FEASIBILITY STUDY AND COST ESTIMATE OF THE LAKE MANITOBA - GARRISON RESERVOIR DIVERSION

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ABSTRACT

The Lake Manitoba - Garrison Reservoir Diversion is a feasibility and cost estimate study of diverting water from Lake Manitoba to the Garrison Reservoir on the Missouri River.

The study indicated that is is feasible to carry out this diversion by a series of pumping stations in conjunction with a canal, a series of dams and reservoirs on the Assiniboine and Souris Rivers and tunnels through the divide between the Souris and Missouri Rivers.

The estimated capital and annual per acre-foot cost for the Lake Manitoba - Garrison Reservoir Diversion for the four levels of supply studied are as follows:

Flow	Acre-Feet per Year	Estimated Capital Cost	Annual Cost per Acre-Foot
70,000 cfs.	51,100,000	$5,820,000,000	$11.18
52,500 cfs.	38,300,000	$4,556,000,000	$11.78
35,000 cfs.	25,500,000	$3,287,500,000	$12.52
17,500 cfs.	12,775,000	$1,978,000,000	$14.85

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CHAPTER I

PRELIMINARY

1. Introduction

The Lake Manitoba-Garrison Reservoir Diversion is a scheme to divert water by pumping from Lake Manitoba via a canal, the Assiniboine and Souris Rivers and tunnels to the Garrison Reservoir on the Mississippi River.

It has become apparent in recent years that Canada should be conducting a water resource study to investigate and establish a plan for the development of the water resources of the nation. This is particularly true in the Prairie Provinces where local water supplies are insufficient for future development of agriculture and industry. To ensure growth and prosperity of the agricultural and industrial communities of the semi-arid region of the prairies it will become necessary to import water from the McKenzie and Churchill River watersheds which flow into the Arctic Ocean.

In order to develop a plan for water resources development of the prairie provinces, an interdiciplinary study of water resources and water utilization in Western Canada was initiated at the University of Manitoba.

It is proposed that the interdiciplinary study will indicate the magnitude of the future water requirements of Western Canada, and establish the amount of water available for diversion from the north. Should the water available for the diversion from the northern part of Canada exceed the water requirements of Western Canada, Canada could, if it chooses, be in a position to export water to the U.S.A. to help finance the developments of water resource schemes in Western Canada.

The Lake Manitoba-Garrison Reservoir Diversion is one possible scheme for water export.

2. Scope

The purpose of the study is to establish whether it is feasible from an engineering point of view to divert water from Lake Manitoba to the Garrison Reservoir and, if so, to establish the capital cost and annual cost per acre-foot for water delivered to Garrison Reservoir for the four levels of flow: 17,500 cfs., 35,000 cfs., 52,500 cfs., and 70,000 cfs.

3. Limitations

For the purpose of this study it was assumed that up to 70,000 cfs. could be available throughout the year at Lake Manitoba for use elsewhere.

It was assumed that the quality of the water delivered to Garrison Dam was of sufficient high quality for use in the industrial, agricultural, and municipal applications. No attempt was made to determine what the demand may be at Garrison Dam for Canadian water or to what specific use it may be put.

Water is not available "free" at Lake Manitoba. This study did not assume a cost for water at this point nor was any attempt made to establish this cost[1].

4. Thesis Organization

The main body of the report was divided into eight chapters: Chapter 1, an introductory chapter; Chapters II, III, IV, V, each dealing respectively with the following sections of the diversions: Lake Manitoba-Assiniboine River Section, the Assiniboine River Section, the Souris River Section, and the Velva-Garrison Reservoir Section. Chapter VI covers the pumping and power aspects of the diversion. Capital costs and annual charges are covered in Chapter VII. Chapter VIII contains the summary and conclusion of this report.

Hydraulics and Hydrology of the Souris and Assiniboine Rivers; Dams; Reservoir Damages; Canals; Velva Tunnels; Pipelines; Pumping Stations; Power; and Unit Costs were covered in Appendices A to I respectively.

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1. G.A. Filmon in his April, 1967, Department of Civil Engineering, University of Manitoba thesis entitled "An Investigation of the Diversion of Northern Manitoba Waters into Lake Manitoba" established the cost of 53,000,000 acre-feet of water diverted from the Churchill River, Saskatchewan River and Lake Winnipeg, at $2.05 per acre-foot at Lake Manitoba.

CHAPTER II

LAKE MANITOBA-ASSINIBOINE RIVER REACH

1. Introduction

The Lake Manitoba-Garrison Dam Diversion for the purpose of this study was divided up into four basic reaches; a reach from Lake Manitoba to the Assiniboine River, a reach on the Assiniboine River from a point a few miles upstream of the City of Portage la Prairie to the confluence of the Souris River with the Assiniboine River, a reach on the Souris from the outlet of the Souris River to Velva, North Dakota, and a reach from Velva to the Garrison Reservoir. These reaches are shown in Figure 2.

This chapter will deal with design considerations and alternatives available for the Lake Manitoba-Assiniboine River Reach.

2. Description of Reach

The Lake Manitoba-Assiniboine River Reach originates on the shore of Lake Manitoba and terminates at the Assiniboine River. The reach is 20.5 miles in length lying one mile west and parallel to the Portage Diversion. As shown in Figure 3, ground rises from elevation 812 on the lake to elevation 925 at the river, an average of 6 feet per mile. In the first 16 miles the ground rises 28 feet with the remaining 85 feet of rise concentrated in the last four and one half miles. The soils in this area vary from a sand to silty sand; to silty clay to clay.

This section enters the Assiniboine River five miles upstream from the City of Portage la Prairie. Five roads including the Trans-Canada Highway and five railroad tracks are transversed by this section of the diversion.

3. Lake Manitoba-Assiniboine River Canal

A canal system with suitably located pumping stations was selected to convey the diversion water along this reach.

The first reach of the canal consists of a three-mile long inlet canal originating one mile offshore of the beach on Lake Manitoba. The inlet canal was designed 13 feet deep corresponding to the average depth of Lake Manitoba. The inlet canal terminates at the first pumping station where the flow is lifted 25 feet into an above prairie canal and flows by gravity a distance of 7 miles to the next pumping station. Here again the flow is lifted 25 feet and flows a distance of 6 miles to the third pumping stations. From this point on the ground rises rapidly necessitating two pumping stations in the last three miles.

It was assumed that the entire length of the canal upstream of Pumping Station #1 would have to be concrete lined because of the pervious nature of the foundation material. It is possible that a small portion of the canal, which transverses impervious material, may not require lining.

However, it was assumed that the entire canal would require lining. Lining was assumed to be carried to a point five feet above the design water surface.

Although the allowable velocity for a concrete lined canal is in the order of 5.0 fps., the limiting velocity in this study was set at 3.0 fps. In order to increase the velocity from 3.0 fps. to 5.0 fps. additional head would be required at the pumping stations with the result that power and capital costs for the pumping stations would go up. On the other hand canal costs would probably decrease because of the smaller channel cross-section required. To obtain an opitmum design a number of alternative designs would have to be examined. It was felt that such a study was beyond the scope of this report.

The design sections that were used for the design of the lined sections of the canal are shown below. A dyke freeboard of five feet was assumed for all flows studied.

Flows	Base Width	n	Side Slopes	Depth of Flow	Gradient
70,000 cfs.	790'	0.015	6	25'	0.0000135
52,500 cfs.	550'	0.015	Horizontal	25'	0.0000140
35,000 cfs.	310'	0.015	to	25'	0.0000146
17,500 cfs.	80'	0.015	1 Vertical	25'	0.0000168

The design for the 70,000 cfs. Lake Manitoba - Assiniboine River Canal is shown in Figure 3. The design of the canal is covered in detail in Appendix D.

4. <u>Alternatives to Lake Manitoba-Assiniboine River Canal</u>

It is possible that the existing Portage Diversion could be modified as a conveyance system to accommodate the design discharges studied. The Portage Diversion originates on the Assiniboine River, three miles downstream of the entry point for the Lake Manitoba - Assiniboine River Canal and therefore if used could require at least one additional dam on the Assiniboine River.

It was assumed for the purpose of this study that whatever saving would result from the use of the Portage Diversion would be nominal and therefore this alternative was not investigated.

A preliminary design was carried out on a pipeline as an alternative to the Lake Manitoba - Assiniboine River Canal. The pipeline was sized at 40 feet in diameter with a limiting velocity of 14 fps. for a flow of 17,500 cfs. per conduit. It was found that the cost of the pipeline would exceed the cost of the canal for all discharges studied. The design and cost estimate for the pipeline is contained in Appendix F.

5. Capital Cost Estimate

A detailed cost estimate for the 17,500 cfs., 35,000 cfs., 52,500 cfs. and 70,000 cfs. capacity canals was made and is contained in Appendix D. The capital cost of the pumping stations in covered in Appendix G. The capital cost for the canals including the cost of the pumping stations was estimated at $73,655,000; $118,475,000; $162,375,000; and $194,735,000 for the 17,500,cfs., 35,000 cfs., 52,500 cfs., and 70,000 cfs. flows studied. Capital cost for both the canals and canal pumping stations are summarized in Table 3.

CHAPTER III

ASSINIBOINE RIVER REACH

1. Introduction

The Assiniboine River Reach of this diversion was required to life the diversion water from elevation 925 at the outlet end of the Lake Manitoba - Assiniboine River Canal to elevation 1150 at the confluence of the Souris River with the Assiniboine River.

This Chapter will deal with some of the design considerations for the reach.

2. Description of Reach

In the region between the Souris River confluence with the Assiniboine River and the City of Portage la Prairie, a distance of 76 miles, the Assiniboine River transverses the Upper and Lower Assiniboine Delta formed during the glacial period of Lake Agassiz. In this region the river flows in a wide and deep valley, actively eroding its valley banks and degrading its bed. The valley averages 1/2 to 1 mile in width.

The bottom of the valley has a ditch-like shape with alluvial deposits forming a thin layer on top of the original delta formation. The average slope of the river is about two feet per mile.

Although there are no villages or towns located in the Assiniboine River Valley along this reach, there are approximately 83 farmsteads and 4 vehicular crossings. There are no railroad crossings.

3. Conveyance System

The conveyance system in this reach was designed as a series of dams, pumping stations, and an impounding reservoir.

In order to keep the pumping stations cost down it was decided to concentrate the static lift at as few pumping stations as possible. An attempt was made to keep a sufficiently high positive head over the pumping station intake to keep pumping efficiencies as high as possible (8). Channel velocities were kept below 3.0 fps. so as not to cause any unnecessary channel erosion. The above criteria essentially set the location of the dams.

For the 70,000 cfs. and 52,500 cfs. design flows studied, it was found that four dams and three pumping stations were required. The height of the dams varied between 75 and 195 feet. It was found for the 35,000 cfs. and 17,500 cfs. flows that one of the dams could be eliminated; the 195 foot high dam reduced in height by 50 feet and a new dam constructed to replace the reduction in height of the 195 foot high dam. This scheme reduced the flooded area by 3,000 acres.

It is possible that if the number of dams on the

Assiniboine River Reach of the diversion is increased, that the total cost of the reach would be decreased. The saving would result from a decrease in reservoir damages and smaller total volumes of dam embankments. It should be noted that the cost of the pumping stations for the 70,000 cfs. and 17,500 cfs. flows make up 51% and 53% of the total cost of this reach. As was shown in Appendix G, the unit cost for pumping stations are particularly sensitive to the MW size of the installation with unit costs rising sharply for low MW pumping stations. If the number of dams are increased, it is conceivable that with the lower pump head per dam that increased cost of the pumping stations would offset the saving in reservoir damages and dam costs. This aspect was not investigated since it was felt a study of this nature was not justified for the purpose of this report.

The Assiniboine River Valley in this reach is particularly suited as a conveyance system as proposed here. For example, it was calculated that the channel friction loss from Dam #1 to the confluence of the Souris River with the Assiniboine River, a distance of 71 miles, was 0.2 feet for the 70,000 cfs. flow.

Percolation losses into the banks of the Assiniboine River are expected to be significant at the beginning of the flooding of the reservoirs. Although high initial losses are expected, it is anticipated that losses will drop sharply as the available hydraulic gradient is flattened by the raising of the water table in the general area of the reservoir. It is anticipated that the general ground water conditions within twenty miles of the reservoir will be affected by the empoundment of water behind the proposed dams. The ground water regime may be noticeably changed with a significant increase in the number of springs developing along the slope of the Manitoba Escarpment.

The hydrology and hydraulics of the Assiniboine River, dams, reservoir damages, and pumping stations required for this section were covered in Appendices A, B, C and G.

The design for this reach for the 70,000 cfs. is illustrated in Figure 4.

4. Alternatives to Assiniboine River Section

No alternatives were investigated to the Assiniboine River Section of the Diversion.

5. Capital Cost Estimates

A detailed cost estimate for the various components of the reach for each of the four levels of supply studied was made and is contained in Appendices A, B, C and G.

The capital cost for the dams, dyking, channel improvements, reservoir damages and pumping stations was estimated to be $240,437,000; $212,547,000; $172,674,000; and $135,857,000 for the four levels of supply studied. Capital costs for the reach are summarized in Table 3.

CHAPTER IV

SOURIS RIVER REACH

1. Introduction

The Souris River Reach of this diversion was required to lift the diversion water from elevation 1150 at the confluence of the Souris River with the Assiniboine River to elevation 1550 at Velva, North Dakota.

This chapter will deal with some of the design considerations for this reach.

2. Description of Reach

The Souris River Valley from its confluence with the Assiniboine River to Minot, North Dakota, has three distinct reaches.

The reach of the Souris River from the Assiniboine River to near the west end of Lang's Valley is an example of stream piracy. After the receeding of the glaciers from the last ice age, a tributary of the Assiniboine River eroded a channel through the Tiger Hill Region separating Glacial Lake Souris area from the Assiniboine River Delta and captured the Souris River as it outletted through Lang's Valley. The Souris River Valley is deep, "V" shaped, averages 1/8 mile to 1/2 mile in width, and very irregular. The river is actively eroding its valley banks and degrading its bed in this reach. The valley bottom has a slope of 6.0 feet per mile. This section of the Souris River Valley is twenty-two miles in length.

The Souris River Valley from Lang's Valley to a point a few miles downstream of Verendrye, North Dakota, a distance of approximately 165 miles, is located in the plain once occupied by Glacial Lake Souris. The valley width varies from 1/2 to 3 miles with the valley extended less than 100 feet below the surrounding plain and in places shows practically no valley incision. The valley in this area has an averaging bottom slope of 1.5 to 2.5 feet per mile.

The portion of the Souris River Valley upstream from Verendrye to Minot averages 3/4 miles in width and lies 100 to 200 feet below the surrounding plain. The valley walls are steep-sided. The valley bottom slope averages 1.5 feet per mile in this reach. The section of the Souris River Valley from Verendrye to Velva is 10 miles in length.

The towns of Wawanesa, Souris, Melita, Upham, Velva, and Sawyer are located on the valley floor with 174 farmsteads, 9 railroad bridges, 30 vehicular bridges, and 11 small dams.

On the American portion of the diversion from the international border to a point south of the town of Verendrye the U.S. Fish and Wildlife Service has established a wildlife refuge known as the Lower Souris National Wildlife Refuge. The wild fowl refuge was developed by constructing 5 small dams on the Souris River causing the creation of very shallow marshy empoundments.

3. <u>Conveyance System</u>

The conveyance system in this reach was designed as a series of dams, pumping stations and impounding reservoirs.

As on the Assiniboine River Section an attempt was made to concentrate the static lift at as few pumping stations as possible and to keep channel velocities to 3.0 fps. or less.

For this reach it was found that 8 dams and pumping stations were required along with two additional dams, one to prevent the loss of water down the Blind Souris, and another on the divide (Lang's Valley) between the upper end of the Pembina River system and the Souris River to prevent the loss of water down the Pembina River system. The height of the dams on the Souris River varied between 35 feet and 160 feet. It was found necessary to use one layout of the dams for all the discharges studied.

It is not expected that problems related to water percolations will be as severe as on the Assiniboine River.

In order to keep channel velocities below 3.0 fps. it was found necessary to carry out extensive channel improvements along certain reaches of the Souris River. With the improvements in effect it was calculated that the reservoir water surface at the inlet to the pumping station would vary between 3 and 6 feet from the FSL during the period of pumping.

For the purpose of calculating the size of pump installation these channel losses were assumed to be included in the loss of efficiency of the pump units.

All of the dyking, as was the case on the Assiniboine Reach, was required to provide freeboard requirements around the abutments of the dams.

The towns of Wawanesa, Souris, Melita, Upham, Velva, and Sawyer would be flooded by this diversion.

The hydrology and hydraulics of the Souris River, dams, reservoir damages, and pumping stations required for this section were covered in Appendices A, B, C, and G.

The design for the 70,000 cfs. flow in this reach is illustrated in Figure 5, Sheets 1 and 2.

4. <u>Alternatives to Souris River Section</u>

The Bunclody Canal was investigated as an alternative to using the Souris River as a conveyance system between a point downstream of the town of Souris, near the village of Bunclody and point upstream of the town of Melita.

The Bunclody Canal is essentially a contour canal. The water is lifted out of the "low reservoir" behind Dam #7 (FSL 1350) to elevation 1465 on the high bank of the Souris and gravity conveyed to the Blind Souris, an abandoned channel of the Souris River above Melita, and then to the reservoir behind the Dam #10 (FSL 1450). The soils along the canal route vary from silty sand, gravel, fine sand, loamy sand and silt. It was felt that with these foundation conditions the canal would have to be concrete lined.

It was found that for all discharges studies except the 17,500 cfs. flow the canal was more expensive than the Souris River conveyance system. For the 17,500 cfs. flow a 10% saving resulted. For the purpose of this study it was assumed that this small saving was insignificant and that the water would be conveyed up the Souris River. A comparative cost estimate between the Souris River between Dam #7 and Dam #10 and the Bunclody Canal is shown in Appendix D, Table D-3.

It was found that it could be possible to construct a contour canal along the east or west high bank of the Souris River from the vicinity of Dam #9 to either of the reservoirs behind Dams #11 or #12. These contour canals would be in the order of 90 to 120 miles in length. Based on unit costs per mile for the Bunclody Canal it was found that the capital cost of these canals would exceed the saving in dam costs, reservoir damages, and pumping stations that would result because of their construction.

5. <u>Capital Cost Estimate</u>

A detailed cost estimate for the various components of the reach for each of the four levels of supply studied was made and is contained in Appendices A, B, C, and G.

The capital cost of the dam, dyking, channel improvements, reservoir damages, and pumping stations was estimated to be $579,217,000; $542,676,000; $447,849,000 and $367,196,000 for the four levels of supply studied. Capital costs for the reach are summarized in Table 3.

