA DAM
SPILLWAY RATING CURVE
OCT. 1974

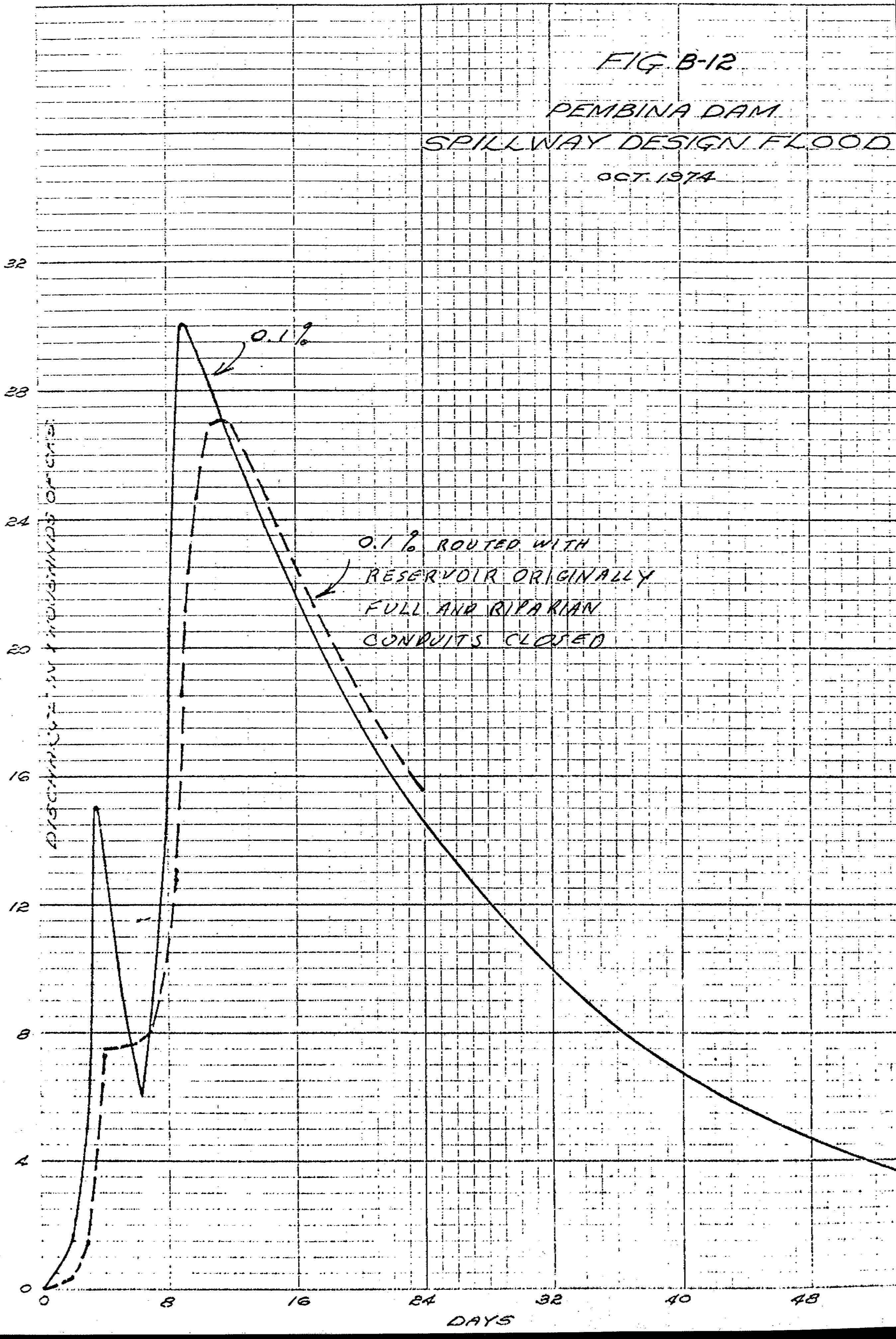


FIG. B-12
PEMBINA DAM
SPILLWAY DESIGN FLOOD
OCT. 1974

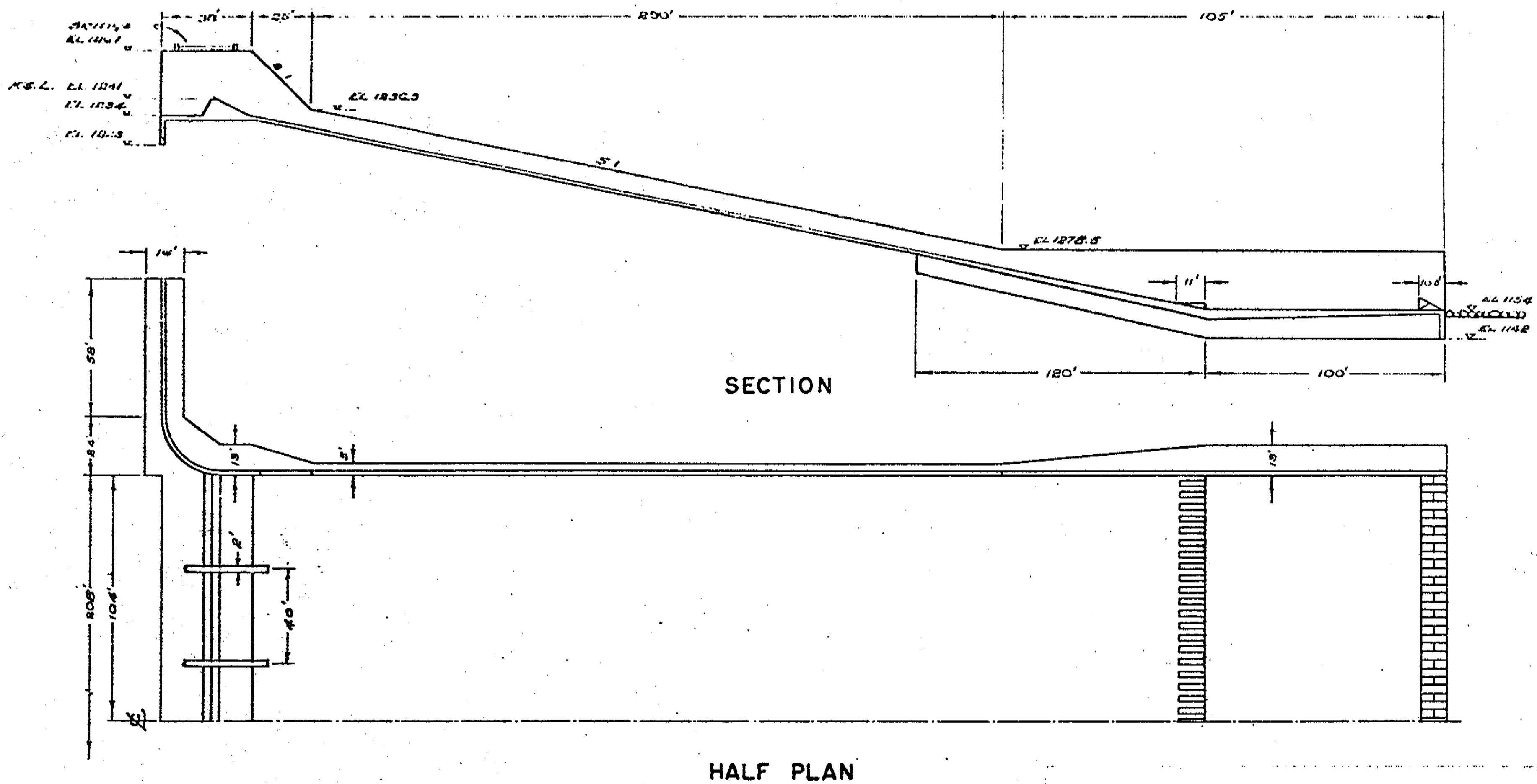


FIG. B-13

GENERAL PLAN OF SPILLWAY

OCT. 1974

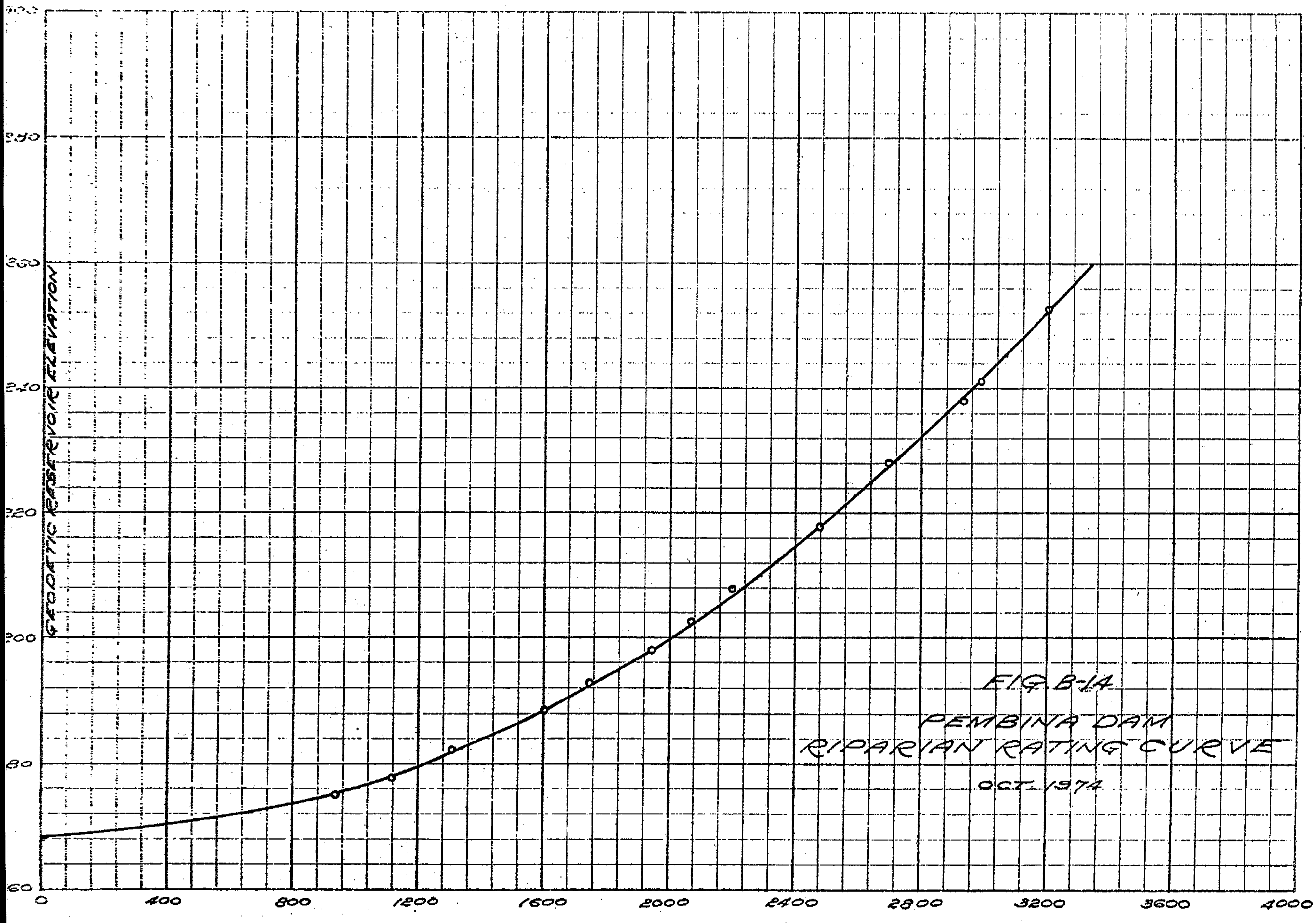
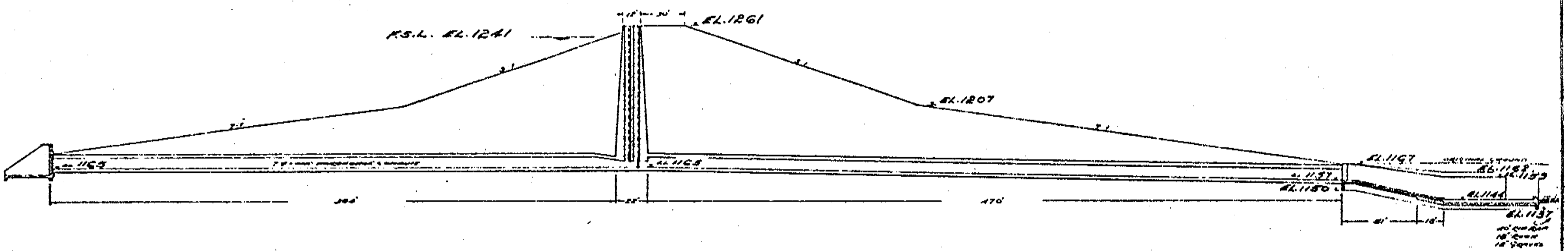
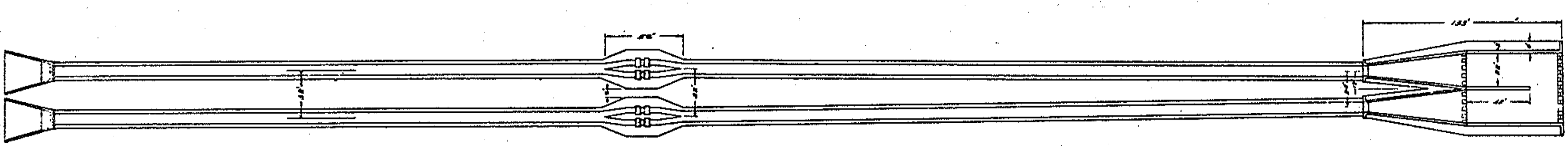