CHAPTER V

VELVA-GARRISON RESERVOIR SECTION

1. Introduction

Diversion water was to be conveyed from elevation 1550 near Velva on the Souris River to elevation 1850 at the Garrison Reservoir on the Missouri River.

This chapter will deal with some of the design considerations for this reach.

2. Description of Reach

Between the Souris and Missouri Rivers lies the divide that separates the watersheds draining into the Hudson Bay and those draining into the Gulf of Mexico. Following a line drawn from Velva to the northeast corner of the Garrison Reservoir, the top of the divide would be reached at elevation 2180. The distance between these two points is 31 miles. A saddle located south of Velva is located at elevation 2060 but increased the length between Velva and the Garrison Reservoir by twenty some miles.

The north and south sides of the divide are very steep with slopes in some reaches being 40 to 50 feet per mile. The top of the divide is covered with a series of sloughs and is very undulating.

3. Conveyance System

It is proposed that the diversion water be conveyed from Velva to the Garrison Reservoir by tunnels constructed through the divide.

The tunnels would have a diameter of 40 feet and would convey 17,500 cfs. each at a velocity of 14 fps.[2]

Although existing information as to the exact nature of the bedrock is sketchy, it is known that the bedrock is of the Fort Union Association (10) which is similar to the Turtle Mountain Formation in Manitoba. The Fort Union Formation is covered by 50 to 150 feet of glacial drift. Except for the last three or four miles of tunnels, where the tunnels are expected to be located in glacial drift, the tunnels will be located in the Fort Union Formation.

Since the Fort Union Formation is young, tunnelling should be relatively easy. However, because the Formation is very young it is not expected to be highly consolidated, particularly within 75 feet of the surface of the bedrock. This aspect may present some problems in tunnelling.

The pumping station for the tunnels would operate against a static head of 300 feet and a friction head of 155 feet.

The design and cost estimate for the tunnels is covered in Appendix E. A profile of the tunnels in contained

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2. See Appendix E for analysis of optimum pipeline diameter.

in Figure 6.

4. Alternatives to the Velva Tunnels

As an alternative to the Velva Tunnels it would be possible to construct a canal from Reservoir #12 along a line drawn straight south of Velva to a point where a saddle occurs in the divide. The elevation of the top of the saddle is 2060. The length of this canal would be 20 miles from Velva to the top of the divide and 32 miles from the top of the divide down to the Garrison Reservoir. The canal would follow a route due south of Velva to the upper end of Camp Lake and Strawberry Lake in the Camp National Wildlife Refugee and thus to Long Lake and Crooked Lake. From this point, the canal would flow south-southwest to enter the Garrison Reservoir at elevation 1850 approximately the same point as the Velva Tunnels.

No actual design was carried out on this canal. However, an approximate cost estimated based on the average cost per mile for the Lake Manitoba-Assiniboine River Canal was prepared. It was found that an additional pumping head of 145 feet was inherent in the design of the canal over that required for the tunnels. Since additional generating stations would have to be provided an allowance for this was made. The cost estimate for this canal is contained in Appendix D, Table D-5.

On this basis it was found that the canal would be slightly more expensive for the 17,500 cfs. diversion, and 10%, 20% and 24% less expensive than the Velva Tunnels for the 35,000 cfs., 52,500 cfs., and 70,000 cfs. flows respectively. The Velva tunnels were estimated as separate entities and it is possible for example, if two or more tunnels were contracted together that the cost of the tunnels could drop 10% or more bringing the cost of the tunnels more or less in line with that for the canal. Since the purpose of this study was to establish the feasibility and the order of magnitude of the cost of the diversion, it was not felt that a detailed cost comparison between the canal and the tunnels was justified. For these reasons, it was decided to use the Velva tunnels in this report for conveying the diversion waters from Velva to the Garrison Reservoir. However, no reduction in the cost of the tunnels for the 35,000 cfs., 52,500 cfs., or 70,000 cfs. flows was made to account for possible volume discounts.

Another alternative to the Velva tunnels would be to construct a pipeline from Velva to the top of the divide at elevation 2060. This pipeline would replace the first twenty miles of the canal mentioned above. However, the pipeline was found to be far too costly to serve as an alternative.

5. Cost Estimate

A detailed cost estimate for the various components of the Velva tunnels is contained in Appendix E and G.

The capital cost for the Velva tunnels including the pumping stations for the 70,000 cfs., 52,500 cfs., 35,000 cfs., and 17,500 cfs. flows was estimated at $1,162,600,000, $874,950,000, $583,300,000, and $297,150,000 respectively. Capital costs for the tunnels are summarized in Table 3.

CHAPTER VI

PUMPING AND POWER

1. Introduction

Approximately 70% of the estimated capital cost of the proposed diversion is invested in pumping and power generating plants. It is apparent from the above figure that the pumping stations be selected with care and that power be made available to the diversion at the lowest possible cost.

2. Pumping Stations

The pumping stations in this study varied in size from 18.3 MW to 3550 MW. Pumping total heads ranged from 10 to 455 feet.

With the range of sizes of pumping stations and pump heads it was found that it was very difficult to estimate the cost of the pumping stations. A megawatt size versus cost per megawatt pump stations capital cost curve was derived. It was felt that a much more accurate costing could have been carried out if a megawatt size versus cost per megawatt pump station capital cost curve was available for a range of heads from 10 to 500 feet since it was felt that the costs of the pumping stations should vary with MW size as well as head. However, sufficient information was not available to derive such curves.

Capital costs per megawatt for the pumping stations were obtained from Appendix G, Figure G-1. The method that was used in obtaining Figure G-1 is described in Appendix G. The pumping stations were assumed to have an efficiency of 80%.

3. Power

The power consumption for the four levels of supply studied was as follows:

Level of Supply	Power Required
70,000 cfs.	11,000 MW
52,500 cfs.	8,000 MW
35,000 cfs.	5,500 MW
17,500 cfs.	2,700 MW

Presently the combined thermal, gas turbine, and hydro generated output of Manitoba Hydro and Winnipeg Hydro is 1640 MW. A potential exists for the development of another 5,000 MW of hydro generated electrical power.

Assuming a constant yearly increase in electrical consumption of 10% over the next two decades; it can be expected that the electrical demand by 1985 - 1990 will be in the order of 5,000 MW.. It is apparent from the above figure that electrical power imput for the diversion could not be supplied from the existing electrical generating system nor does the potential exist for developing the power required from presently undeveloped hydro electrical generating sites since these sites are already committed.

It was assumed that the large block of electrical power required for this project could be best produced by atomic powered generating stations. Presently the largest plants under consideration are 1000 MW capacity. The power plants were assumed to be located along the diversion with one station on Lake Manitoba and another on Garrison Reservoir. Cooling water would be drawn from the diversion itself.

Capital and annual energy charges were calculated as shown in Appendix G.

CHAPTER VII

CAPITAL COSTS AND ANNUAL CHARGES

1. Capital Costs

The capital cost of the project includes the cost of the reservoir damages, canals, pumping stations, power generating plants, dams, tunnels, and all other civil engineering works necessary to make the diversion functional.

The total capital costs of the Lake Manitoba - Garrison Reservoir Diversion for the four levels of supply were found to be as indicated below:

Level of Flow	Capital Cost
70,000 cfs.	$5,820,000,000
52,500 cfs.	$4,556,000,000
35,000 cfs.	$3,287,500,000
15,500 cfs.	$1,978,000,000

The capital cost in dollars are itemized in Table 3.

2. Percentage Breakdown of Capital Costs and Annual Charges

A percentage breakdown of the capital costs and annual charges of the major components for the 70,000 cfs. and 17,500 cfs. flows are tabulated in the table on the following page. By inference the order of magnitude of the percentage breakdown applicable to the 70,000 cfs. and 17,500 cfs. diversions is true for the 52,500 cfs. and 35,000 cfs. diversions.

As can be seen from the table that over 70% of the capital cost of the proposed diversion is accounted for by three items: Atomic Powered Generating Stations, Velva Tunnels, and the Pumping Stations.

Capital Cost and Annual Charge Distribution

	70,000 cfs. Diversion		17,500 cfs. Diversion	
	Capital Cost	Annual Charge	Capital Cost	Annual Charge
Atomic Powered Generating Stations[3]	40.5%	43.7%	31.6%	33.0%
Velva Tunnels	22.5%	21.3%	17.3%	17.0%
Pumping Stations	20.6%	19.6%	21.2%	20.8%
Powerline	5.2%	4.9%	4.5%	4.4%
Reservoir Damages	4.6%	4.3%	13.0%	12.7%
Dams	3.5%	3.3%	9.1%	8.9%
Lake Manitoba Assiniboine River Canal	1.8%	1.7%	2.3%	2.2%
Channel Improvements	1.3%	1.2%	1.0%	1.0%
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2. Interest, Operating and Maintenance and Amortization Allowance

At the present time financing of large public projects are running considerably above the figure of 7% used

3. Capital cost of the atomic powered generating stations was included in the total cost since this capital must be raised if the diversion is to be constructed. The annual energy charge for the diversion was calculated using a cost per MW /hour as shown in Appendix H.

in this report. Since it was difficult to predict what interest rate would apply, 7% was arbitrarily chosen.

The maintenance allowance was taken as 1% of the estimated capital cost.

Since various components of the project such as the pumps and civil works have different lengths of useful life it is difficult to assign an amortization allowance. For the purpose of this study, it was assumed that the amortization allowance was 1% of the capital cost of the project with the amortization fund yielding 4½%. Under these conditions the total capital cost of the project would be recovered in 40 years.

3. Annual Charge

The annual charge for the project was calculated by multiplying the total estimated capital cost less the capital cost[3] of the generating stations by the interest, operating and maintenance, and amortization allowance.

The period of construction for the diversion was taken as eight years with interest during construction paid at a rate of 7% on half the capital value of the project, not including the power stations, for this eight year period.

The annual charge for power was calculated on a per MW hour basis. This charge included operating, maintenance, interest, interest during construction, fuelling costs, and amortization allowances for the nuclear generating plants.

The reason that the annual charge for the nuclear plants was not taken as 1% as was done for the remaining works was that the combined operating and fuelling costs for the nuclear plants run considerably more than 1% (20).

The estimated annual design for the four levels of supply studied were found to be as indicated below:

Level of Flow	Annual Charge
70,000 cfs.	$570,800,000
52,500 cfs.	$450,440,000
35,000 cfs.	$319,300,000
17,500 cfs.	$189,840,000

The annual charges in dollars are itemized in Table 2.

CHAPTER VIII

CONCLUSIONS

As was pointed out in the last chapter over 70% of the total capital cost of the proposed diversions is accounted for by three items: generating stations, Velva tunnels, and the pumping stations.

One would have to assume that by the nature of the background information (20) used in calculating the cost of the generating stations, which account for between 30% and 40% of the capital cost and annual charges, that the capital and operating costs for the generating stations are firm.

The capital cost and annual charges of the pumping stations were found to account for approximately 20% of the costs of the project. The capital costs, as estimated, are based upon hydro generating stations on the Nelson River (19) and other data (18). It was felt that the costs as derived from the background information were lacking in that the costs did not reflect the foundation conditions and more specifically the head conditions at each pumping station site. If more studies of this nature are contemplated it is recommended that an extensive study be carried out to arrive at a more precise costing technique for the pumping stations.

The Velva tunnels account for 17% to 22% of the capital cost and annual charge of the project. Although little information is available as to the exact nature of the material through which the tunnels will be bored there appears little doubt that tunnels can be constructed in this manner. The question, of course, is at what cost. Existing tunnels of the length of the Velva tunnels, 31 miles, are rare. The quantities of excavation, steel, and concrete involved in the construction of the tunnels are very high in comparison to quantities experienced on some of the tunnels constructed in the past. For these reasons, it was found difficult to estimate this section of the diversion. Unit prices used were those experienced on local construction projects where the volume of the work involved is considerably less. Barring unforeseeable foundation problems, the volume discount on a single tunnel could run 10% or more and possibly higher on two to four tunnels. It is interesting to note that even with these possible savings (based on 10% discount) that the total capital cost of the project for the 17,500 cfs. and 70,000 cfs. schemes would only be reduced 1.7% and 2.3% respectively.

One of the more difficult items to estimate was found to be the reservoir damages. Since the area to be flooded was rather large in the order of 430 square miles, the study lacked detail in accounting for present land use. The rather broad classifications of treed, pastured, and cultivated, were used to classify the land. In a number of areas where it was difficult to establish the exact nature of the use of the land, the land was assumed to be pasture. Since land prices have fluctuated rapidly in the last few years, an attempt was made in this report to use an average cost per acre based on land purchases made or contempleted by various government water resource agencies. Figures used in North Dakota were land costs for comparable land in Manitoba.

The relocation costs were calculated by establishing the replacement cost for the farmstead or town flooded. The relocation cost may be low in that it does not include an allowance for a decrease in earnings that may occur because of the move necessitated by flooding. Since it is difficult to estimate what these losses may be at this time no allowance was made for them. However, the reservoir damages account for between 4% and 13% of the total capital cost for the levels of flows studied and a large increase in relocation costs would therefore not influence the overall cost of the project significantly.

Although the dams associated with the diversion are significant structures themselves they were found to only represent between 3.5% and 9% of the total capital costs of the diversion slightly more than the cost of the powerlines for the 17,500 cfs. capacity diversion and slightly less than the cost of the powerlines for the 70,000 cfs. capacity diversion.

It would therefore appear that if an attempt was made to firm up the cost of the diversion that additional studies would be best spend on firming up the costing of the pumping stations, the Velva tunnels, and alternatives to the Velva tunnels.

A number of possible effects of the diversion were either covered lightly in this report or else were completely ignored and are therefore areas of possible further study. These areas are:

1. the effect of the reservoir scheme on the ground water regime,
2. sociological effect of the diversion,
3. the effect of the diversion on the ecology of the area,
4. the quality of water delivered to Garrison Reservoir.

In conclusion, it was found from this study that it is possible to divert water from Lake Manitoba to Garrison Reservoir via the Assiniboine and Souris Rivers and tunnels through the divide separating the Souris and Missouri Rivers.

It was estimated that for the four levels of supply studied: 70,000 cfs., 52,500 cfs., 35,000 cfs., and 17,500 cfs. that water could be delivered to Garrison Reservoir from Lake Manitoba by this diversion at an annual cost of \$11.18, \$11.78, \$12.52, and \$14.85 per acre-foot respectively.

TABLE 1

Estimated Annual Cost per Acre-foot of Water Delivered from Lake Manitoba to Garrison Reservoir

(1) 70,000 cfs. Capacity

Acre-feet of water delivered per year	=	51,100,000 acre-feet
Estimated annual charge	=	$570,800,000
Estimated annual cost per acre-foot	=	$570,800,000/51,100,000 acre-feet
	=	$11.18

(2) 52,500 cfs. Capacity

Acre-feet of water delivered per year	=	38,325,000 acre-feet
Estimated annual charge	=	$450,440,000
Estimated annual cost per acre-foot	=	$450,440,000/38,325,000 acre-feet
	=	$11.78

(3) 35,000 cfs. Capacity

Acre-feet of water delivered per year	=	25,550,000 acre-feet
Estimated annual charge	=	$319,300,000
Estimated annual cost per acre-foot	=	$319,300,000/25,550,000 acre-feet
	=	$12.52

(4) 17,500 cfs. Capacity

Acre-feet of water delivered per year	=	12,775,000 acre-feet
Estimated annual charge	=	$189,840,000
Estimated annual cost per acre-foot	=	$189,840,000/12,775,000 acre-feet
	=	$14.85

TABLE 2

ANNUAL CHARGES

(1) Statistics

Interest Rate:-	7%
Operating Allowance:-	1%
Amortization:-	1%
Total	9%

Annual Energy Charge calculated as shown in Appencix H, Table H-3.

(2) 70,000 cfs. Capacity

Total estimated capital cost less capital cost of generating stations

= $4,120,000,000

Annual Interest, Operating Allowance, and Amortization Charge	$4,120,000,000 x 0.09	= $370,800,000
Annual Energy Charge		= 200,000,000
Total Estimated Annual Charge		= $570,800,000

(3) 52,500 cfs. Capacity

Total estimated capital cost less capital cost of generating stations

= $3,316,000,000

Annual Interest, Operating Allowance, and Amortization Charge	$3,316,000,000 x 0.09	= $298,440,000
Annual Energy Charge		= 152,000,000
Total Estimated Annual Charge		= $450,440,000

TABLE 2 (continued)

Annual Charges Continued ..