FIG. B-1A
PEMBINA DAM
RIPARIAN RATING CURVE
OCT. 1974



SECTION



PLAN

FIG. B-15

RIPARIAN

CENTRE LINE SECTION

OCT. 1974

APPENDIX C

DESIGN AND ESTIMATES OF CONVEYANCE SYSTEM

INDEX: PAGE:

DESIGN AND ESTIMATES OF CONVEYANCE SYSTEM

General

In this section preliminary designs and cost estimates are presented of the overland conveyance system from the Pembina Dam to the Morden-Winkler Irrigation District. Delivery of the water will involve a pumping set-up whereby the water is lifted over the height of land at the dam site to the Dead Pig Creek Canal. From this point it will flow by gravity to the Dead Horse Creek and into the existing Morden Reservoir. A gravity canal will then carry it to a system of laterals which will distribute it to the individual farm fields. (See Figure 2 in the main report).

Design of Pressure Conduit

The design of the pressure conduit along with the rest of the conveyance system will be based on the maximum monthly irrigation diversion requirement. Assuming that past climatic trends are an accurate reflection of future conditions, the maximum monthly irrigation diversion requirement would have occurred on July 1936 and it would have amounted to 0.96 feet over 11,975 acres. This value will be used in design and will entail the diversion of 11,500 acre-feet of water per month or 185 cfs/day. Daily or weekly fluctuations to this demand will be taken care by the pondage available in the Morden Reservoir.

A 60-inch high pressure concrete pipe will be used to convey the water from the pumping station to the Dead Pig Creek. The length of pipe needed from El. 1185 (intake elevation) to El. 1565 (discharge elevation) is 19,000 feet. The pipe will be laid in a shallow trench with the top half of the pipe exposed. Thrust blocks will be placed at changes in pipe alignment. See cross-section in Figure C-1.

The toal friction loss in the pipe can be computed from the following equation[25]:

$$h_f = \frac{185\ n^2}{D^{1/3}} \ \frac{L}{D} \ \frac{V^2}{2g}$$

where h_f = total friction loss in feet

n = Manning's roughness coefficient

D = pipe diameter in feet

L = length of pipe in feet

V = water velocity in feet/second

g = acceleration due to gravity infeet/second^2

Assuming that the average velocity in the pipe will be 9 feet per second, the friction loss from the above formula is 74 feet. The total dynamic head on the pumps will then be 454 feet.

Pumping Units and Pumping Station

The total horsepower required to pump 185 cfs over a 454 foot head can be found from the following formula[22]:

$$P = \frac{QH}{8.8e}$$

where P = power in horsepower

Q = discharge in cfs

H = head in feet

e = efficiency

Assuming a motor efficiency of 0.8 the total horsepower required is 12,000.

Local distributors are able to supply pumping units with motor rating of 2,500 hp. Each unit will be able to pump 14,000 gpm yielding the required capacity. No standby pump will be necessary in the system.

The pumping units will be installed in a pumphouse located near the toe of the downstream face of the dam as shown on Figure B-9. A 60-inch concrete conduit, 800 feet long will supply water from the reservoir to the pumping well. Two 60-inch Butterfly Valves will be installed in series near the pumping well east of the conduit. Both will be used only during maintenance operations or in times of emergency. Five other Butterfly Valves will be needed, one for each pumping unit, to allow for separate shut down. A travelling cane will be provided in the pumphouse for installation and maintenance of the pumping equipment.

Costing procedures for the pumping station involves the preparation of estimates for the individual pieces of equipment which are required. Equipment prices including installation were obtained from local distributors, the main items being pumps and motors, valves, and a travelling crane. The substructure and superstructure costs of the pumphouse was assessed at 20% of the total equipment cost.*

Power Requirements and Costs

Pumping from the Pembina Reservoir is required for the months of April to October inclusive to meet the irrigation and the Municipal and Industrial (M & I) water supply requirements. The table below outlines the distribution and the quantities of water to be pumped and the number of hours of continuous pump operation.

TABLE C-1

Month	I.D.R.** (feet/acre)	I.D.R. (acre-feet)	M&I*** D.R. (acre-feet)	Total D.R. (acre-feet)	Time Equivalent To Continuous Operation At Design Capacity: Days	Hours
April	-	-	1,530	1,530	4.15	100
May	-	-	990	990	2.70	65
June	0.37	4,430	-	4,430	12.00	288
July	0.56	6,710	-	6,710	18.20	436
Aug.	0.50	6,000	-	6,000	16.20	389
Sept.	0.28	3,360	1,900	5,260	14.20	340
Oct.	-		990	990	2.70	65

* Rule of thumb used by pump manufacturers

** Average Irrigation Diversion Requirements

*** Municipal & Industrial Diversion Requirements

During the remaining months of the year, there will be no pumping and the entire installation will be idle. In estimating the energy demand, the motors operation is assumed at 80% Power Factor (to be corrected to as near unity as possible). No allowance has been made for standby pumps.