(4) 35,000 cfs. Capacity

Total estimated capital cost less capital cost of generating stations

= $2,420,000,000

Annual Interest, Operating Allowance, and Amortization Charge	$2,420,000,000 x 0.9	= $217,800,000
Annual Energy Charge		= 101,500,000
Total Estimated Annual Charge		= $319,300,000

(5) 17,500 cfs. Capacity

Total estimated capital cost less capital cost of generating stations

= $1,546,000,000

Annual Interest, Operating Allowance, and Amortization Charge	$1,546,000,000 x 0.09	= $139,140,000
Annual Energy Charge		= 50,700,000
Total Estimated Annual Charge		= $189,840,000

TABLE 3

CAPITAL COST OF LAKE MANITOBA

GARRISON DAM DIVERSION

	70,000 cfs.	52,500 cfs.	35,000 cfs.	17,500 cfs.
1. Capital Cost by Reach				
i. Lake Manitoba-Assiniboine River Reach				
Canal	$ 75,735,000	$ 60,375,000	$ 43,275,000	$ 31,655,000
Pumping Stations	119,000,000	102,000,000	75,200,000	42,000,000
	$ 194,735,000	$ 162,375,000	$118,475,000	$ 73,655,000
ii. Assiniboine River Reach				
Dam #1 to Dam #4	$ 72,200,000	$ 72,200,000	$ 48,950,000	$ 48,950,000
Pumping Stations	140,500,000	113,000,000	98,800,000	62,200,000
Dyking	Nil	Nil	Nil	Nil
Canal Improvements	Nil	Nil	Nil	Nil
Reservoir Damages	27,737,000	27,347,000	24,924,000	24,707,000
	$ 240,437,000	$ 212,547,000	$172,674,000	$135,857,000
iii. Souris River Reach				
Dam #5 to Dam #12	$ 75,420,000	$ 75,420,000	$ 75,420,000	$ 75,420,000
Pumping Stations	282,340,000	233,600,000	194,800,000	124,700,000
Dyking	245,000	245,000	245,000	245,000
Canal Improvements	56,340,000	50,840,000	21,955,000	14,383,000
Reservoir Damages	164,872,000	182,571,000	155,429,000	152,448,000
	$ 579,217,000	$ 542,676,000	$447,849,000	$367,196,000

TABLE 3 (continued)

	70,000 cfs.	52,500 cfs.	35,000 cfs.	17,500 cfs.
1. Capital Cost by Reach (continued)				
iv. Velva Tunnels				
Tunnels	$ 944,600,000	$ 708,450,000	$472,300,000	$236,150,000
Pumping Stations	218,000,000	166,500,000	111,000,000	61,000,000
	$1,162,600,000	$ 874,950,000	$583,300,000	$297,150,000
v. Powerlines	$ 220,000,000	$ 160,000,000	$110,000,000	$ 61,000,000
vi. Generating Stations	$1,700,000,000	$1,240,000,000	$867,500,000	$432,000,000
2. Summary of Capital Costs				
i. Lake Manitoba - Assiniboine River Reach	$ 194,735,000	$ 162,375,000	$118,475,000	$ 73,655,000
ii. Assiniboine RiverRReach	240,437,000	212,547,000	172,674,000	135,857,000
iii. Souris River Reach	579,217,000	542,676,000	447,849,000	367,196,000
iv. Velva Tunnels	1,162,600,000	874,950,000	583,300,000	297,150,000
v. Powerlines	220,000,000	160,000,000	110,000,000	61,000,000
vi. Sub-total	2,396,989,000	1,952,548,000	1,432,298,000	934,858,000

TABLE 3 (continued)

		70,000 cfs.	52,500 cfs.	35,000 cfs.	17,500 cfs.
2.	Summary of Capital Costs (continued)				
vi.	Brought forward	$2,396,989,000	$1,952,548,000	$1,432,298,000	$ 934,858,000
vii.	Generating Stations	1,700,000,000	1,240,000,000	867,500,000	432,000,000
viii.	Contingencies (Approx. 20%)	819,398,000	638,509,000	459,596,000	273,372,000
ix.	Interest During Construction (0.07x8x (vi + viii)/2)	903,613,000	724,943,000	528,106,000	337,770,000
	Total Estimated Capital Cost	$5,820,000,000	$4,556,000,000	$3,287,500,000	$1,978,000,000

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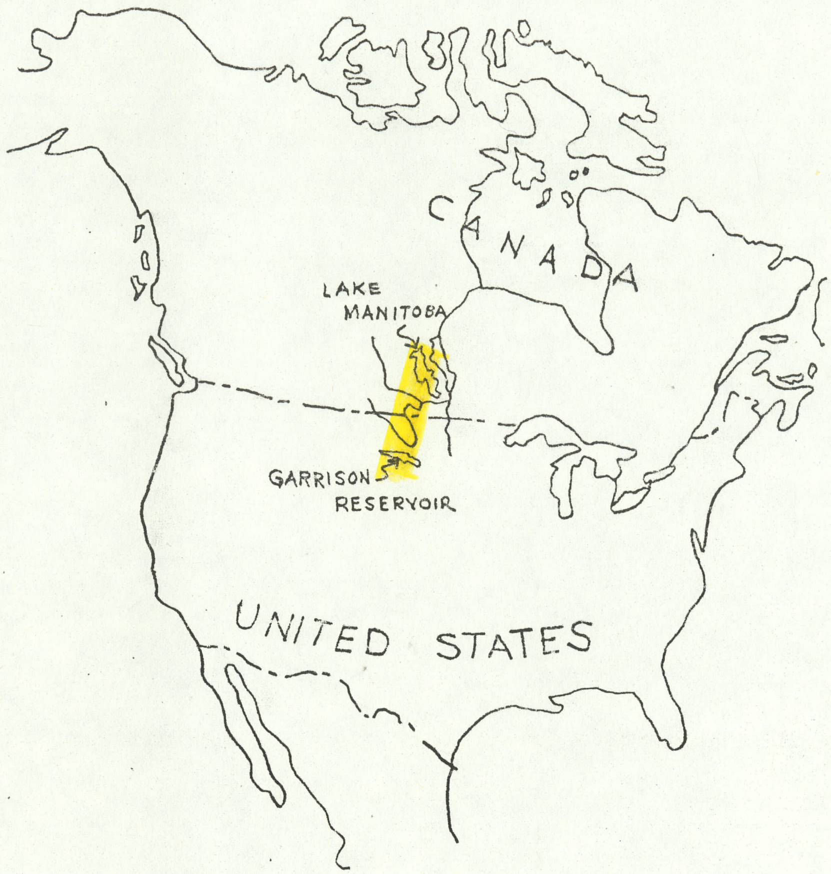
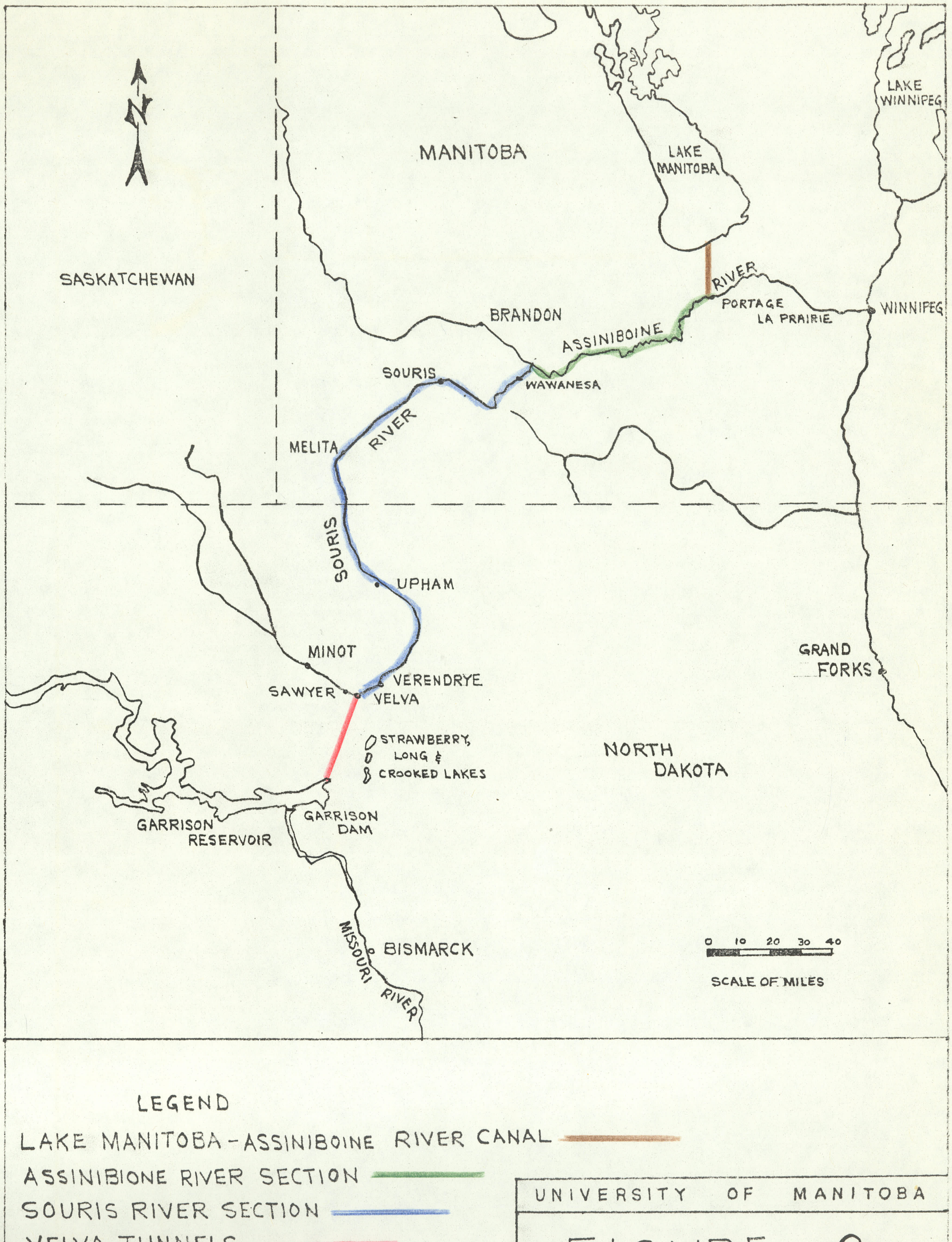


STUDY AREA

UNIVERSITY OF MANITOBA

FIGURE 1



LEGEND

LAKE MANITOBA - ASSINIBOINE RIVER CANAL

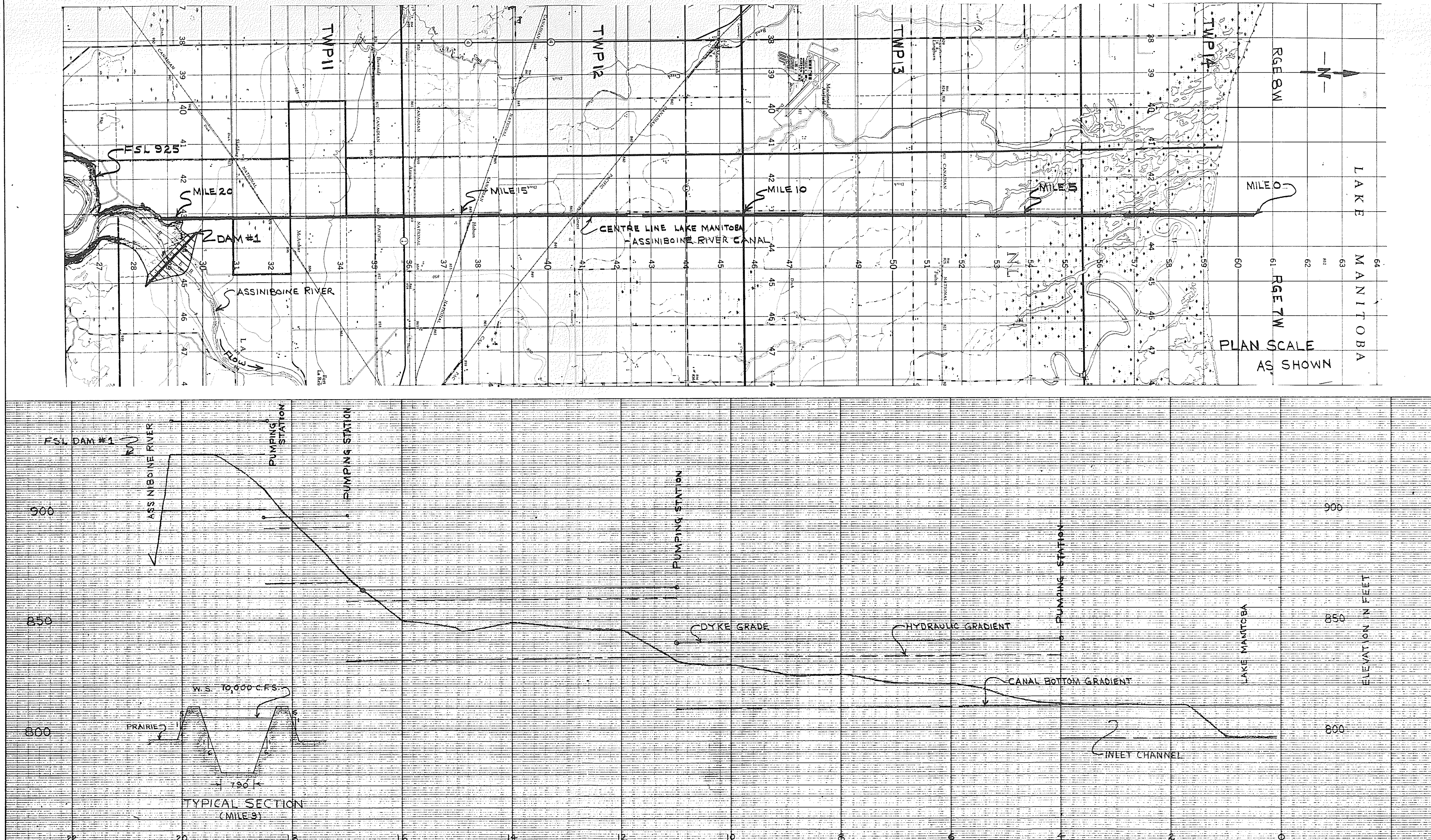
ASSINIBIONE RIVER SECTION

SOURIS RIVER SECTION

VELVA TUNNELS

UNIVERSITY OF MANITOBA

FIGURE 2

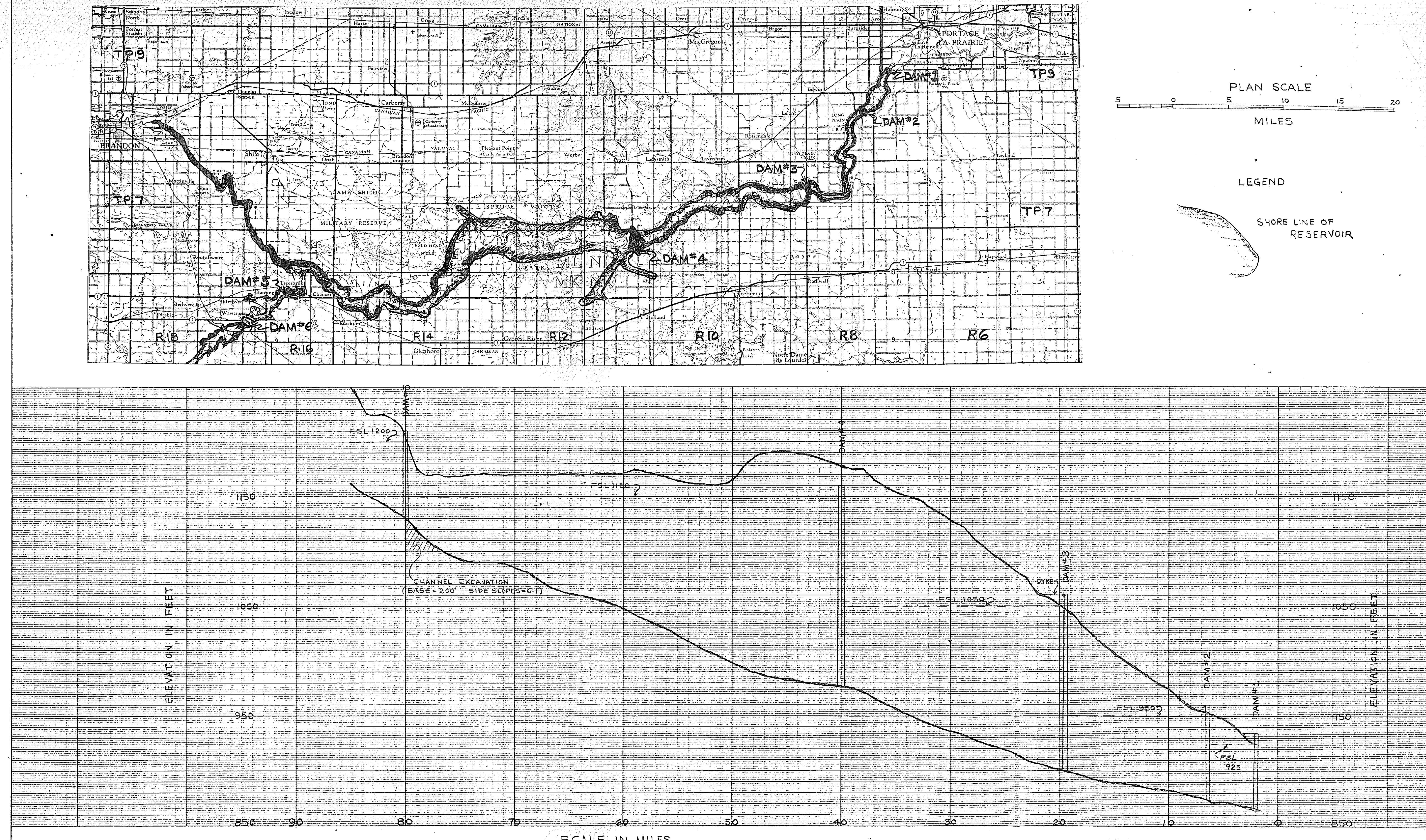


UNIVERSITY OF MANITOBA

LAKE MANITOBA - GARRISON RESERVOIR DIVERSION

LAKE MANITOBA - ASSINIBOINE RIVER CANAL

SCALE	DATE	SHEET	
AS SHOWN	JULY 70	1 OF 1	FIGURE 3.