The table below will outline the energy use by month. The KWA demand column was computed from the power formula:

$$P_{KW} = \frac{QH}{11.8e}$$

TABLE C-2

Estimated Demand and Energy Use by Month

(1) Month	(2) Hours of Continuous Motor Operation	(3) KWA Demand	(4) (2) X (3) KWH Consumption
April	100	8,900	890,000
May	65	8,900	577,000
June	288	8,900	2,560,000
July	436	8,900	3,880,000
Aug.	389	8,900	3,460,000
Sept.	340	8,900	3,020,000
Oct.	65	8,900	577,000

The cost of electric power was obtained from the Manitoba Hydro. The table below gives the average rate schedule for the type of service required.

TABLE C-3

Demand Charge	Average Rate
First 500 KVA	$1.50/KVA
Next 9,500 KVA	1.50/KVA
Energy Charge	
First 100 hours	1.02¢/KWH
Next 200 hours	0.61¢/KWH
Next 200 hours	0.50¢/KWH
Balance of Energy	0.45¢/KWH

Manitoba Hydro gives no discount for wholesale or prompt payment.

It may be noted from the above rate schedule that regardless whether the pumps are being used or not the demand charge on the 8,900 KWA installation has to be paid. Also the minimum payment for any month is the basic demand charge.

The table below lists the computed monthly hydro payments:

TABLE C-4

Basic Demand Charge:	$ 10,410.00
Energy Charge:	
April	10,410.00
May	10,410.00
June	19,265.00
July	25,986.00
August	23,886.00
September	21,686.00
October	10,410.00
November-March inclusive: 5 X Demand Charge	52,050.00
Average Annual Pumping Costs:	$184,513.00

Design of Dead Pig Canal

The Dead Pig Canal has been designed to carry the irrigation flow from the height of land above the dam, a distance of approximately 11,000 feet into the existing Dead Pig channel. The method of permissible velocity as outlined by Ven Te Chow[26] has been employed in the design of the canal. The material to be excavated is a stiff clay interspersed with glacial till. It is fairly compact and contains many boulders. For this type of material the permissible velocity is given as 4 feet per second[26] and Manning's "n" as 0.025. With the design parameters as given the channel properties have been computed and are as follows:

bottom slope:	0.001
side slopes:	3:1
bottom width:	15 feet
depth of flow:	2.5 feet

A freeboard allowance of 1.5 feet will be used in the determination of earthwork quantities.

Along its route the canal will drop 55 feet. This will be accomplished utilizing 9, 5-foot concrete drop structures.

The canal will be constructed on 100 foot right-of-way. A 14-foot road dike on the southeastern side of the canal will accommodate inspection and maintenance vehicles.

Furthermore, 3 timber bridges will be required so as not to disrupt the road system of the area. These for reasons of economy will be combined with the canal drop structures.

Dead Horse Creek Channel

The flow from the proposed canal will enter the Dead Pig Creek at elevation 1,500 and will travel a distance of 2 miles where it will enter the Dead Horse Creek which will take the flow into the existing Morden Reservoir.

The bankfull capacity of both natural creek channels and road crossings in this reach is more than adequate to pass the design flow of 185 cfs. No diking or dredging is required, however, a certain amount of cleaning and local channel repair will be necessary in order to ensure efficient flow.

A trip to the area by the author on July 15, 1974 noted that both natural channel bottoms are heavily paved with boulders and the sides are composed of very stiff clay. No recent evidence of bank erosion was noted even though the natural channel slope is approximately 0.005. This visual examination coupled with other available information* enabled the author to conclude that the existing channel is very stable

* This conclusion is supported by recent (1971) PFRA findings that no detectable sedimentation has taken place in the Morden Reservoir since it was constructed 20 years ago. This is in spite of the very high and sporadic flows in the creek recorded during the same period.

and will carry the design flow without the necessity of having expensive drop structures in the reach. No long-term disconfiguration of the channel cross section is expected.

Morden Reservoir Irrigation Spillway

The Morden Reservoir on Lake Minnewashta as it is better known is a 2,100 acre-foot[27] man-made lake required primarily to supply the Town of Morden with its water needs.

The proposed irrigation flows from the Pembina Dam will accumulate in this reservoir and will be diverted into the main canal by a spillway located on the northeast corner of the dam. The spillway will be on natural ground and will have a crest elevation of 1,069 or 6 feet below the reservoir F.S.L. of 1,075. The crest will be controlled by a single radial gate at the inlet.

Design of Main Supply Canal

The main supply canal will consist of a straightened section of the Dead Horse Creek below the Morden Dam, and an overland flow section to convey the water from the creek to the project area where it will be distributed into the four main laterals. Figure 2 shows the location of the canal. Total length of canal is 15.2 miles. The method of Simons and Albertson[28] has been employed in the design of the canal cross-section. Final design was also checked by the method of Blench[29]. The following are the final canal properties:

bottom slope: 0.0002

side slope: 3:1

bottom width: 20 feet

depth of flow: 4.0 feet

A freeboard allowance of 2 feet will be used in the determination of earthwork quantities. No lining is necessary because of the clay-like soils through which the canal will pass. Velocities in the canal will be kept at about 2 feet/second. Over its length the canal will drop approximately 55 feet. This will be accomplished by 8, 5-foot vertical drop structures. In addition to these, 8 inverted siphons will be required to pass the irrigation flow beneath existing escarpement creeks. The canal will be constructed on a 150-foot right-of-way. An 8-foot wide drainage ditch will be excavated along the high side of the canal to intercept local runoff. This ditch will pass the flows into local drainage channels. which in turn will pass it under the canal at the creek crossings. The dike on the low side of the canal will be widened to 14-feet to serve as a road for inspection and maintenance vehicles. A total of 11 timber bridges will be erected to provide the necessary road crossings in the 15 mile reach. Inspection of aerial photographs of the area shows clearly that the main canal intersects both the Morden Town water pipeline at the interprovincial gas pipeline. The Town water pipe will be dug up and replaced by a siphon at both crossings. The gas pipeline will not be moved, instead the canal will be aligned to cross over it at one of the creek crossings.