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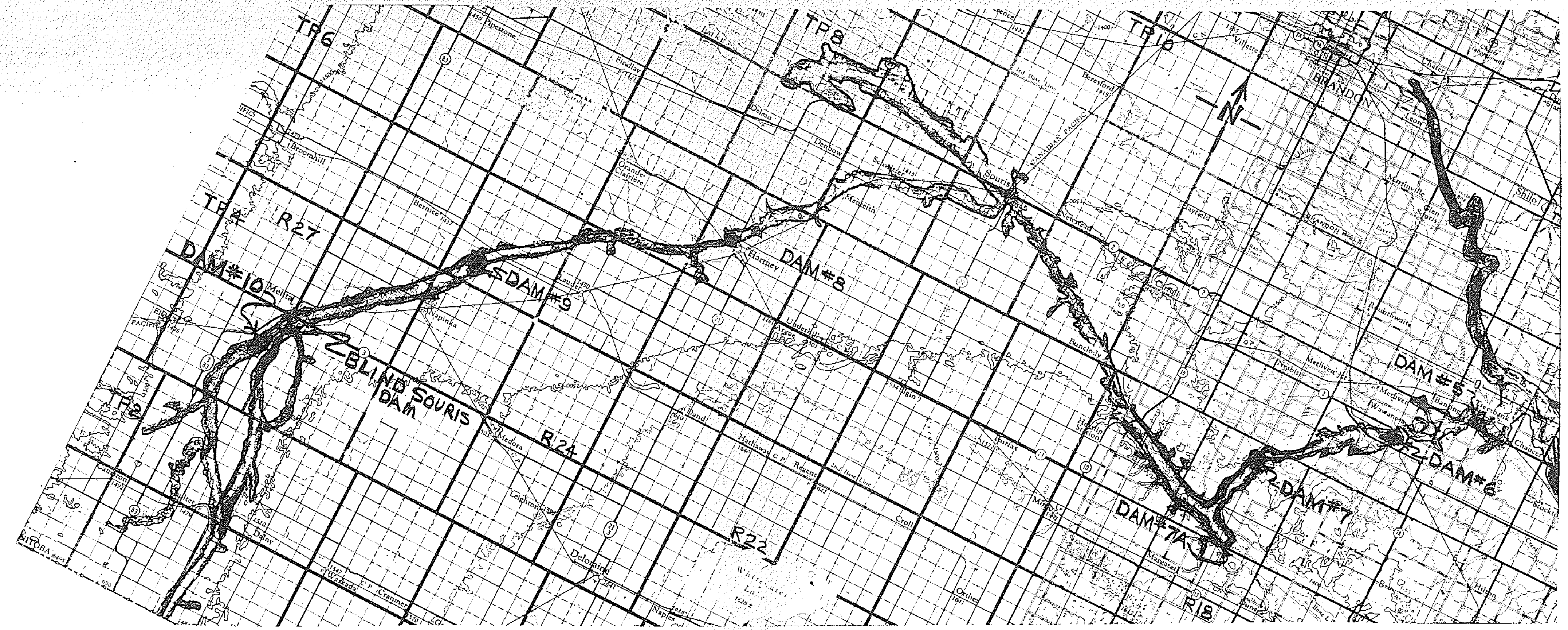
LAKE MANITOBA - GARRISON RESERVOIR DIVERSION

ASSINIBOINE RIVER REACH

SCALE	DATE	SHEET	
AS SHOWN	JULY 70	1 OF 1	FIGURE 4



PLAN SCALE

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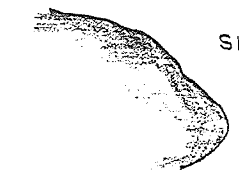
MILES

LEGEND



SHORE LINE OF RESERVOIR

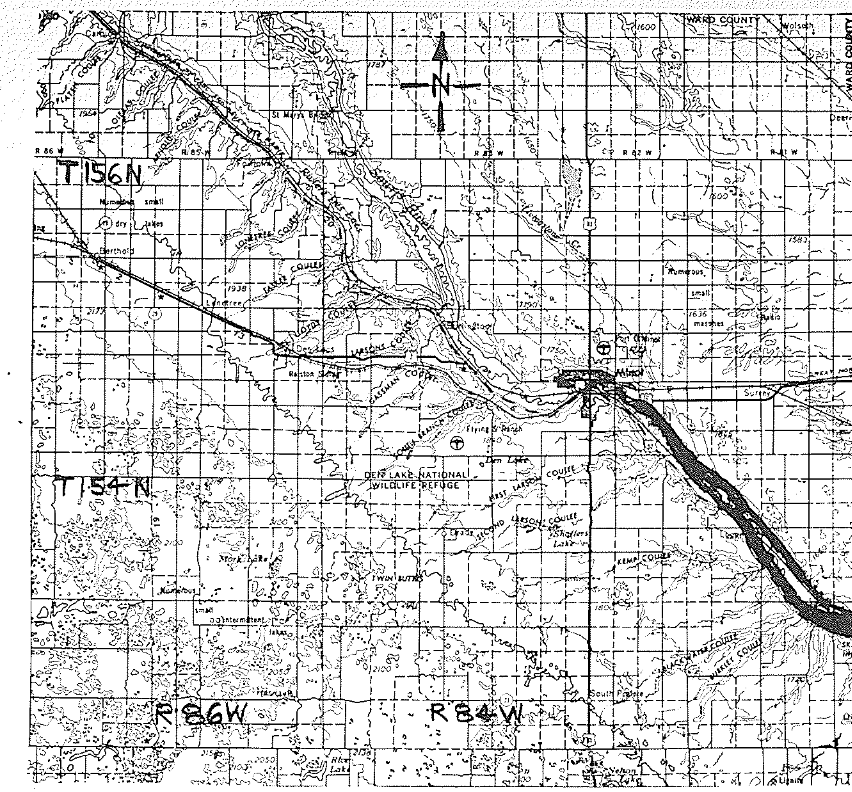
SCALE IN MILES

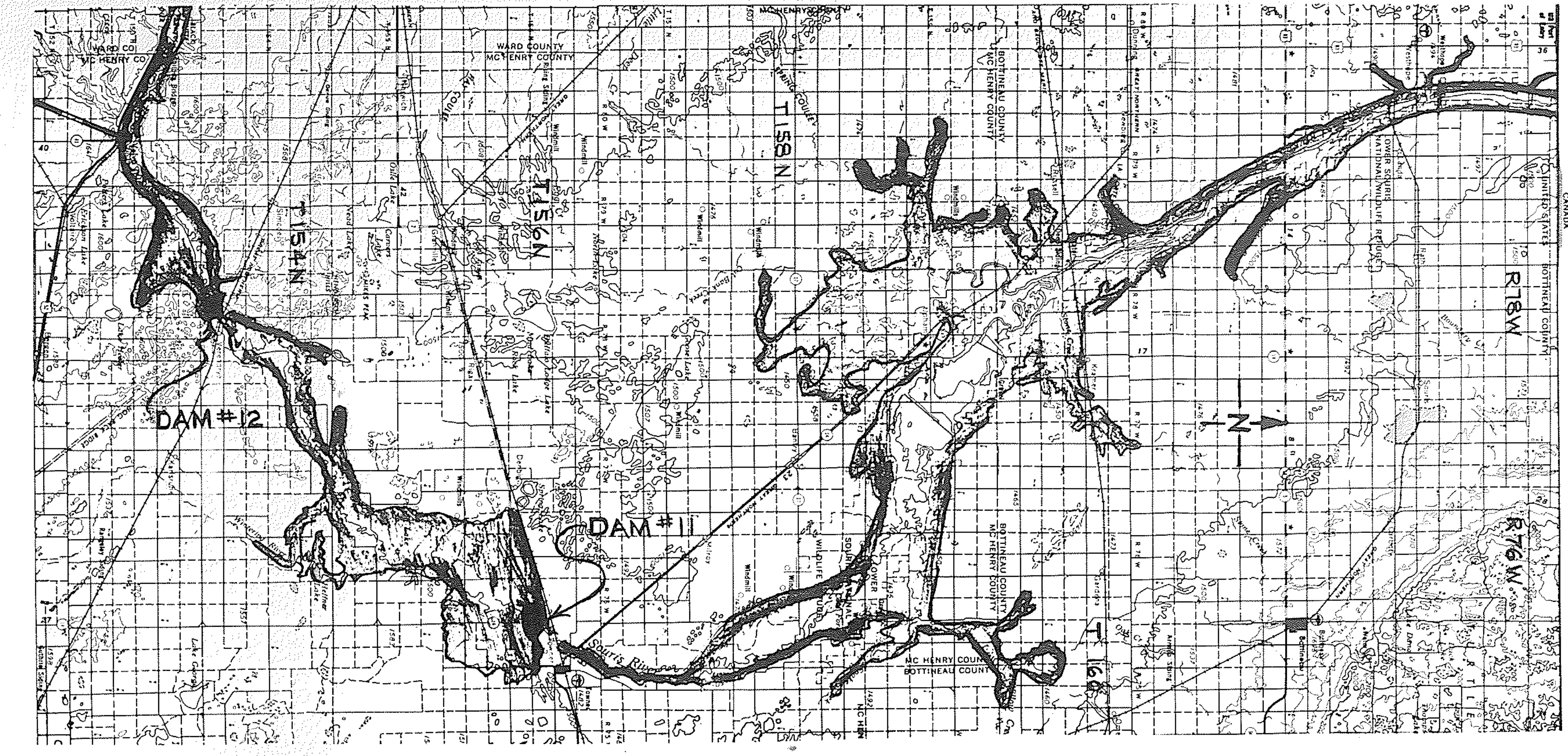
UNIVERSITY OF MANITOBA

LAKE MANITOBA - GARRISON RESERVOIR DIVERSION

SOURIS RIVER REACH

SCALE	DATE	SHEET	
AS SHOWN	JULY 70	1 OF 2	FIGURE 5





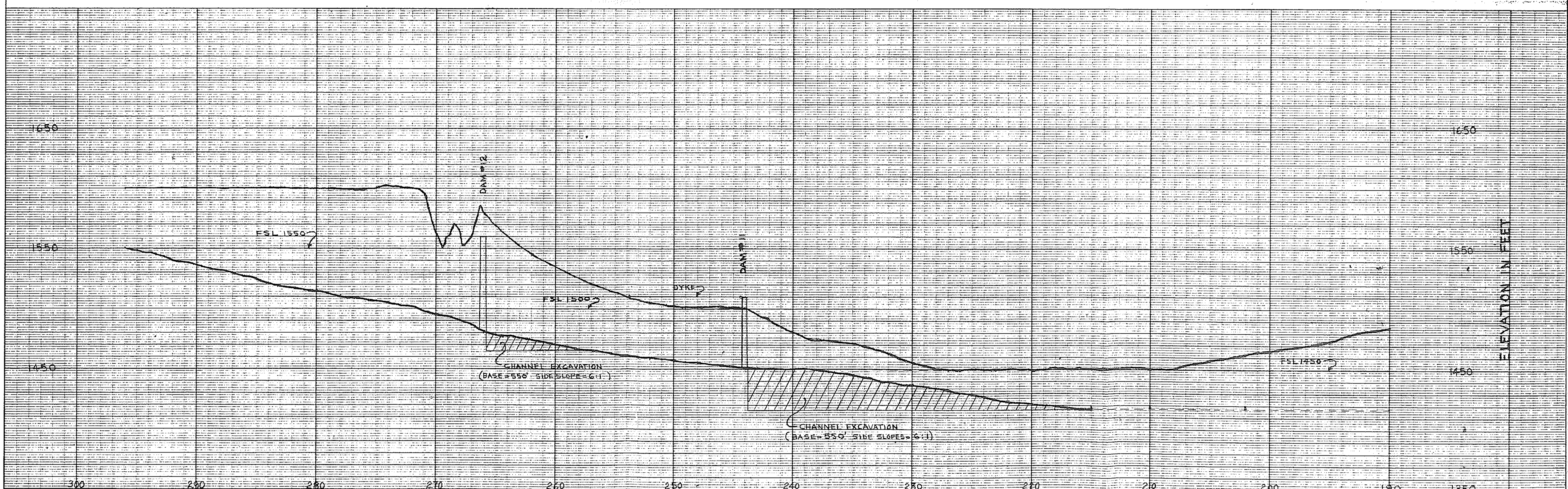
PLAN SCALE

5 0 10 15

MILES

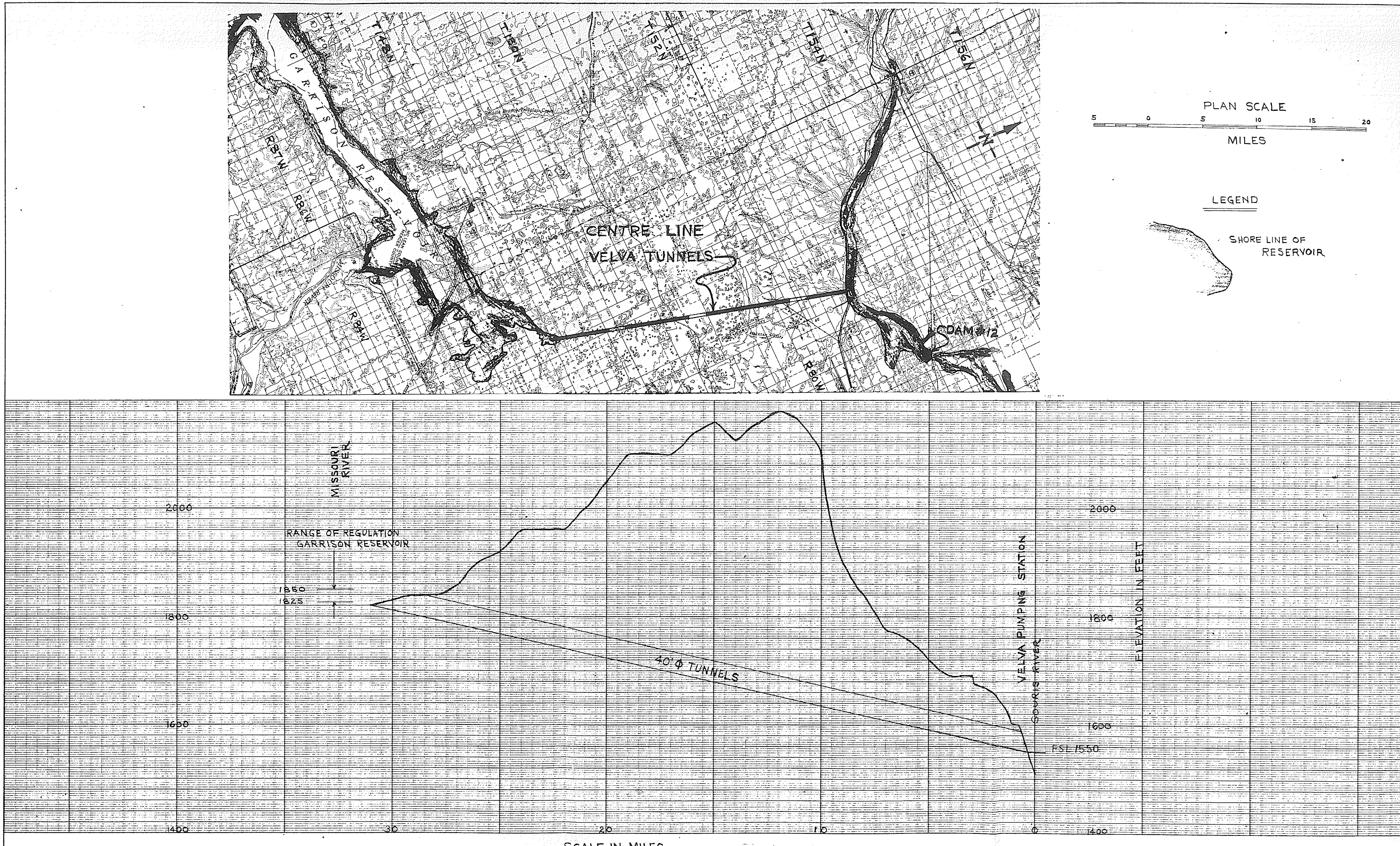
LEGEND

SHORE LINE OF RESERVOIR



SCALE IN MILES

UNIVERSITY OF MANITOBA			
LAKE MANITOBA - GARRISON RESERVOIR DIVERSION			
SOURIS RIVER REACH			
SCALE AS SHOWN	DATE JULY 70	SHEET 2 OF 2	FIGURE 5



UNIVERSITY OF MANITOBA

LAKE MANITOBA - GARRISON RESERVOIR DIVERSION

VELVA - GARRISON RESERVOIR TUNNELS

SCALE	DATE	SHEET	
AS SHOWN	JULY 70	1 OF 1	FIGURE 6

LAKE MANITOBA - GARRISON RESERVOIR DIVERSION

A P P E N D I X   A

HYDROLOGY AND HYDRAULICS OF THE SOURIS AND ASSINIBOINE RIVERS

APPENDIX A

INDEX

APPENDIX A

LIST OF TABLES

APPENDIX A

HYDROLOGY AND HYDRAULICS

OF THE

SOURIS AND ASSINIBOINE RIVERS

1. Introduction

The proposed diversion scheme required the construction of a number of dams and the creation of a corresponding number of reservoirs on the Souris and Assiniboine Rivers for the purpose of conveying diversion water from a point on the Assiniboine River a few miles upstream of Portage la Prairie, Manitoba to the vicinity of Velva, North Dakota, on the Souris River.

Since 70,000 cfs., the maximum diversion requirement, is considerable in excess of the natural runoff of the Souris and Assiniboine Rivers, it was necessary to verify whether or not the river valleys in question would be capable of containing the diversion flow.

The hydrological study of the Souris and Assiniboine Rivers, along the diversion route, was limited to a review of published and unpublished hydrological reports. The purpose of the hydrological study was to establish the order of magnitude of the spillway design flood for the dams and also to determine the effect of average runoff on the diversion.

2. Description of the Assiniboine River Valley

In the region between the Souris River confluence with the Assiniboine River and City of Portage la Prairie, a distance of 76 miles, the Assiniboine River transverses the Upper and Lower Assiniboine Delta formed during the glacial period of Lake Agassiz. In this region the river flows in a wide and deep valley, actively eroding its valley banks and degrading its bed. The valley averages $\frac{1}{2}$ to 1 mile in width.

The bottom of the valley has a ditch-like shape with alluvial deposits forming a thin layer on top of the original delta formation. The average slope of the river is about two feet per mile.

Although there are no villages or towns located in the Assiniboine River Valley along its reach, there are approximately 83 farmsteads and 4 vehicular crossings. There are no railroad crossings.

The Assiniboine River Valley is approximately 50% covered in with tree growth with the open area devoted to pasture and cultivated land.

3. Description of Souris River Valley

The Souris River Valley from its confluence with the Assiniboine River to Minot, North Dakota, has three distinct reaches.

The reach of the Souris River from the Assiniboine River to near the west end of Lang's Valley is an example of stream piracy. After the receeding of the glaciers from the last ice age, a tributary of the Assiniboine River eroded a channel through the Tiger Hill Region separating the Glacial Lake Souris area from the Assiniboine River Delta and captured the Souris River as it outletted through Lang's Valley. The Souris River Valley is deep, "V" shaped, averages 1/8 mile to 1/2 mile in width, and very irregular. The river is actively eroding its valley banks and degrading its bed in this reach. The valley bottom has a slope of 6.0 feet per mile. This section of the Souris River Valley is twenty-two miles in length.

The Souris River Valley from Lang's Valley to a point a few miles downstream of Verendrye, North Dakota, a distance of approximately 165 miles, is located in the plain once occuplied by Glacial Lake Souris. The valley width varies from 1/2 to 3 miles with the valley extended less than 100 feet below the surrounding plain and in places shows practically no valley incision. The valley in this area has an averaging bottom slope of 1.5 to 2.5 feet per mile.

The portion of the Souris River Valley upstream from Verendrye to Minot averages 3/4 miles in width and lies 100 to 200 feet below the surrounding plain. The valley walls are steep-sided. The valley bottom slopes average 1.5 feet per mile in this reach.

The towns of Wawanesa, Souris, Melita, Upham, Velva and Sawyer will be affected by the diversion if the diversion uses the Souris River Valley in the reaches where these particular towns are located as part of the conveyance system.

It is possible that as many as 174 farmsteads, 9 railroad bridges, 30 vehicular bridges, and 11 small dams will be affected by the diversion.

On the American portion of the diversion from the international border to a point south of the town of Verendrye, the U.S. Fish and Wildlife Service has established a wildlife refuge known as the Lower Souris National Wildlife Refuge. The wild fowl refuge was developed by constructing 5 small dams on the Souris River causing the creation of very shallow marshy empoundments.

In general, on the Canadian portion of the Souris River considered in this study approximately 50% of the area to be flooded is covered by tree growth. The remainder is either left to pasture or is cultivated. On the American portion approximately 10% of the area to be flooded is covered by marsh, a very small portion by tree growth and the remainder is pasture or cultivated land.

Reservoir damages for the proposed Assiniboime and Souris River empoundments are covered in Appendix C.

4. <u>Source of Topographical Data Used in the Study</u>

Topographic information was obtained from topographical charts prepared by the Surveys and Mapping Branch, Canada Department of Mines and Technical Surveys, for areas in Canada and from charts prepared by the Geological Survey U.S.A. Department of the Interior, for areas in the U.S.A.

In Canada, complete coverage of the area studied was available in 1:50,000 scale with a 25 foot contour interval with limited coverage available at 1:25,000 scale with a 10 foot contour interval. Coverage in the U.S.A. for the area studied was available at 1:25,000 scale with a 5 foot contour interval, with limited coverage at 1:50,000 scale with a 25 foot contour interval. The key plan used in both the U.S.A. and Canada portion of this study was at 1:250,000 scale with 50 foot contour interval and 100 foot contour interval respectively. Additional contour information on the Souris River and Assiniboine River in Manitoba was available from the Department of Mines and Natural Resources, Water Control and Conservation Branch, Province of Manitoba.

5. Source of Hydrological Data

Hydrological information for the Assiniboine River between Portage la Prairie and the Souris River confluence was obtained from the report "Assiniboine River Storage Project, Holland Dam" January, 1960, Manitoba Regional Office, Prairie Farm Rehabilitation Administration Engineering Branch, Canada Department of Agriculture.

Hydrological information for the Souris River between the Souris River confluence with the Assiniboine

River and Minot, North Dakota, was obtained from:

1. Review Survey of Souris River, North Dakota for Flood Control, November, 1965, U.S. Army Engineer District, St. Paul, Corps of Engineers, St. Paul, Minnesota.

2. Flood Frequency Studies for Drainage and Waterway Design in the Province of Manitoba, March, 1963, Water Control and Conservation Branch, Department of Mines and Natural Resources, Province of Manitoba.

3. Assiniboine River Storage Project, Holland Dam, P.F.R.A. 1960.

4. Prairie Provinces Water Board Report #7, Compilation and Reconstruction of Monthly Stream Records for the Qu'Appelle - Assiniboine Study, P.F.R.A., 1963.

6. Assiniboine River Hydrology

Past hydrological studies (1) have indicated that the maximum probable flood for the Assiniboine River, at the confluence of the Cypress River with the Assiniboine would be 87,000 cfs. This is indicative of the magnitude of the flow that would have to be used as the flood peak for the spillway design flood of all dams between Portage la Prairie and the Souris River confluence.

The average annual flow of the Assiniboine River for the period 1911 - 1956 in this reach was 1,287,243 acre-feet (2). Since the average annual flow represents only 2% and 8% of the 70,000 cfs. and 17,500 cfs. flow respectively it can be concluded that the average annual flow of the

Assiniboine River will have little or no effect on the diversion scheme.

The average annual gross evaporation from lake areas for the Assiniboine River along the proposed diversion route is about 27.5 inches (3). Annual net evaporation (gross evaporation less precipitation) averages about 9.0 inches (3).

7. Souris River Hydrology

In a report (11) prepared by the Corps of Engineers the maximum probable flood calculated for the Souris River just upstream from Burlington (contributing area = 3500 square miles) and for the Des Lacs River near Kenmore (contributing area = 259 square miles) was 45,200 cfs. and 21,500 cfs. respectively. The contributing drainage area of the Souris River at Minot, 19 miles downstream of the confluence of the Des Lacs River with the Souris, is 4200 square miles, consisting of 3500 square miles of contributing drainage area upstream of Burlington and 700 square miles of contributing drainage from Des Lacs River with low inflow between Burlington and Minot. Using the method and data outline in the report (11), the maximum probable flood at Minot would be in the order of 51,000 cfs.

Using a period of study of 1921 - 1965 at Wawanesa and a period of study of 1930 - 1965 at Westhope, a study (5) by the Water Control and Conservation Branch, Department of Mines and Natural Resources, Province of Manitoba, established the 0.1% floods on the Souris River at Westhope and Wawanesa of 87,000 cfs. and 24,000 cfs. respectively.

It would appear from the above mentioned figures that the order of magnitude of the maximum probable flood on the Souris River between Minot and Wawanesa would be 50,000 cfs. to 87,000 cfs. Since it is proposed to operate all reservoirs with no design storage allowance for floods, it can be anticipated that the maximum probable flood will lie towards the maximum of the suggested range. Therefore, for the purpose of this study 80,000 cfs. was used to indicate the order of magnitude of the spillway flood on the Souris River.

The average annual flow of the Souris River for the period 1911 - 1956 was 228,000 acre-feet (2). This flow constitutes part of the average annual flow reported in the Assiniboine River Hydrology Section of this appendix.

The average annual gross evaporation from lake areas for the Souris Basin in the U.S.A. is about 33 inches (7). Net evaporation (gross evaporation less precipitation) averages about 17.5 inches per year.

The average annual gross evaporation from lake areas for the Souris Basin in Canada is about 29 inches (3). Annual net evaporation (gross evaporation less precipitation) averages about 12 inches per year.

8. <u>Assiniboine River Hydraulics</u>

The reach of the Assiniboine River Valley between the location of Dam #1 and the confluence of the Souris River is practically suited to a reservoir system such as proposed in this diversion scheme. The river valley is wide and deep providing more than adequate cross-sectional flow area for the diversion flow.

The dam sites were selected with the view of concentrating the head lift at as few pumping stations (dam sites) as possible, provide sufficient (35 feet or more) tailwater (8) for pump submergence, and keep channel velocities below 3 fps. With the dam sites selected on this basis, the operating reservoir water surface was set.

Twenty-one cross-sections were established along the seventy-six miles of the Assiniboine River Valley for the purpose of carrying out backwater computations through the reservoirs. For the 70,000 cfs. flow it was calculated that the channel friction loss for 76 miles of the Assiniboine River Valley was 0.2 feet. Water in this reach is raised and conveyed from elevation 925 at Reservoir #1 to elevation 1050 at the confluence of the Souris and Assiniboine Rivers. This rather small friction loss does indicate quantitively the adequancy of the cross-sectional area of the Assiniboine River Valley available for flow.

It is possible to raise the terminal water surface of this reach higher than elevation 1150, however, any additional raising in this water surface would cause a determinal backwater effect at Brandon during floods on the Assiniboine River. Brandon is located 25 miles upstream of the confluence of the Souris and Assiniboine Rivers on the Assiniboine River.

No channel improvements are required for the 70,000 cfs. and 52,500 cfs. design flows. However, in order to provide sufficient submergence for the pumping stations at Dam #3 and Dam #4A some channel excavation will be required for the 35,000 cfs. and 17,500 cfs. design flows. These improvements would be local and minor in nature. Approach velocities at both Dam #3 and Dam #4A are less than 3.0 fps. under natural conditions. Table A-1 contains an example of a backwater calculation.

9. Souris River Hydraulics

The Souris River Valley is much smaller than the Assiniboine River Valley and not as ideally suited for conveying the diversion flow.

As on the Assiniboine River, dam sites were selected with the view of concentrating the head lift at as few pumping stations as possible, provide tailwater (8) for pump submergence, and keep channel velocity below 3 fps.

Ninety-six cross-sections were established along the two hundred and twenty miles of the Souris River Valley forming part of the proposed diversion.

In order to keep the channel velocities below 3.0 fps. it was found necessary to carry out extensive channel improvements along the Souris River. The exception to this was for the reservoir behind Dam #9 for all discharges studied and for the reservoirs behind Dam #7 and Dam #8 for the 35,000 cfs. and 17,500 cfs. flows studied. Local channel improvements at the intakes to the pumping stations at Dam #8 and Dam #9 will have to be made to provide sufficient submergence for the pumps. These improvements will be minor in nature.

It was felt that an economical channel improvement design would be established by enlarging the channel to the point where the incremental annual charge on the capital cost of the enlargements equalled the incremental annual saving in power costs. However, before that point could be reached the velocity in the improved channel equalled 3.0 fps.

It was found that with the channel improvements proposed that the reservoir levels were drawn down from four to six feet from the F.S.L. at the inlet to pumping stations for all the design flows studied. Table A-2 contains a list of river improvements for dams on the Souris and Assiniboine Rivers.

10. Capital Cost of Channel Improvements

Capital cost and yardage involved in the channel improvements are listed in Table A-3.

TABLE A-1

SAMPLE BACKWATER CALCULATION

From Dam #1 to Dam #2

Section 1-1 near Dam #1

Q = 70,000 cfs.
FSL = 925
Flow Area (A) at 925 = 141,000 sq. ft.
Width at water surface (tw) = 3600 ft.

$$\text{Wetted Perimeter} = tw + \frac{2A}{tw}$$

$$\text{Wetted Perimeter (P) } 3600 + \frac{2(141,000)}{3600}$$

$$= 3680$$

$$\text{Hydraulic Radius (R)} = \frac{A}{P}$$

$$= \frac{141,000}{3680}$$

$$= 38.3$$

$$\text{Conveyance factor (Kd)} = \frac{1.486\ A\ R^{2/3}}{n}$$

Let n = 0.03

$$Kd = \frac{1.486 \times 141,000 \text{ ft.} \times (11.3)^{2/3}}{0.03}$$

$$= 79 \times 10^6$$

$$\text{Slope of water surface} = \frac{Q}{Kd}\ 2$$

$$= \frac{70,000}{79 \times 106}\ 2$$

$$= 79 \times 10^{-8}$$

Section 2-2 near Dam #2

FSL = 925
Flow Area (A) to 925 = 121,000 sq. ft.
Width at water surface (tw) = 3320 ft.

$$\text{Wetted Perimeter} = tw + \frac{2A}{tw}$$

$$\text{Wetted Perimeter (P)} = 3320 + \frac{2(121,000)}{3320}$$

$$= 3392$$

$$\text{Hydraulic Radius (R)} = \frac{A}{P}$$

$$= \frac{121{,}000 \text{ sq. ft.}}{3392 \text{ ft.}}$$

$$= 10.7$$

Conveyance Factor (Kd) $= \dfrac{1.486\ AR^{2/3}}{7}$

Let $n = 0.03$

$$Kd = \frac{1.486 \times 121{,}000 \times (10.7)^{2/3}}{0.03}$$

$$= 64 \times 10^{6}$$

Slope of water surface $S = \left(\dfrac{Q}{Kd}\right)^2$

$$= \left(\frac{70{,}000}{64 \times 10^{6}}\right)^2$$

$$= 118 \times 10^{-8}$$

Average Slope $= \dfrac{\text{Slope at Section 1-1} + \text{Slope at Section 2-2}}{2}$

$$= \frac{79 \times 10^{-8} + 118 \times 10^{-8}}{2}$$

$$= 98.5 \times 10^{-8}$$

Distance between Dam #1 and Dam #2 = 4.5 miles

Drop in water surface between Dam #1 and Dam #2

= average slope x distance

$= 98.5 \times 10^{-8} \times 4.5 \text{ miles} \times 5200 \text{ ft/mile}$

= 0.023 ft.

TABLE A-2

CHANNEL IMPORVEMENTS

(A) 70,000 cfs.

Location	Improvement	Length of Improvement	Base Elevation for Improvement
Downstream of Dam #5	base = 200' side slopes = 6 to 1	3.0 miles	1100
Downstream of Dam #6	same as above	2.8 miles	1150
Downstream of Dam #8	same as above	16.5 miles	1350
Downstream of Dam #9	same as above	14.0 miles	1360
Downstream of Dam #11	base = 550' side slope = 6 to 1	28.0 miles	1415
Downstream of Dam #12	base = 550' side slopes = 6 to 1	7.5 miles	1465

(B) 52,500 cfs

Location	Improvement	length of Improvement	Base Elevation for Improvement
Downstream of Dam #5	base = 100' side slope = 6 to 1	3.0 miles	1100
Downstream of Dam #6	base = 100' side slope = 6:1	2.8 miles	1150
Downstream of Dam #8	base = 150' side slope = 6:1	16.5 miles	1350
Downstream of Dam #9	base = 150' side slope = 6:1	14.0 miles	1360
Downstream of Dam #11	base = 475' side slope = 6:1	28.0 miles	1415

Location	Improvement	Length of Improvement	Base Elevation for Improvement
Downstream of Dam #12	base = 475' side slope = 6:1	7.5 miles	1465

(C) 35,000 cfs.

Location	Improvement	Length of Improvement	Base Elevation for Improvement
Downstream of Dam #3	Local Improvement to provide sufficient depth for pump submergence		
Downstream of Dam #4A	Local Improvement to provide sufficient depth for Pump submergence		
Downstream of Dam #5	base = 50' side slope = 6:1	3.0 miles	1100
Downstream of Dam #6	base = 50' side slope = 6:1	2.8 miles	1150
Downstream of Dam #8	Local Improvement to provide sufficient depth for pump submergence		
Downstream of Dam #9	Local Improvement to provide sufficient depth for pump submergence		
Downstream of Dam #11	base = 200' side slope = 6:1	28.0 miles	1415
Downstream of Dam #12	base = 200' side slope = 6:1	7.5 miles	1465

(D) 17,500 cfs.

Location	Improvement	Length of Improvement	Base Elevation for Improvement
Downstream of Dam #3	Local Improvement to provide sufficient depth for pump submergence		
Downstream of Dam #4A	Local Improvement to provide sufficient depth for pump submergence		
Downstream of Dam #5	base 25' side slope = 6:1	3.0 miles	1100
Downstream of Dam #6	base = 25' side slope = 6:1	2.8 miles	1150
Downstream of Dam #8	Local Improvement to provide sufficient depth for pump submergence		
Downstream of Dam #9	Local Improvement to provide sufficient depth for pump submergence		

Downstream of Dam #11	base = 80' side slope = 6:1	28.0 miles	1415
Downstream of Dam #12	base = 80' side slope = 6:1	7.5 miles	1465

(E) Improvements Downstream of Bunclody Canal Pumping Station

Flow	Improvements	Length of Improvements	Base Elevation of Improvement
70,000 cfs.	base = 550' side slope = 6:1	4.0 miles	1315
62,500 cfs.	base = 475' side slope = 6:1	4.0 miles	1315
35,000 cfs.	base = 200' side slope = 6:1	4.0 miles	1315
17,500 cfs.	base = 80' side slope = 6:1	4.0 miles	1315

TABLE A-3

CAPITAL COST OF CHANNEL

IMPROVEMENTS

(A) 70,000 cfs.

Location	Yardage	cost/cubic yard		Capital Cost
Downstream of Dam #5	2,600,000 cu.yds.	@ $0.40 /cu.yd.	=	$ 1,040,000
Downstream of Dam #6	1,750,000 cu.yds.	@ $0.40 /cu.yd.	=	700,000
Downstream of Dam #8	16,800,000 cu.yds.	@ $0.40 /cu.yd.	=	6,700,000
Downstream of Dam #9	24,300,000 cu.yds.	@ $0.40 /cu.yd.	=	9,700,000
Downstream of Dam #11	88,000,000 cu.yds.	@ $0.40 /cu.yd.	=	35,200,000
Downstream of Dam #12	7,500,000 cu.yds.	@ $0.40 /cu.yd.	=	3,000,000

(B) 62,500 cfs.

Location	Yardage	cost/cubic yard		Capital Cost
Downstream of Dam #5	1,830,000 cu.yds.	@ $0.40 /cu.yd.	=	$ 740,000
Downstream of Dam #6	1,200,000 cu.yds.	@ $0.40 /cu.yd.	=	480,000
Downstream of Dam #8	13,500,000 cu.yds.	@ $0.40 /cu.yd.	=	5,400,000
Downstream of Dam #9	21,000,000 cu.yd.	@ $0.40 /cu.yds.	=	8,400,000
Downstream of Dam #11	83,800,000 cu.yd.	@ $0.40 /cu.yd.	=	33,500,000
Downstream of Dam #12	5,800,000 cu.yd.	@ $0.40 /cu.yd.	=	2,320,000

(C) 35,000 cfs.

Location	Yardage	cost/cubic yard	Capital Cost
Downstream of Dam #3	Assumed to be included in the capital cost of the pumping station		
Downstream of Dam #4A	Assumed to be included in the capital cost of the pumping station		
Downstream of Dam #5	1,470,000 cu.yds.	@ $0.40 /cu.yd. =	$ 585,000
Downstream of Dam #6	930,000 cu.yds.	@ $0.40 /cu.yd. =	370,000
Downstream of Dam #8	Assumed to be included in the capital cost of the pumping station		
Downstream of Dam #9	Assumed to be included in the capital cost of the pumping station		
Downstream of Dam #11	49,500,000 cu.yds.	@ $0.40 /cu.yd. =	19,800,000
Downstream of Dam #12	3,000,000 cu.yds.	@ $0.40 /cu.yd. =	1,200,000

(D) 17,500 cfs.

Location	Yardage	cost/cubic yard	Capital Cost
Downstream of Dam #3	Assumed to be included in the capital cost of the pumping station		
Downstream of Dam #4A	Assumed to be included in the capital cost of the pumping station		
Downstream of Dam #5	1,290,000 cu.yds.	@ $0.40 /cu.yd. =	515,000
Downstream of Dam #6	800,000 cu.yds.	@ $0.40 /cu.yd. =	318,000
Downstream of Dam #8	Assumed to be included in the capital cost of the pumping station		
Downstream of Dam #9	Assumed to be included in the capital cost of the pumping station		
Downstream of Dam #11	32,000,000 cu.yds.	@ $ 0.40 /cu.yd. =	12,800,000

Downstream of Dam #12	1,870,000 cu.yds.	@ $0.40 /cu.yd.	= 750,000

(E) Improvements Downstream of Bunclody Pumping Station

Flow	Yardage	cost/cubic yard	Capital Cost
70,000 cfs.	3,760,000 cu.yds.	@ $0.40 /cu.yd.	= $1,500,000
62,500 cfs.	3,300,000 cu.yds.	@ $0.40 /cu.yd.	= 1,320,000
35,000 cfs.	1,700,000 cu.yds.	@ $0.40 /cu.yd.	= 680,000
17,500 cfs.	1,000,000 cu.yds.	@ $0.40 /cu.yd.	= 400,000

LAKE MANITOBA - GARRISON RESERVOIR DIVERSION

A P P E N D I X B

DAMS

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APPENDIX B

DAMS

1. Introduction

The purpose of this section is to carry out a cursory review of the foundation conditions at each damsite to see if there are any reasons why the dam cannot be built at the locations selected; to suggest the type of dams to be built; and to calculate the cost of each dam.

In addition a brief review is made of the spillway and gate design criteria; water diversion during construction; availability of construction materials; and water losses from the reservoir system.

2. Foundation Data

For the Canadian section of the diversion, foundation and soils information was obtained from the following reports:

1. Report of Reconnaissance, Soil Survey of Carberry Map Sheet Area, Soils Report No. 7, 1957, Manitoba Department of Agriculture and Immigration.
2. Report of Reconnaissance Soil Survey of South-Central Manitoba, Soil Report No. 4, March, 1943, Dominion Department of Agriculture and Soils Department, The University of Manitoba.