DETAILED COST ESTIMATES

Pumping Works

Intake:				
Conduit (60" Ø concrete) - 800 feet	@ $	65.00	=	$ 52,000
Earthwork (tamped back-fill) - 1,600 cu. yd.	@	4.00	=	6,400
Inlet structure (concrete) - one lump sum			=	1,500
Pumping Station:				
Pumps and motors - 5 units	@	115,000.00	=	575,000
Electrical switch-gear-10% of pumps and motors cost			=	57,500
Pumphouse-20% of pumps and motors cost			=	115,000
Travelling crane - one lump sum				25,000
Valves (60" Ø butterfly) 2	@	12,000.00	=	24,000
(36" Ø butterfly) 5	@	6,000.00	=	30,000
Discharge:				
Conduit (60" Ø concrete) 19,000 feet	@	65.00	=	1,235,000
Placing pipe (partially trenched)-19,000 feet	@	4.00	=	76,000
Right-of-way-10 acres	@	150.00	=	1,500

Dead Pig Canal

Right-of-way - 25 acres	@	300.00	=	7,500
Earthwork:				
Excavation and compacted embankment - 62,600 cu. yds.	@	.60	=	37,560
Structures:				
Drop Structures (concrete)-9	@	10,000	=	90,000

DETAILED COST ESTIMATE

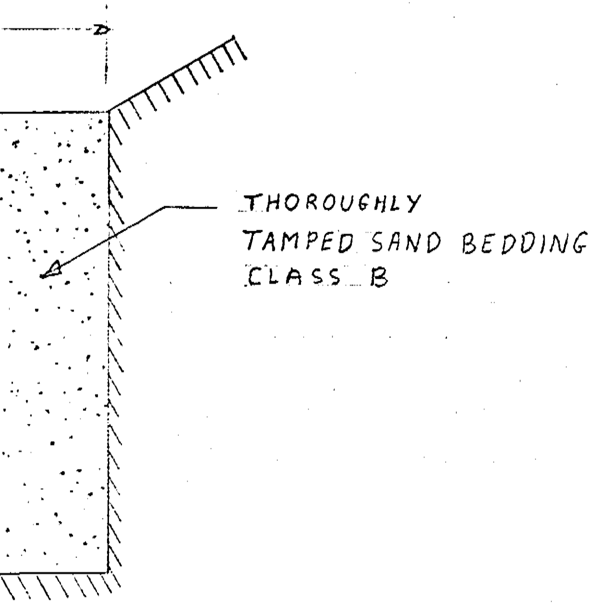
Dead Pig and Dead Horse Creeks			
Improving channels - 13 miles	@ $5,000.00	=	$ 65,000
Morden Reservoir Irrigation Spillway			
Structure - lump sum			100,000
Cofferdam - lump sum			25,000
Main Supply Canal			
Right-of-way - 275 acres	@ 300.00	=	82,500
Earthwork: Excavation and Compacted embankment- (800,000 cu. yd.)	@ .60	=	480,000
Structures:			
Drop structures (concrete)	8@ 15,000.00	=	120,000
Inverted siphons (concrete)	8@ 14,000.00	=	112,000
Bridges (timber)	11@ 21.00/ sq. ft. of surface	=	275,000
Turnouts (gated pipe) (2x24" Ø 30 ft.)	4@ 2,000.00	=	8,000
Check Structures (concr.)	4@ 20,000.00	=	80,000
Main Canal Drainage Ditch			
Excavation 80,000 cu. yds.	@ .60	=	48,000
Miscellaneous			
Moving Morden Town Water Supply Line	- Lump Sum	=	2,000
			$3,731,460
Indirect Items			
Contingencies: 20% of direct items			718,540
			$4,550,000
Engineering: 10% of direct items			365,000

DETAILED COST ESTIMATE

Interest during construction: 8% for 2 years	$ 535,000
Capital Cost:	$5,450,000

Annual Charges

Interest: 8% x $5,450,000	436,000
Depreciation on Canals: 50 years	1,000
Depreciation on concrete elements: 50 years	5,000
Depreciation on pumps, motors and valves: 25 years	10,000
Operation and Maintenance: 1.5% of capital cost	82,000
Cost of Pumping	185,000
Annual Cost:	$ 719,000



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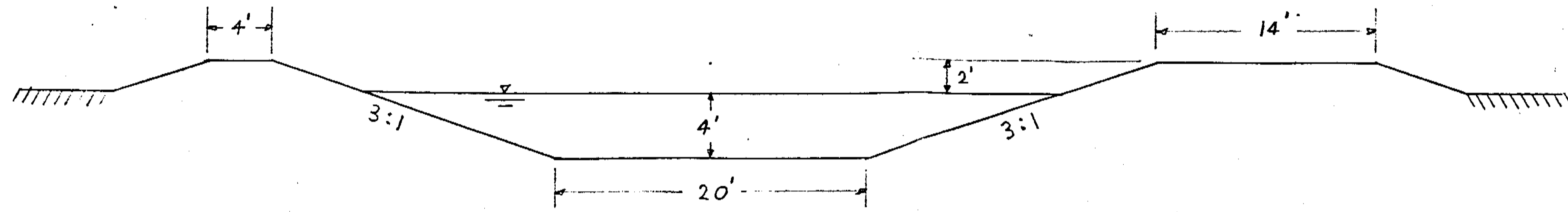
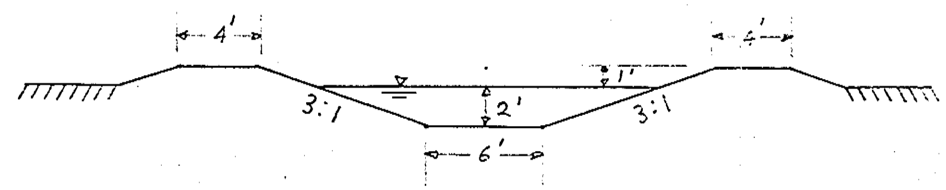
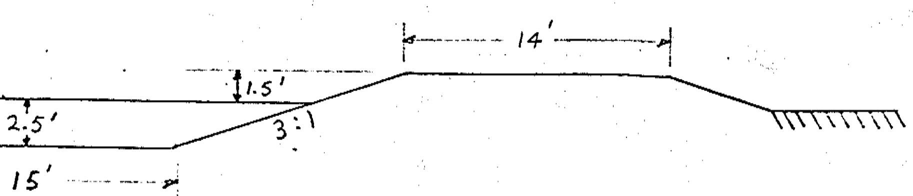