3. Reconnaissance Soil Survey South-Western Manitoba, Soil Report No. 3, December, 1940, Dominion Department of Agriculture, Provincial Department of Agriculture and Soils, University of Manitoba.

4. Surface Deposits and Ground-water Supply of Winnipeg Map Area, Manitoba, Memoir 17, Bureau of Economic Geology, Geological Survey, Department of Mines.

Additional soils information in Canada was obtained from bridge soil logs made available by the Bridge Office, Department of Highways, Province of Manitoba and from the report "Assiniboine River Storage Projects, Holland Dam", January, 1960, Manitoba Regional Office, Prairie Farm Rehabilitation Administration Engineering Branch, Canada Department of Agriculture.

For the American Section of the Diversion, foundation and soils information was obtained from the following reports:

1. Report on Garrison Diversion Unit, Garrison Diversion Appendix IV, United States Department of the Interior, Bureau of Reclamation, October 2, 1956.

2. Geology of the Souris River Area, North Dakota, Geological Survey of Professional Paper #325, 1960.

3. <u>Review of Foundation Conditions on Assiniboine River</u>

In the region between the Souris River confluence with the Assiniboine River and Portage la Prairie, the Assiniboine River transverses the upper and lower Assiniboine Delta.

The Upper Assiniboine Delta area consists of outwash and lacustrine plains located above the Manitoba Escarpment. The lacustrine plain is composed of course, medium to fine textured deposits.

The Lower Assiniboine Delta area consists of a smooth sandy lacustrine plain located below the Manitoba Escarpment. The sandy deposits vary from three to fifteen feet in thickness and are underlain by lacustrine deposits and boulder till.

Dams #1 and #2 and associated structures are located on an area covered by 5 to 15 feet of sand developed on lacustrine deposits. Internal soil drainage in the area is imperfect-to-poor which would suggest that little or no water loss should occur from the reservoir area to ground water. Depth to bedrock below the valley is unknown.

The north bank of the valley, in the vicinity of Dam #1, and the north and south bank, in the vicinity of Dam #2, shows signs of erosion.

Test borings for P.R. #305 Assiniboine River Crossing (Location of Dam #2) indicated that grey clayey silt extended down to at least 45 feet below the river bottom. Depth to bedrock is unknown.

Dam #3 is located at the toe of the Manitoba Escarpment at the lower boundary of the Upper Assinboine Delta. The lacustrine deposits in the area are covered by 5 to 15 feet of loamy sands. Bedrock consists of sandstone, shale and low grade coal. Depth to bedrock is unknown. Both valley banks show evidence of erosion. The south bank of the reservoir area formed behind Dam #3 is developed on sandy-to-medium textured lacustrine deposits which are internally well drained. The north bank consists of sandy deltaic deposits to a depth of up to 200 feet. These deltaic deposits have good-to-excessive internal soil drainage which would indicate a high permeability of the sandy material. The nature of the deposits on the south and north banks of the reservoir suggests that considerable loss of reservoir water could occur to these deposits.

Highways Department test borings for the P.R. #244 crossing of the Assiniboine River approximately 3 miles upstream of Dam #3 indicated that grey silty sand underlain the river to a depth of 70 feet. Depth to bedrock is unknown.

Dam #4 is located in the vicinity of the once proposed Holland Dam immediately downstream of the Cypress River confluence. The area adjacent to the north abutmemt of the dam consists of a deltaic deposit of sand developed on a lacustrine deposit up to 200 feet thick. These sandy soils have a high permeability indicating that there may be high loss of reservoir water to ground water storage. The south bank of the river valley in the area of the dam is eroded and consists of sandy soils. The reservoir banks are formed of coarse textured materials. Internal drainage is good-to-excessive. Bedrock in the area of the dam and reservoir consists of shale and bentonite.

Actual field soils drilling have been carried out at the proposed location for Dam #4 which would be located in the vicinity of P.T.H. #34 Assiniboine River Crossing. This location is the location that was originally selected as the proposed site for the once proposed Holland Dam. Soil drilling (1) at the site indicated that shale would be located at approximately elevation 960 and was covered by glacial clay, alluvial clays and silts, with sand located at the surface. The river itself has been able to cut its channel down to shale at this site exposing on its valley sides the different soil horizons. This generally confirms the information obtained from the soil sheets.

In review, the Assiniboine Valley in the reach from Dam #1 to the Souris River confluence with the Assiniboine consists of alluvial deposits. The depth of the alluvial deposits is not known. Generally the river is eroding its banks and is in the process of degrading the river valley. The problems anticipated with this type of foundation conditions are settlement, possible piping, excessive percolation losses, erosion of the river banks, and the largest problem of all, embankment stability. However none of these problems appear to be severe enough to rule out the possibility of constructing dams at the selected locations.

4. <u>Review of Foundation Conditions on the Souris River</u>

Dams #5, #6 and #7 are located in the reach of the Souris that lies between the Assiniboine River and the confluence of the Souris River and the Pembina River Valley. This section of the Souris River is relatively young and is eroding. This section of the river is characterized by a narrow valley with steep banks. After the last glacial age Glacial Lake Souris drained to Lake Agassiz by following what is now the Pembina River Valley. With the glacier receding to the north, a tributary of the Assiniboine River eroded back and "captured" the Souris River giving it an outlet alongs its present course. The west end of the Pembina River Valley (known as Lang's Valley) and the Souris River Valley are located at elevation 1375. Because the F.S.L. of Reservoir #7 is 1400, it will be necessary to construct Dam #7A east of the confluence of the Souris and Pembina River Valleys in order to prevent water spilling out of the Souris River into the upper reaches of the Pembina River Valley. For Dam #7 (F.S.L. 1350) associated with the Bunclody canal, Dam #7A will not be required.

Soils in this reach of the Souris Valley are very fine, sandy loams to clay loams which are founded on lacustrine deposits in the area of Dams #5 and #6 and on boulder till which is found in the general area of Dams #7 and #7A.

It is anticipated that problems associated with construction of Dams #5, #6, #7 and #7A will be seepage and stability problems associated with the dam and the valley banks. It is not expected that settlements will be excessive. The potential frost heave associated with sandy loam soils may cause problems with the design of the spillways.

Dam #8 is located immediately west of Hartney in an area where the soil is essentially a loamy sand. Seepage problems can be expected with this site. Settlement or dam stability should not be a problem.

Dams #9 and #10 are located immediately upstream of the Village of Napinka and the Town of Melita on the Souris River. These dams are located in an area in which the Souris Valley is covered by loamy, coarse sand over gravel deposits. Settlement, and dam settlement should not be a major problem at these two sites. There is a possibility that if the silty clay deposits covering the valley in this area does not extend to full supply level of Dam #9 that some water may be lost to the gravel deposits forming the high banks.

Dam #11 is the first dam in the proposed system located in the U.S.A. Dam #11 is located immediately upstream of the Town of Towner in the vicinity of U.S. Highway #22.

Dam #11 is located on the floor of Glacial Lake Souris. The Souris River in this area has cut into the bottom of the lake. In general, the river bottom consists of outwash and inwash deposits. No information is available as to the nature of the material forming the foundation for the proposed dam but is assumed that the usual problems of settlement, seepage and stability associated with glacial lake bottoms will be present.

Dam #12 would be located in the general vicinity of the proposed Velva Canal Siphon, a component of the Garrison Diversion Unit (12). The preliminary investigation of the proposed siphon site revealed that materials forming the foundation for the siphon are chiefly of two types: glacial till and associated sands and gravels on the abutments, and alluvial clays and sands in the valley. The valley floor may present some problems associated with settlement and seepage losses. The valley walls, however, should present suitable foundations for the dam abutments.

In general, the Souris River provides a much better foundation condition for the construction of dams than does the Assiniboine River. There does not appear to be any problems severe enough to rule out the possibility of constructing a dam at any of the sites selected.

5. Type of Dam

Foundation conditions along the Assiniboine and Souris Rivers are such that general and differential movement of the dams and structures associated with dams can be expected. For this reason, maximum flexibility will have to be built into the structures. Since foundation requirements for earthfill dams are less stringent than for other types of dams, earth dams will be used on this diversion.

6. Availability of Construction Materials

It would appear by a general appraisal of the available materials in the area that much of the construction material for the construction of earth embankment dams is readily available near each dam although much of the material will not be of the highest grade. It is expected that much of the aggregate for the concrete work will have to be manufactured by screening and washing native material. Suitable material for rip rap may be difficult to find in sufficient quantities. However, in general, most material will be available within twenty miles of each site.

7. Design Considerations for Dams on Assiniboine River

For the deisgn of Dams #1, #2, #3 and #4 it was assumed that the fine to coarse grained alluvial soils forming the Assiniboine River Valley bottom in this area had sufficient bearing strength to withstand the loading of the dam would impose upon it without excessive amounts of settlement developing. However, it was assumed that the shearing strength of the fine grained alluvial deposits was low and that these deposits extended to a depth greater than the height of the dam. Because of the possibility of the slip failure developing under these conditions, the design of the dam called for flat side slopes.

Because of the availability of impervious and pervious fill material in the general vicinity of the structures, a rolled earth fill zoned embankment type of construction was adopted for the design of the dams. The available pervious borrow consists principally of sand and silty sand, which is not ideal, but is acceptable for pervious sections of the embankment. Impervious material would be available from the lacustrine deposits underlying the sandy surface deposits in the area. The spillway would be located largely on overburden and would transverse materials varying from sands, with high potential frost heave, to impervious clays with probable swelling problems. The pumphouse conduits would be located on the valley floor on an impervious foundation. Probable problems would be initial swelling of the consolidated clays, settlement, and differential settlements caused by the weight of the dam embankment.

The preliminary examination of the dam site indicates that dam construction will be difficult and costly. However, there is no reason to believe that the problem will be so serious as to rule out the sites chosen.

8. Design Consideration for Dams on Souris

In general, the foundation conditions for the dams on the Souris River are much better than those on the

Assiniboine River. The valley bottom on the Souris River should have sufficient bearing strength to withstand the loading imposed upon it without excessive amount of settlement. It is anticipated that because the depth to firm foundation (till on the Souris) is less than that on the Assiniboine River that foundation conditions on the Souris River are expected to be much less severe than on the Assiniboine River. However, it was assumed that the shearing strength of the fine grained alluvial deposits was low and that these deposits extended to a greater depth than the height of the dam. Although this is probably not true for many of the sites on the Souris River, it is difficult to assume otherwise without actual soil borings on the proposed sites. Under these circumstances it was deemed advisable to assume the worst possible conditions. Because of the possibility of a slip failure developing under these conditions, the design of the dams called for flat side slopes.

Because of the availability of impervious and pervious fill material in the general vicinity of the structures, a rolled earth fill zoned embankment type of construction was adopted for the design of the dams. In general, the comments attributed to the availability of borrow, spillway locations, and pumphouse conduits applicable to the dams on the Assiniboine River are applicable here.

The preliminary examination of the dam sites indicates that the dam construction will be difficult and costly. It is not anticipated that any foundation problems will develop that would be serious enough to rule out the sites chosen.

9. Dam Design

A preliminary design of a number of dams was made using approximate design procedures (9) for the condition where the depth to bedrock under the dam exceeds the height of the dam. It was assumed that the foundation material consisted of fine grained material with a low shearing strength.

The resulting dam cross-section for the conditions described above is indicated in Figure B-1.

Although it was anticipated that foundation conditions would be considerably less severe on the Souris River than the Assiniboine River, the same design assumptions were made for the dams on the Souris as were made for the dams on the Assiniboine River.

10. Spillway and Gate Design Criteria

As pointed out in Appendix A, the maximum possible floods on the Souris and Assiniboine Rivers are in the order of 80,000 cfs. and 87,000 cfs. This is the order of magnitude of flow that the spillways on the Souris and Assiniboine Rivers would have to be designed to handle. Since in a supply system such as this diversion little or no storage would be available in the reservoir to reduce the maximum possible floods, it would be necessary to pass the floods through the system without any appreciable reduction in the peak.

For this reason the spillways would have to be fitted with gates so that the reservoir levels could be manipulated to pass the design flood with little increase in the water surface of the reservoir.

11. Water Diversion During Construction

For the purpose of this study it was assumed that the diversion of the normal river flow was accomodated in the pumping station conduits during the construction of the dam. The conduits would be constructed at the beginning of dam construction and the river flow divered to them while the dam was completed.

It is possible by constructing the upstream dams on the Souris and Assiniboine Rivers first that a significant saving in cofferdams costs could be realized during construction by storing peak runoffs in the reservoirs created by these dams and releasing the water during the year and thus reducing the peak stages on these rivers.

Since this study is preliminary in nature this aspect was not investigated further.

12. Water Losses - Evaporation, Percolation and Seepage

Evaporation losses on the Assiniboine and Souris segments of the diversion are expected to average 60,500 acre-feet and 244,000 acre-feet respectively based on a net annual evaporation of 9 and 15 inches on the Assiniboine and Souris Rivers respectively.

Percolation losses into the banks of the Assiniboine and Souris Rivers are difficult to calculate with any accuracy. The loss of water to the groundwater aquifer is dependent upon the type of aquifer, the hydraulic conductivity, storage capacity, and existing hydraulic gradient available in the aquifer, as well as the level of the water table in relation to the F.S.L. of the reservoir system (22). Even if high initial losses are experienced it is anticipated that the losses will drop sharply as the available hydraulic gradient is flattened by the raising of the water table in the general area of the reservoir. It is anticipated that the general ground water condition within twenty miles of the reservoir will be effected by the empoundment of water behind the proposed dams. In the case of the reservoirs on the Assiniboine River the ground water regine may be noticeably changed with a significant change in the number of springs developing along the slope of the Manitoba Escarpment. No attempt was made to calculate the amount of water that may be lost due to percolation since it was felt that this type of a study was beyond the scope of this report.

Percolation losses into the banks of the Souris River are not expected to cause any difficulties. The percolation losses are not expected to alter the ground water regime significantly along the Souris. Some springs may develop in the vicinity of Dam #11 where the Souris River leaves glacial Lake Souris. Most of the problems along the Souris are expected to be related to seepage losses rather than percolation losses.

Seepage losses which are usually considered to be the loss of water from the upstream impoundment to the tailwater of the dam are expected to present a piping problem in the dam foundation for most of the dam locations considered. It is anticipated that in order to control this loss so as not to cause any distress to the dam foundation that suitable cutoffs will have to be constructed. The design of the dam embankment will have to be such to reduce seepage through the dam proper to control seepage to an acceptable level.

13. Cost Estimate for Dam

For the purpose of estimating the cost of constructing the dams, a review was made of all dams of any significant size (in excess of 330,000 cubic yards) either proposed or built on the Assiniboine, Souris or Pembina Rivers.

In total nine dams were reviewed. The actual cost for the dam proper, including conduits, spillways, and gates but excluding reservoir damages, right-of-way and clearing costs, and the number of cubic yards of embankment in each dam were tabulated as shown in Table B-1. A cost per cubic yard of embankment was established and these plotted to form a "volume of embankment versus cost per cubic yard of embankment" curve. This is shown in Figure B-1.

Cost of constructing the dam in this study was calculated by computing the volume of embankment at each dam site, using the site cross-section and seven to one side slopes both upstream and downstream of the dam and a 50 foot dam top, and obtaining the appropriate cost per cubic yard of embankment from Figure B-1.

Table B-1

COST OF ACTUAL DAMS

The cost of the dams listed in this table were obtained from construction costs for dams actually built and from cost estimates prepared by various federal and provincial agencies for dams not yet built.

Assiniboine River Dams

Dam	Cost	Volume of Embankment[1]	Cost/Cu.Yd. of Embankment[1]
Proposed Dam Upstream of Brandon			
Reservoir Level 1	$ 5,204,000	1,953,000 cu.yd.	$2.67
Reservoir Level 2	$ 6,461,700	2,720,000 cu.yd.	$2.38
Reservoir Level 3	$ 7,310,000	3,700,300 cu.yd.	$1.98
Holland Dam	$12,828,000	4,200,000 cu.yd.	$3.06
Shellmouth Dam	$ 6,805,000	8,810,000 cu.yd.	$0.77
Souris River Dams			
Proposed Dam Upstream of Wawanesa	$ 7,869,360	6,750,000 cu.yd.	$1.16
Proposed Dam Upstream of Wawanesa	$ 4,740,000	4,000,000 cu.yd.	$1.18
Proposed Dam Upstream of Souris	$ 1,627,370	330,000 cu.yd.	$4.94
Pembina River Dams			
Pembilier Dam			
FSL 1141.5	$15,296,000	9,965,000 cu.yd.	$1.54
FSL 1093.0	$ 8,978,000	4,750,000 cu.yd.	$1.90
FSL 1053	$ 6,574,000	2,450,000 cu.yd.	$2.68
Swan Lake			
FSL 1340	$ 3,951,000	1,624,000 cu.yd.	$2.43
FSL 1365	$ 6,428,000	4,945,000 cu.yd.	$1.30
Pembina Dam			
Low Scheme	$ 3,220,000	1,248,880 cu.yd.	$2.50
High Scheme	$ 5,213,450	2,969,560 cu.yd.	$1.76

1. See Figure B-2 for a plot of these figures.

TABLE B-2

CAPITAL COST OF DAMS

35,000 cfs & 17,500 cfs Capacity

	Cu. yds. embankment	Cost/cubic yard	Total Capital Cost
(1) Assiniboine River Dams			
Dam #1 - FSL 925	3,256,000 cu. yds.	$2.55 cu. yd.	8,300,000
Dam #2 - FSL 950	NOT Required	nil	nil
Dam #3 - FSL 1050	14,935,000 cu. yds.	$0.80 cu. yd.	12,000,000
Dam #4 - FSL 1100	21,120,000 cu. yds.	$0.80 cu. yd.	17,000,000
Dam #4A- FSL 1150	5,990,000 cu. yds.	$1.95 cu. yd.	11,650,000
			$48,950,000
(2) Souris River Dams			
Dam #5 - FSL 1200	2,777,500 cu. yds.	$2.60 cu. yd.	7,200,000
Dam #6 - FSL 1300	5,776,000 cu. yds.	$2.00 cu. yd.	11,500,000
			$18,700,000
Dam #7 - FSL 1350	3,999,000 cu. yds.	$2.40 cu. yd.	9,600,000
Dam #7A- FSL 1350	NOT Required	nil	nil
			$ 9,600,000
Dam #7 - FSL 1400	9,230,000 cu. yds.	$1.15 cu. yd.	$10,600,000
Dam #7A- FSL 1400	2,624,000 cu. yds.	2.70 cu. yd.	7,100,000
Dam #8 - FSL 1410	509,000 cu. yds.	3.10 cu. yd.	1,575,000
Dam #9 - FSL 1440	2,290,000 cu. yds.	2.75 cu. yd.	6,300,000
			$25,575,000
Blind Souris Dam - FSL 1450	1,820,000 cu. yds.	2.85 cu. yd.	5,200,000
Dam #10- FSL 1450	2,221,000 cu. yds.	2.80 cu. yd.	6,200,000
Dam #11- FSL 1500	13,400,000 cu. yds.	0.80 cu. yd.	10,700,000
Dam #12- FSL 1550	3,690,000 cu. yds.	2.45 cu. yd.	9,050,000
			$31,150,000