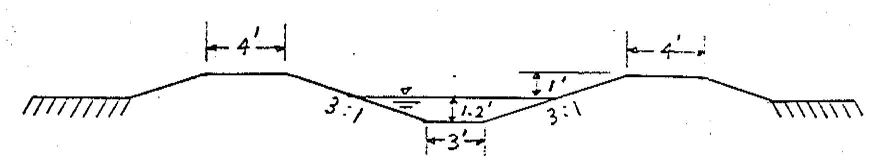
X-SEC. MAIN SUPPLY CANAL



X-SEC. LATERAL



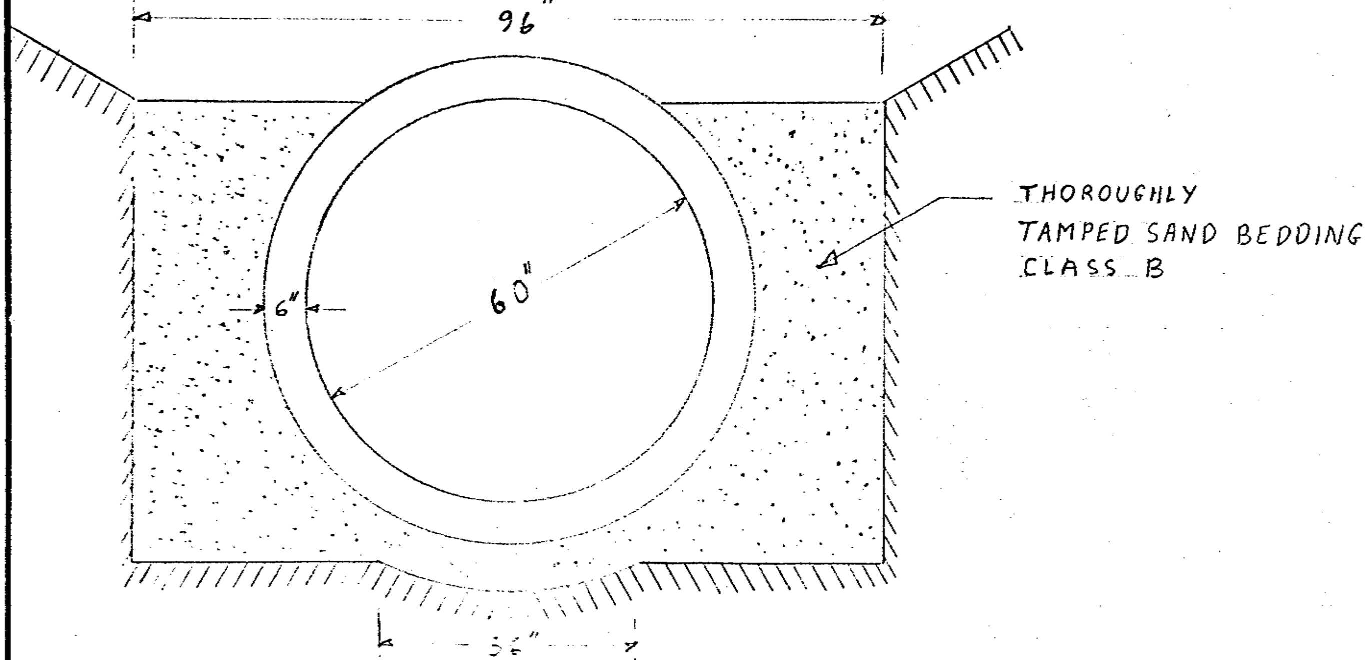
D PIG CANAL
E: 1" = 10'



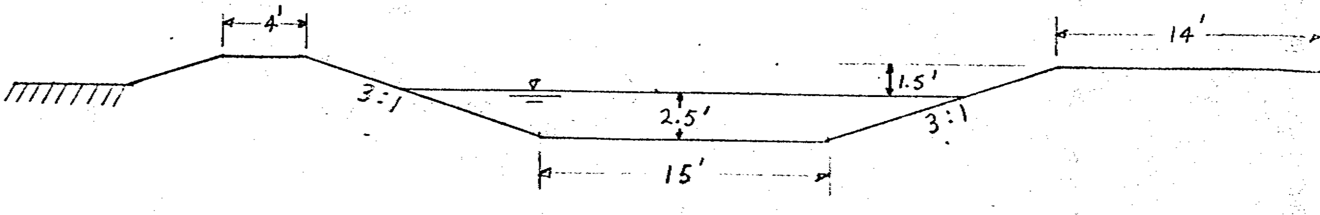
X-SEC. SUBLATERAL

FIG. C-1

OCT. 1974



X-SEC. CONCRETE PRESSURE CONDUIT
NOT TO SCALE



X-SEC. DEAD PIG CANAL
SCALE: 1" = 10'

APPENDIX D

DESIGN AND ESTIMATE OF IRRIGATION SYSTEM

INDEX:

DESIGN AND ESTIMATE OF IRRIGATION SYSTEM

General

In this section preliminary design and estimates are presented of the proposed Morden-Winkler Irrigation system. The irrigation unit is 11,975 productive acres. An estimate of the amount and cost of land leveling has also been prepared and is included in here.

Land Leveling

Almost all natural land surfaces under a gravity irrigation system require some initial surface preparation in order that field efficiency may be better controlled. The immediate benefit from a well-planned and well-constructed leveling job is the saving in irrigation time and labor. Farmers in Alberta[30] report that they can irrigate 2 to 3 times as much land as previously with proper leveling.

In the project area the land topography is very flat with very few undulations requiring minimal alterations. For cost purposes it has been assumed that approximately 100 cu. yds. per irrigable acre will be leveled. No damage to land productivity is expected since soil surveys show that between 10 and 15 feet of topsoil exist in the area. This is more than adequate to meet the 12-inch minimum soil depth standard required by the U.S. Department of Agriculture[31].

The existing east-west coulees transversing the project area are not to be altered by the land leveling. The small creeks will be utilized as natural project drain outlets eliminating the need for costly drain construction.

The leveling will be accomplished by tractor-train loading type scrapers equipment. The unit cost to accomplish the work has been estimated at $0.35 per cu. yd. yielding a total cost of $420,000.

Laterals

The lateral system carries the irrigation water from the main canal and distributes it to the sublaterals which then carry it to the farmers' fields. There are four laterals in the project area. The design discharge of each lateral has been estimated at 50 cfs. or approximately ¼ of the main canal capacity. The laterals have been designed with a 6-foot bottom width at a slope of 0.0006. Assuming a Manning's "n" of 0.025 yields canal velocities of 2.8 ft./sec. at a depth of flow of 2 feet. A minimum of 1 foot has been allowed for freeboard. The laterals are all lined with 1 foot of impervious clay material. There are 24 miles of laterals in the project area.

Sublaterals

The sublateral system carries water from the laterals to the farmers' fields along quarter section lines. In general sublaterals are approximately ½ mile in length. Each sublateral has been designed for a discharge of 10 cfs. This is more than adequate to meet the average farm delivery requirement of 5 cfs. The sublateral cross-section was designed with a 3 foot bottom width and 3:1 side slopes. Canal velocities of 1.5 ft./sec. have been calculated at depth of flow of 1.2 feet and at a slope of 0.0006. A minimum of 1 foot has been allowed for freeboard. All sublaterals are lined with a 1 foot impervious clay material. There are 31 miles of sublaterals in the project area.

Drains

The drainage system was laid out to remove irrigation waste water, to remove storm water and to control ground water. Each drain will collect waste water at the lowest point of each quarter section and discharge it to the nearest natural creek channel in the area. The drains' cross-section has been assumed similar to the sublaterals' cross-section. There are approximately 34.5 miles of drains in the project area.

Drop Structures

Drop structures provide a safe means of lowering canal flows in areas of steep topography. It is anticipated that these structures will be required for the lateral system. Many of these will be combined to serve as check structures also. No drop structures will be required for the sublateral system due to the low velocities and short distances encountered. The structures will be made of timber and will have an average drop of 3 feet.

Check Structures

Check structures are required to raise water levels in the canals at either a farm turnout or at a lateral turnout. The 4 check structures in the main canal will be of concrete and the others on the laterals will be made of timber.

Lateral Turnouts

Lateral turnouts are required at a junction in the lateral system to pass water from the through canal to the branch. It may be of 2 types, a gated corrugated metal pipe or a timber check structure with a lift gate. There are a total of 30 lateral turnouts in the project area.

Farm Turnouts

A farm turnout consists of an 18-inch corrugated metal pipe through the canal embankment used to pass water from the canal to the farmers' land. There are 116 of these in the project area.

Measuring Devices

Although not included in the design of this system, it is likely that some type of measuring device would be installed at the farm turnout. Such devices are necessary to control the use of water on a project of this nature. They may consist of Parshall flumes, weirs, gauges, etc. It is probable that the measuring device and the turnout would be incorporated into a single structure.

DETAILED COST ESTIMATE

Lateral Distribution System

Right-of-way - 90 acres	@	$ 300.00	$ 27,000
Earthwork:			
Excavation - 170,000 cu. yds.	@	.60	102,000
Clay lining - 84,000 cu. yds.	@	.60	50,400
Structures:			
Turnouts (gated pipe) - 30	@	250.00	7,500
Check structures (timber) 30	@	3,000.00	90,000
Drop structures - 8	@	2,000.00	16,000

Sublateral Distribution System

Right-of-way - 90 acres	@	300.00	27,000
Earthwork:			
Excavation - 73,000 cu. yds.	@	.60	43,800
Clay lining - 53,000 cu. yds.	@	.60	31,800
Structures:			
Turnouts (gated pipe) 118	@	200.00	23,600

Project Drains

Right-of-way - 100	@	300.00	30,000
Earthwork:			
Excavation - 120,000	@	.60	72,000

DETAILED COST ESTIMATE

Miscellaneous

Bridges (timber) - 20	@	$15,000.00	$ 300,000
Land leveling - 1,197,500	@	.35	419,300
			$1,240,400

Indirect Items

Contingencies: 20% of direct items	229,600
Engineering: 15% of direct items	173,000
Interest during construction: 8% for 1 year	142,000
Capital Cost	$1,785,000

Annual Charges

Interest: 8% x $1,785,000	142,800
Depreciation on canals: 50 years	500
Depreciation on remaining structures: 25 years	6,700
Operation and Maintenance; 3% of capital cost	54,000
Annual Cost	$ 204,000

APPENDIX E

BRIEF DISCUSSION ON TWO ALTERNATIVE SOURCES OF SUPPLY

BRIEF DISCUSSION ON TWO ALTERNATIVE SOURCES OF SUPPLY

Lake Manitoba - Pembina Triangle Diversion

In August 1971, the Province of Manitoba Department of Mines, Resources and Environmental Management - Water Resources Branch published a preliminary engineering report[40] for the Saskatchewan-Nelson Basin Board outlining a scheme to direct water from Lake Manitoba to the Pembina Triangle. The scheme as depicted on Figure E-1 consists of four components; the proposed diversion from Lake Manitoba to the Assiniboine River, the proposed Hood Dam and Pumping Station, the proposed Rathwell Pumping Station and the proposed canal from the Assiniboine River to the Pembina Triangle. Three discharges were considered in the design of the diversion works, namely 200, 1,000 and 2,000 cfs. The study concluded that a total capital cost of $21,826,000 (1971 prices) would be required to divert 200 cfs from Lake Manitoba to the Pembina Triangle.

Analysis of diversion requirements from Lake Manitoba show that to irrigate 11,975 acres of land in the project area requires the diversion of 215 cfs. This is 30 cfs higher than the diversion requirement from the Pembina Reservoir. The reasons, for the difference are, the additional losses incurred due to longer distances travelled and also additional evaporation losses from the Hood Reservoir. For preliminary cost estimates it will be assumed that the scheme to divert 200 cfs to the Pembina Triangle is adequate to supply the irrigation, municipal and industrial water requirements of the project area.