TABLE B-2 (continued)
CAPITAL COST OF DAMS

70,000 cfs & 52,500 cfs Capacity

	Cu. Yds. Embankment	Cost/cu. yd.	Total Capital Cost
(1) Assiniboine River Dams			
Dam #1 - FSL 925	3,256,000 cu yds.	2.55 /cu. yd.	$ 8,300,000
Dam #2 - FSL 950	4,942,000 cu.yds.	2.20 /cu. yd.	10,900,000
Dam #3 - FSL 1050	14,935,000 cu.yds.	0.80 /cu. yd.	12,000,000
Dam #4 - FSL 1150	51,435,000 cu.yds.	0.80 /cu. yd.	41,000,000
			$72,200,000
(2) Souris River Dams			
Dam #5 - FSL 1200	2,777,500 cu.yds.	2.60 /cu. yd.	7,200,000
Dam #6 - FSL 1300	5,776,000 cu.yds.	2.00 /cu. yd.	11,500,000
			$18,700,000
Dam #7 - FSL 1350	3,999,000 cu.yds.	2.40 /cu. yd.	9,600,000
Dam #7A- FSL 1350	NOT Required ---	---nil---	----nil----
			$ 9,600,000
Dam #7 - FSL 1400	9,230,000 cu.yds.	1.15 /cu. yd.	10,600,000
Dam #7A- FSL 1400	2,624,000 cu.yds.	2.70 /cu. yd.	7,100,000
Dam #8 - FSL 1410	509,000 cu.yds.	3.10 /cu. yd.	1,575,000
Dam #9 - FSL 1440	2,290,000 cu.yds.	2.75 /cu. yd.	6,300,000
			$25,575,000
Blind Souris Dam - FSL 1450	1,820,000 cu.yds.	2.85 /cu. yd.	5,200,000
Dam #10- FSL 1450	2,221,000 cu.yds.	2.80 /cu. yd.	6,200,000
Dam #11- FSL 1500	13,400,000 cu.yds.	0.80 /cu. yd.	10,700,000
Dam #12- FSL 1550	3,690,000 cu.yds.	2.45 /cu. yd.	9,050,000
			$31,150,000

TABLE B-3

CAPITAL COST OF DYKES

35,000 cfs. & 17,500 cfs. Capacity

(1) Assiniboine River Dam Dykes

Dam	Cubic yards of Dykes	Cost/cubic yard	Total Capital Cost
Dam #1 - FSL 925	36,000 cu. yds.	Included in cost of Dam #1	Nil
Dam #2 - FSL 950	---- Dam NOT	Required --------	Nil
Dam #3 - FSL 1050	35,000 cu. yds.	Included in cost of Dam #3	Nil
Dam #4 - FSL 1100	---- No Dyke	Required --------	Nil
Dam #4A FSL 1150	---- No Dyke	Required --------	Nil
			Nil

(2) Souris River Dam Dykes

Dam	Cubic yards of Dykes	Cost/cubic yard	Total Capital Cost
Dam #5 - FSL 1200	17,500 cu. yds.	Included in cost of Dam #5	Nil
Dam #6 - FSL 1300	140,000 cu. yds.	$0.35 /cu. yd.	$49,000
			$49,000
Dam #7 - FSL 1350	---- No Dyke	Required --------	nil
Dam #7A- FSL 1350	---- Dam NOT	Required --------	nil
Dam #7 - FSL 1400	---- No Dyke	Required --------	nil
Dam #7A- FSL 1400	---- No Dyke	Required --------	nil
Dam #8 - FSL 1410	525,000 cu. yds.	$0.00 cu. yd. Borrow available from channel enlargement	nil
Dam #9 - FSL 1440	2,450,000 cu. yds.	$0.35 /cu. yd.	$86,000
			$86,000

TABLE B-3
CAPITAL COST OF DYKES (contd.)

35,000 cfs. & 17,500 cfs. Capacity

(2) Souris River Dam Dykes

		Cubic Yards of Dykes	Cost/cubic yard	Total Capital Cost
Blind Souris Dam	FSL 1450	----No Dyke Required	----	nil
Dam #10	FSL 1450	----No Dyke Required	----	nil
Dam #11	FSL 1500	314,000 cu. yds.	$0.35 /cu. yd.	$110,000
Dam #12	FSL 1550	----No Dyke Required	----	nil
				$110,000

70,000 cfs. & 52,500 cfs. Capacity

(1) Assiniboine River Dam Dykes

		Cubic Yards of Dykes	Cost/cubic yard	Total Capital Cost
Dam # 1	FSL 925	36,000 cu. yds.	Included in Cost of Dam #1	nil
Dam # 2	FSL 950	70,000 cu. yds.	Included in Cost of Dam #2	nil
Dam # 3	FSL 1050	35,000 cu. yds.	Included in Cost of Dam #3	nil
Dam # 4	FSL 1150	----No Dyke Required	----	nil
				Nil

TABLE B-3
CAPITAL COST OF DYKES (contd.)

70,000 cfs. & 52,500 cfs. Capacity

(2) Souris River Dam Dykes

	Cubic yards of Dykes	Cost/cubic yard	Total Capital Cost
Dam #5 - FSL 1200	17,500 cu. yds.	Included in cost of Dam #5	nil
Dam # 6 - FSL 1300	140,000 cu. yds.	$0.35 cu. yd.	$49,000
			$49,000
Dam #7 - FSL 1350	---- No Dyke Required	----	nil
Dam #7A- FSL 1350	---- Dam Not Required	----	nil
Dam #7 - FSL 1400	---- No Dyke Required	----	
Dam #7A- FSL 1400	---- No Dyke Required	----	nil
Dam #8 - FSL 1410	525,000 cu. yds.	$0.00 cu. yd. Borrow available from channel enlargement	nil
Dam #9 - FSL 1440	2,450,000 cu. yds.	$0.35 cu. yd.	$86,000
			$86,000
Blind Souris Dam FSL 1450	---- No Dyke Required	----	nil
Dam #10 FSL 1450	---- No Dyke Required	----	nil
Dam #11 FSL 1500	314,000 cu. yds.	$0.35 cu. yd.	$110,000
Dam #12 FSL 1550	---- No Dyke Required	----	nil
			$110,000

TYPICAL DAM CROSSECTIONS

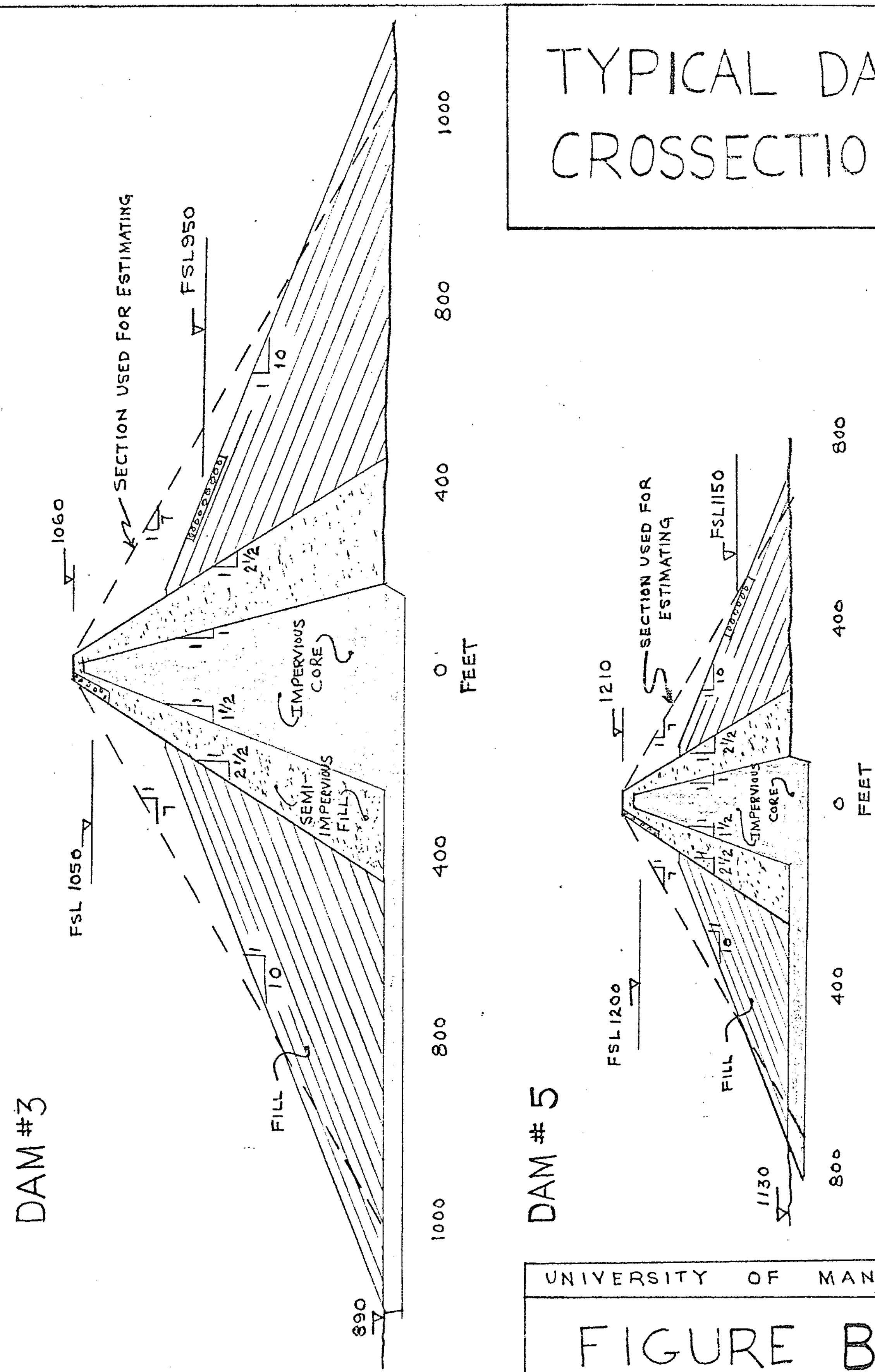

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FIGURE B-1

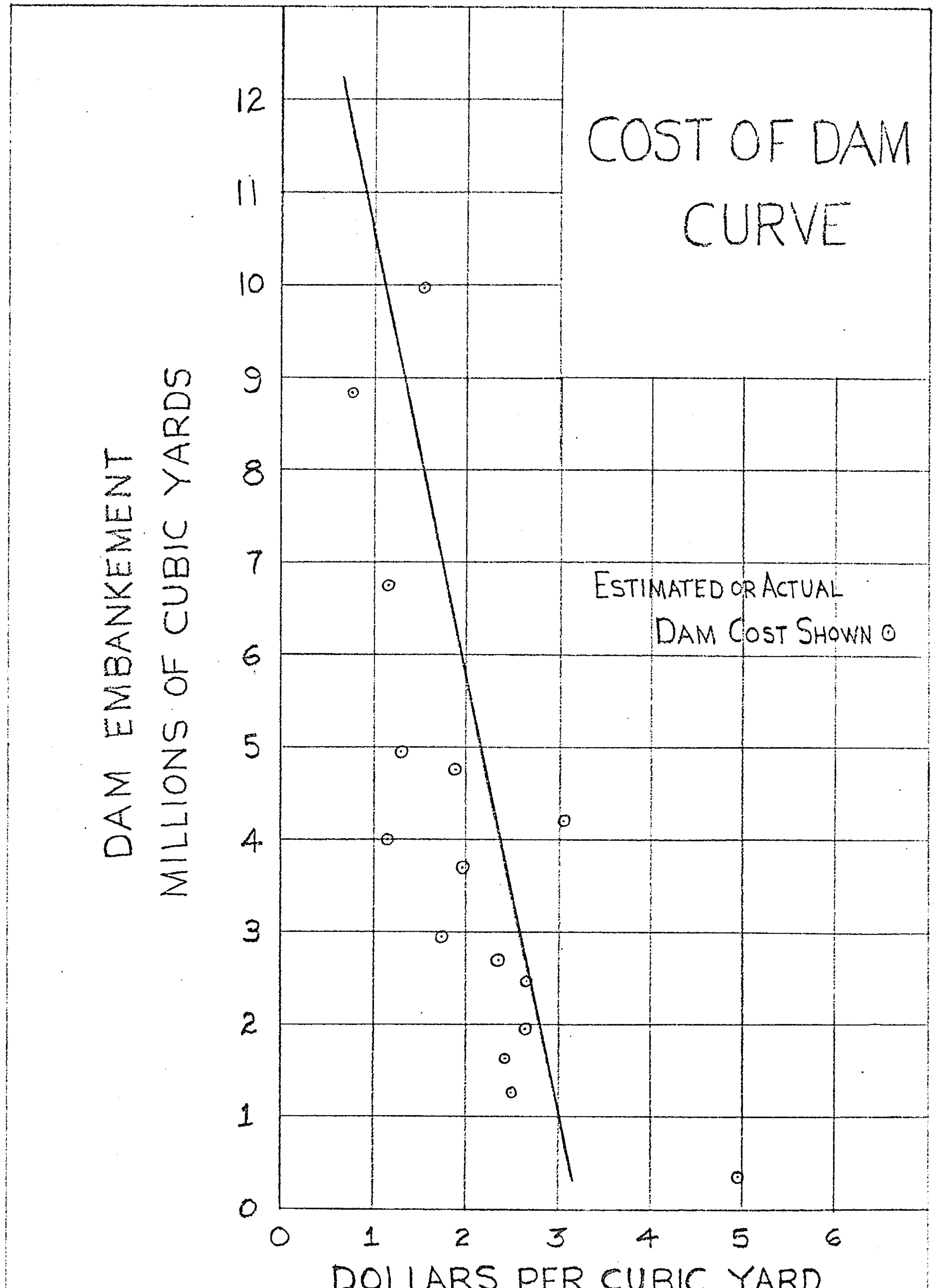
COST OF DAM
CURVE
ESTIMATED OR ACTUAL
DAM COST SHOWN ⊙
DAM EMBANKEMENT
MILLIONS OF CUBIC YARDS
DOLLARS PER CUBIC YARD
0
1
2
3
4
5
6
7
8
9
10
11
12

FIGURE B-2

LAKE MANITOBA - GARRISON RESERVOIR

DIVERSION

A P P E N D I X   C

RESERVOIR DAMAGES

APPENDIX C

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APPENDIX C

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APPENDIX C

RESERVOIR DAMAGES

1. Introduction

A major component of the Lake Manitoba-Garrison Diversion is the reservoirs. A study was conducted of the some 430 square miles of area to be flooded to assess the damage caused by the construction of the reservoir system.

It was found that the Towns of Wawanesa, Souris and Melita, Manitoba and Upham, Velva and Sawyer, North Dakota would be flooded by the diversion. In addition, over 250 farmsteads, 34 vehicular bridges, 9 railroad bridges and 11 dams would be effected by the diversion.

2. Study Data

Data for the study was obtained from topographical plans prepared by the Government of Canada for that portion of the diversion in Canada and from topographical plans prepared by the U.S.A. government for that portion of the diversion in North Dakota.

Additional information as to the location of vehicular bridges was obtained from the Highway maps prepared by the Province of Manitoba and the State of North Dakota.

3. Items Included in Reservoir Damages

Items included in the assessment of reservoir damages were land costs, clearing costs, replacement costs for railroad and vehicular bridges, relocation costs for farmsteads, villages and towns flooded by the diversion.

4. Relocation Costs

Relocation costs for towns and farmsteads were calculated as follows:

(a) Cost of Relocating Towns

In order to establish a monetary value to the damage caused by flooding of these towns, it was decided that this would be represented by the cost of relocating the population of these towns in new towns.

The 1969 Community Reports, Department of Industry and Commerce, Province of Manitoba, in conjunction with unit costs for homes, businesses, and services, were used to establish the cost of constructing the new towns of Souris and Melita. These figures are shown in Tables C-2 and C-3.

Since similar community reports were not available for the remaining towns it was decided to use a per capita basis for estimating the cost of relocating the remaining towns based upon the per capita costs established for relocating the Towns of Souris and Melita. For this purpose, the per capita costs of relocating for Souris and Melita were plotted to obtain the per capita cost shown in Figure H-1.

Detailed cost estimates of relocating the Towns of Wawanesa, Upham, Velva and Sawyer are shown in Table C-4.

In summary, the costs of relocating these towns were as follows:

Town	Population	Total Cost of Relocating
Wawanesa	456	$ 7,500,000
Souris	2000	$23,000,000
Melita	1200	$17,000,000
Upham	333	$ 5,650,000
Velva	1330	$18,000,000
Sawyer	390	$ 6,640,000

It was assumed that the salvage value of the buildings would cover the cost of removing or demolishing the old buildings.

(b) Cost of Relocating Farmsteads

To establish the cost of purchasing or relocating the farmsteads, it was assumed that an average farmstead consisted of house complete with a running water and sewerage system, barn, implement shed, and various other miscellaneous sheds.

The cost of an average farmstead was established as follows:

Home:	$30,000
Barn:	15,000
Implement Shed:	5,000
Miscellaneous Sheds:	5,000
Total Cost:	$55,000

The above cost does not include the cost of purchasing the farm land. This is included under right-of-way costs. It was assumed that the salvage value of the buildings would cover the cost of removing or demolishing the old buildings.

5. Land Costs

Land costs were based upon prices paid or anticipated for land in the area on which the Water Control and Conservation Branch, Province of Manitoba and other agencies were proposing to construct or have constructed water resource projects.

6. Civil Engineering Works

Cost of constructing civil engineering works such as bridges were estimated using the prices outlined in Appendix I.

7. Damages

Table C-1 contains a detailed accounting of damages for the 70,000 cfs. scheme. Damages for the 52,500 cfs., 35,000 cfs., and 17,500 cfs. flows are not presented in here in detail because of lack of space. Basically the damages for lower flows were found to be lower because of shorter length of bridge required. With the 17,500 cfs. and 35,000 cfs. flows the reservoir system on the Assiniboine was changed from the 52,500 cfs. and 70,000 cfs. system resulting in a smaller flooded area (3,000 acres less). This also resulted in somewhat smaller reservoir damages for the 17,500 cfs. and 35,000 cfs. systems. The reservoir system on the Souris River is the same for all levels of flow.