To convert the 1971 cost estimate of this scheme to 1974 prices a 15% increase will be added to offset increases in the construction costs yielding a total capital cost of $25,100,000. At the present discount rate of 8% and a project life of 50-years annual charges including pumping for this project have been estimated to be approximately $2,400,000. Allowing $504,000 per year for the irrigation system and farm labor gives a benefit-cost ratio for the overall project of 1.0. From an economic viewpoint this scheme does not seem as good as diversion from the Pembina Reservoir.

The advantage of this scheme is that it exposes all south-central Manitoba to an assured supply of water. Before considering this scheme further, however, a thorough economic evaluation should be undertaken to identify the additional benefits and costs incurred to enlarge the scheme to cover the additional water requirements of the nearby communities along the canal route from the Assiniboine River to the International Boundary.

A disadvantage that has been voiced by some, for this scheme is that Lake Manitoba water contains too many nutrients to be of value to irrigation uses. This would have to be checked further.

<u>Shellmouth Reservoir - Assiniboine River-Pembina Triangle Diversion</u>

This scheme involves the proposed Hood Dam on the Assiniboine River, the proposed Rathwell pumping station, and the proposed Assiniboine River-Pembina Triangle Canal. The required flow of 215 cfs would be guaranteed by the existing 380,000 acre-feet storage reservoir impounded by the Shellmouth Dam. It should be noted that in most years the 64,000 acre-feet storage behind the Hood Dam supplemented by natural flow on the Assiniboine River (originating mainly from the Souris and the Qu'Appelle River) will be adequate to meet the diversion requirements without any need for additional releases from the Shellmouth Dam for the project purposes.

The capital cost for the three components has been estimated at $15,528,000. The annual cost of the project including the annual costs of the irrigation system and labor has been estimated at $2,204,000. The benefit-cost ratio for this scheme is 1.3.

Because of the high "write-off" credited to the existing Shellmouth Dam this scheme is superior, from an economic viewpoint, to the other two.

Before implementation of this scheme is considered, however, it is important to decide on the operating rules of the Shellmouth Dam and also to outline the prior uses of Shellmouth water. It could very well be that this is not "free" water as it has been assumed herein but would have to be paid for by the project users. This would result in a lower benefit-cost ratio.

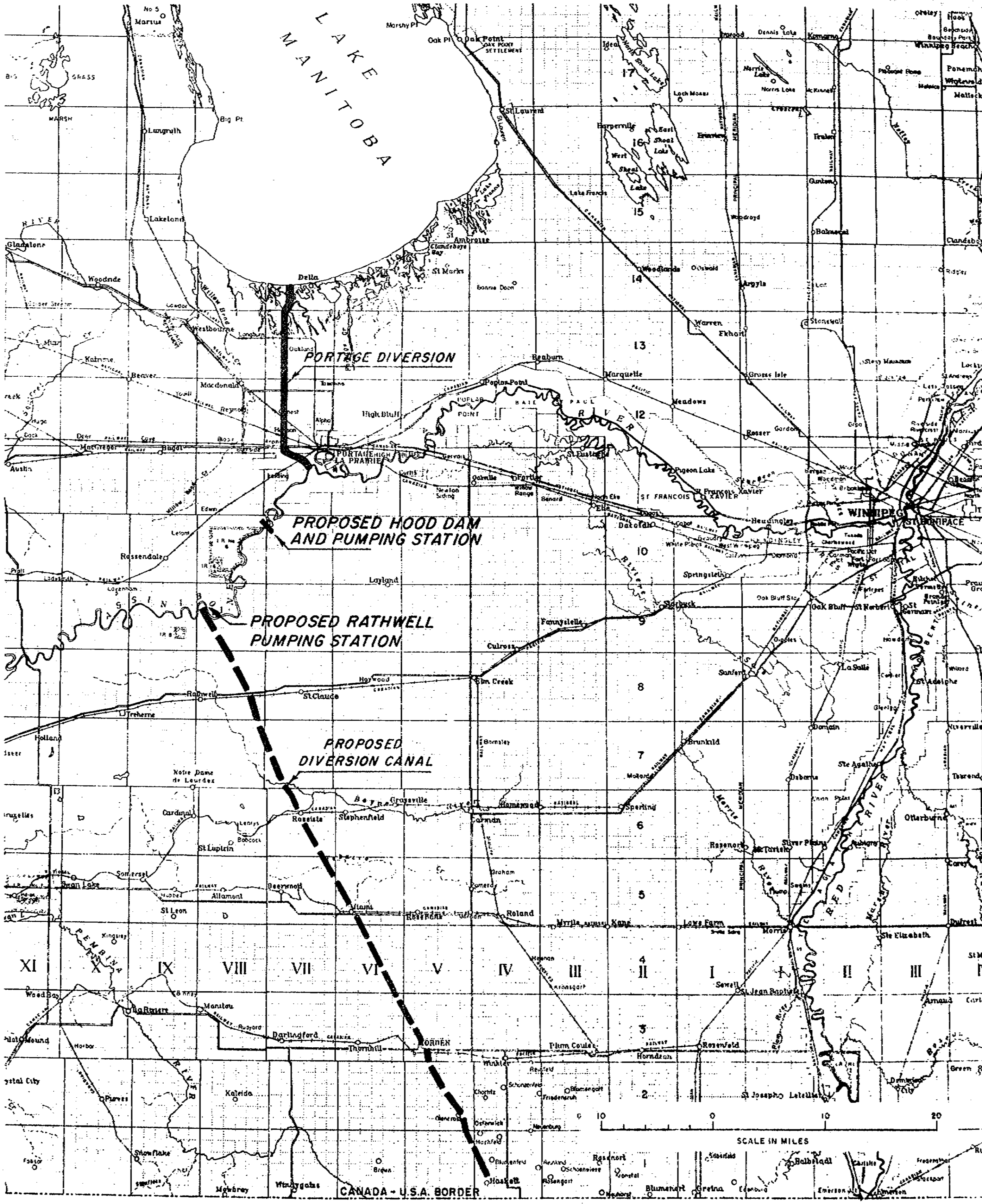


FIG. E-1

LAKE MANITOBA TO PEMBINA TRIANGLE DIVERSION

OCT. 1974