Damages were assessed for each reservoir and compiled in Table C-1. Total damagescosts for the four levels of flow studied are summarized at the end of Table

C-1. All costs are in Canadian Dollars.

8. <u>Damages Not Surveyed</u>

No assessment was made of mineral or wildlife that could be effected by these empoundments.

Socialogical changes that may be caused by the erection of the Lake Manitoba-Garrison Dam Diversion were not considered.

TABLE C-1

RESERVOIR DAMAGES

RESERVOIR DAMAGE

70,000 cfs. Capacity

Reservoir Behind Dam #1 -FSL 925			
R.O.W.			
2560 acres of bush @ $80/acre	=	$ 205,000	
360 acres of cultivated field @ $150 /acre	=	54,000	
Clearing			
2560 acres @ $200 /acre	=	510,000	
Farmsteads			
5 @ $55,000 each	=	275,000	
		$ 1,044,000	$ 1,044,000
Reservoir Behind Dam #2 - FSL 950			
R.O.W.			
4100 acres of bush @ $80 /acre	=	$ 328,000	
1100 acres of cultivated land @ $150 /acre	=	165,000	
Clearing			
4100 acres @ $200 /acre	=	820,000	
Farmsteads			
8 @ $55,000 each	=	440,000	
Relocate P.R. #305 over Dam #2			
2 miles @ $70,000 /mile	=	140,000	
		$ 1,893,000	$ 1,893,000
Reservoir Behind Dam #3 - FSL 1050			
R.O.W.			
7680 acres of bush @ $80 /acre	=	$ 615,000	
7680 acres of cultivated land @ $150 /acre	=	1,150,000	
Clearing			
7680 acres @ $200 /acre	=	1,550,000	

Farmsteads 14 @ $55,000 each	=	$ 770,000	
Bridge for P.R. #242 2000 lin. ft. @ $1,000 /lin. ft.	=	2,000,000	
Relocate P.R. #242 2 miles @ $70,000 /mile	=	140,000	
		$ 6,225,000	$ 6,225,000

<u>Reservoir Behind Dam #4</u> - FSL 1150

R.O.W. 28,600 acres of bush @ $80 /acre	=	$ 2,290,000	
28,600 acres of cultivated land @ $150 /acre	=	4,290,000	
Clearing 28,600 acres @ $200 /acre	=	5,720,000	
Farmsteads 56 @ $55,000 each	=	3,080,000	
Relocate P.T.H. #34 3 miles @ $125,000 /mile	=	375,000	
Bridge for P.R. #258 1400 ft. @ $1000 /foot	=	1,400,000	
Bridge for P.R. #340 (upstream of confluence of Souris and Assiniboine Rivers) 700 ft. @ $1000 /foot	=	700,000	
Bridge for C.P.R. 800 ft. @ $900 /foot	=	720,000	
		$ 18,575,000	$ 18,575,000

<u>Reservoir Behind Dam #5</u> - FSL 1200

R.O.W. 1600 acres of bush @ $80 /acre	=	$ 128,000	
1600 acres of cultivated land @ $150 /acre	=	240,000	
Clearing 1600 acres @ $200 /acre	=	320,000	

Relocate P.R. #344 over Dam #6 2 miles @ $70,000	=	$ 140,000	
Relocate P.T.H. #2 over Dam #6 4 miles @ $125,000 /mile	=	600,000	
Bridge for C.N.R. 1100 ft. @ $900 /foot	=	990,000	
Relocation - Town of Wawanesa	=	7,500,000	
		$ 9,918,000	$ 9,918,000
<u>Reservoir Behind Dam #6</u> - FSL 1300			
R.O.W. 5400 acres of bush @ $80 /acre	=	$ 430,000	
600 acres of cultivated land @ $150 /acre	=	900,000	
Clearing 5400 acres @ $200 /acre	=	1,080,000	
		$ 2,410,000	$ 2,410,000
<u>Reservoir Behind Dam #7</u> - FSL 1400			
R.O.W. 14,400 acres of bush @ $80 /acre	=	$ 1,150,000	
14,400 acres of cultivated land @ $150 /acre	=	2,150,000	
Clearing 14,400 acres @ $200 /acre	=	2,880,000	
Farmsteads 25 @ $55,000 each	=	1,370,000	
Bridge for P.R. 346 1700 lin. ft. @ $1000 /lin. ft.	=	1,700,000	
Bridge for P.T.H. #10 1400 lin. ft. @ $1000 /lin. ft.	=	1,400,000	

Bridge for P.R. #348 1160 lin. ft. @ $1000 /lin. ft.	=	$ 1,160,000	
Relocate P.T.H. #2 2 miles @ $125,000 /mile	=	250,000	
Bridge for P.T.H. #22 860 lin. ft. @ $1000 /lin. ft.	=	860,000	
Relocate P.T.H. #22 2 miles @ $125,000 /mile	=	250,000	
Bridge for P.R. #454 800 lin. ft. @ $1000 /lin. ft.	=	800,000	
Bridge for C.P.R. 800 lin. ft. @ $900 /lin. ft.	=	720,000	
Relocate C.P.R. 4 miles @ $150,000 /mile	=	600,000	
Bridge for P.T.H. #21 800 lin. ft. @ $1000 /foot	=	800,000	
Relocate P.T.H. #21 2 miles @ $125,000 /mile	=	250,000	
Relocate - Town of Souris	=	25,000,000	
		$ 41,340,000	$ 41,340,000

<u>Reservoir Behind Dam #7</u> - FSL 1350

R.O.W. 4000 acres of bush @ $80 /acre	=	$ 320,000
4000 acres of cultivated land @ $150 /acre	=	600,000
Clearing 4000 acres @ $200 /acre	=	800,000
Farmsteads 8 @ $55,000 each	=	440,000

Bridge for P.R. #346 840 lin. ft. @ $1000/lin. ft.	=	$ 840,000	
Bridge for P.T.H. #10 830 lin. ft. @ $1000 /lin. ft.	=	830,000	
Bridge for P.R. #348 830 lin. ft. @ $1000 /lin. ft.	=	830,000	
		$ 4,660,000	$ 4,660,000

<u>Reservoir Behind Dam #8</u> - FSL 1410

R.O.W. 2560 acres of bush @ $80 /acre	=	$ 205,000	
2560 acres of cultivated land @ $150 /acre	=	384,000	
Clearing 2560 acres @ $200 /acre	=	512,000	
Farmsteads 4 @ $55,000 each	=	220,000	
Relocate C.P.R. over Dam #8 2 miles @ $150,000 /mile	=	300,000	
Bridge for Municipal Road 800 lin. ft. @ $1000 /lin. ft.	=	800,000	
Bridge for P.R. #345 800 lin. ft. @ $1000 /lin. ft.	=	800,000	
Bridge for Municipal Road 800 lin. ft. @ $1000 /lin. ft.	=	800,000	
Bridge for C.P.R. 800 lin. ft. @ $900 /lin. ft.	=	720,000	
		$ 4,741,000	$ 4,741,000

<u>Reservoir Behind Dam #9</u> - FSL 1440

R.O.W.			
1640 acres of bush @ $80 /acre	=	$ 131,000	
3580 acres of cultivated land @ $150 /acre	=	537,000	
Clearing			
1640 acres @ $200 /acre	=	328,000	
Farmsteads			
10 @ $55,000 each	=	550,000	
Bridge for P.R. #447			
830 lin. ft. @ $800 /lin. ft.	=	664,000	
Bridge for Municipal Road			
830 lin. ft. @ $800 /lin. ft.	=	664,000	
Bridge for C.P.R.			
830 lin. ft. @ $900 /lin. ft.	=	747,000	
Relocate C.P.R.			
6 miles @ $150,000 /mile	=	900,000	
Bridge for P.T.H. #3			
830 lin. ft. @ $1000 /lin. ft.	=	830,000	
Relocate P.T.H. #3			
2 miles @ $125,000 /mile	=	250,000	
Relocate P.T.H. #83			
2 miles @ $125,000 /mile	=	250,000	
Relocate Municipal Road			
2 miles @ $70,000 /mile	=	140,000	
Relocate - Town of Melita	=	$ 17,000,000	
		$ 22,991,000	$ 22,991,000

Reservoir Behind Dam #10 - FSL 1450

(1) Reach in Canada

R.O.W.			
1000 acres of bush @ $80 /acre	=		$ 80,000
9000 acres of cultivated land @ $150 /acre	=		1,350,000
10,000 acres of marsh @ $15 /acre	=		150,000
Clearing			
1000 acres @ $200 /acre	=		200,000
Farmsteads			
10 @ $55,000 each	=		550,000
Bridge for Municipal Road			
830 lin. ft. @ $800 /lin. ft.	=		664,000
Bridge for P.R. #251			
830 lin. ft. @ $800 /lin. ft.	=		664,000
Bridge for C.P.R.			
830 lin. ft. @ $900 /lin. ft.	=		747,000
Bridge for C.P.R. on Antler Creek			
200 lin. ft. @ $900 /lin. ft.	=		180,000
Raise P.T.H. #83 over Gainsborough and Antler Creeks			
1 mile @ $225,000 /mile	=		225,000
Bridge for P.T.H. #83 over Gainsborough Creek			
200 lin. ft. @ $1000 /lin. ft.	=		200,000
		Sub-Total	$ 5,010,000

(2) Reach in U.S.A.

R.O.W.		
3000 acres of bush @ $80 /acre	=	$ 240,000
34,000 acres of cultivated land @ $150 /acre	=	5,100,000
51,400 acres of marsh @ $15 /acre	=	771,000
Clearing		
3000 acres @ $200 /acre	=	600,000

Farmsteads 78 @ $55,000 each	=	$ 4,290,000
Bridge for Municipal Road 920 lin. ft. @ $800 /lin. ft.	=	738,000
Bridge for Great Northern Railroad 920 lin. ft. @ $900 /lin. ft.	=	828,000
Relocate Great Northern Railroad 1 mile @ $150,000 /mile	=	150,000
Bridge for Highway #5 920 lin. ft. @ $1000 /lin. ft.	=	920,000
Bridge for Minneapolis St. Paul and Sault Ste. Marie Railroad 920 lin. ft. @ $900 /lin. ft.	=	828,000
Raise Minneapolis St. Paul and Sault Ste. Marie Railroad 4 miles @ $150,000 /mile	=	600,000
Bridge for Municipal Road 920 lin. ft. @ $800 /lin. ft.	=	736,000
Bridge for Highway #14 920 lin. ft. @ $1000 /lin. ft.	=	920,000
Relocate - Town of Upham	=	5,650,000
Raise Great Northern Railroad 7 miles @ $150,000 /mile	=	1,050,000
Bridge for Municipal Road 920 lin. ft. @ $800 /lin. ft.	=	736,000
Bridge for Municipal Road 920 lin. ft. @ $800 /lin. ft.	=	736,000
Bridge for Great Northern Railroad 920 lin. ft. @ $900 /lin. ft.	=	828,000

Bridge for Great Northern Railroad 920 lin. ft. @ $900 /lin. ft.	=	$ 828,000	
Bridge for Highway #14 920 lin. ft. @ $1000 /lin. ft.	=	920,000	
	Sub-Total (2)	$ 27,469,000	
	Sub-Total (1)	$ 5,010,000	
		$ 32,479,000	$ 32,479,000

Reservoir Behind Dam #11 - FSL 1500

R.O.W. 7,000 acres of bush @ $80 /acre	=	$ 560,000	
28,000 acres of cultivated land @ $150 /acre	=	4,200,000	
Clearing 7,000 acres @ $200 /acre	=	1,400,000	
Farmsteads 26 @ $55,000 each	=	1,430,000	
Relocate Great Northern Railroad 5 miles @ $150,000 /mile	=	750,000	
Relocate Highway #2 8 miles @ $125,000 /mile	=	1,000,000	
Bridge for Highway #2 920 lin. ft. @ $1000 /lin. ft.	=	920,000	
Bridge for Municipal Road 880 lin. ft. @ $800 /lin. ft.	=	704,000	
Bridge for Municipal Road 880 lin. ft. @ $800 /lin. ft.	=	704,000	

Bridge for Municipal Road 880 lin. ft. @ $800 /lin. ft.	=	$ 704,000	
Bridge for Municipal Road 880 lin. ft. @ $800 /lin. ft.	=	704,000	
Bridge for Great Northern Railroad 880 lin. ft. @ $900 /lin. ft.	=	792,000	
		$ 13,868,000	$ 13,868,000

Reservoir Behind Dam #12 - FSL 1550

R.O.W. 2000 acres of bush @ $80 /acre	=	$ 160,000	
1400 acres of cultivated land @ $150 /acre	=	210,000	
Clearing 2000 acres @ $200 /acre	=	400,000	
Farmsteads 35 @ $55,000 each	=	1,925,000	
Bridge for Municipal Road 800 lin. ft. @ $1000 /lin. ft.	=	800,000	
Bridge for Municipal Road 800 lin. ft. @ $1000 /lin. ft.	=	800,000	
Relocate - Town of Velva	=	18,000,000	
Relocate - Town of Sawyer	=	6,640,000	
Relocate Minneapolis St. Paul and Sault Ste. Marie Railroad 18 miles @ $150,000 /mile	=	2,700,000	
Relocate U.S.A. Highway #52 13 miles @ $250,000 /mile	=	3,250,000	

Bridge for Municipal Road 800 lin. ft. @ $1000 /lin. ft.	=	$ 800,000	
Bridge for Municipal Road 800 lin. ft. @ $1000 /lin. ft.	=	800,000	
Bridge for Municipal Road 400 lin. ft. @ $800 /lin. ft.	=	320,000	
Bridge for Municipal Road 400 lin. ft. @ $800 /lin. ft.	=	320,000	
		$ 37,125,000	$ 37,125,000

C-17

SUMMARY OF RESERVOIR DAMAGES

70,000 cfs. Capacity

Reservoir Behind Dam #1 - FSL 925	$ 1,044,000
Reservoir Behind Dam #2 - FSL 950	1,893,000
Reservoir Behind Dam #3 - FSL 1050	6,225,000
Reservoir Behind Dam #4 - FSL 1150	18,575,000
	$ 27,737,000
Reservoir Behind Dam #5 - FSL 1200	$ 9,918,000
Reservoir Behind Dam #6 - FSL 1300	2,410,000
	$ 12,328,000
Reservoir Behind Dam #7 - FSL 1350	$ 4,660,000
	$ 4,660,000
Reservoir Behind Dam #7 - FSL 1400	$ 41,340,000
Reservoir Behind Dam #8 - FSL 1410	4,741,000
Reservoir Behind Dam #9 - FSL 1440	22,991,000
	$ 69,072,000
Reservoir Behind Dam #10 - FSL 1450	$ 32,479,000
Reservoir Behind Dam #11 - FSL 1500	13,868,000
Reservoir Behind Dam #12 - FSL 1550	37,125,000
	$ 83,472,000

SUMMARY OF RESERVOIR DAMAGES

52,500 cfs. Capacity

Reservoir Behind Dam #1 - FSL 925	$ 1,044,000
Reservoir Behind Dam #2 - FSL 950	1,893,000
Reservoir Behind Dam #3 - FSL 1050	6,225,000
Reservoir Behind Dam #4 - FSL 1150	18,185,000
	$ 27,347,000
Reservoir Behind Dam #5 - FSL 1200	$ 9,828,000
Reservoir Behind Dam #6 - FSL 1300	2,410,000
	$ 12,238,000
Reservoir Behind Dam #7-FSL 1350	$ 4,400,000
	$ 4,400,000
Reservoir Behind Dam #7 - FSL 1400	$ 40,775,000
Reservoir Behind Dam #8 - FSL 1410	4,546,000
Reservoir Behind Dam #9 - FSL 1440	22,816,000
	$ 28,137,000
Reservoir Behind Dam #10 - FSL 1450	$ 31,751,000
Reservoir Behind Dam #11 - FSL 1500	13,470,000
Reservoir Behind Dam #12 - FSL 1550	36,975,000
	$ 82,196,000

SUMMARY OF RESERVOIR DAMAGES

35,000 cfs.

Reservoir Behind Dam #1 FSL 925	$ 3,994,000
Reservoir Behind Dam #3 FSL 1050	6,225,000
Reservoir Behind Dam #4 FSL 1100	9,145,000
Reservoir Behind Dam #4A FSL 1150	5,560,000
	$24,924,000
Reservoir Behind Dam #5 FSL 1200	$ 9,638,000
Reservoir Behind Dam #6 FSL 1300	2,410,000
	$12,048,000
Reservoir Behind Dam #7 FSL 1350	$ 4,300,000
	$ 4,300,000
Reservoir Behind Dam #7 FSL 1400	$39,900,000
Reservoir Behind Dam #8 FSL 1410	3,961,000
Reservoir Behind Dam #9 FSL 1440	21,956,000
	$65,817,000
Reservoir Behind Dam #10 FSL 1450	$28,839,000
Reservoir Behind Dam #11 FSL 1500	12,400,000
Reservoir Behind Dam #12 FSL 1550	36,325,000
	$77,564,000

SUMMARY OF RESERVOIR DAMAGES

17,500 cfs.

Reservoir Behind Dam #1 FSL 925	$ 3,894,000
Reservoir Behind Dam #3 FSL 1050	6,125,000
Reservoir Behind Dam #4 FSL 1100	9,145,000
Reservoir Behind Dam #4A FSL 1150	5,543,000
	$24,707,000
Reservoir Behind Dam #5 FSL 1200	$ 9,548,000
Reservoir Behind Dam #6 FSL 1300	2,410,000
	$11,958,000
Reservoir Behind Dam #7 FSL 1350	4,250,000
	$ 4,250,000
Reservoir Behind Dam #7 FSL 1400	$39,468,000
Reservoir Behind Dam #8 FSL 1410	3,181,000
Reservoir Behind Dam #9 FSL 1440	21,836,000
	$64,485,000
Reservoir Behind Dam #10 FSL 1450	$27,486,000
Reservoir Behind Dam #11 FSL 1500	12,094,000
Reservoir Behind Dam #12 FSL 1550	36,425,000
	$76,005,000

TABLE C-2

COST OF RELOCATING TOWN OF SOURIS, MANITOBA

Population: 2,000

No. of Homes: 2,000 people divided by 4 people / home = 500 homes

No. of Commercial Buildings: 70

Lineal Feet of Streets Required for:

Homes: $\frac{500 \text{ homes} \times 60' \text{/home}}{2}$ = 15,000 lin. ft.

Commercial Buildings: $\frac{70 \text{ bldgs.} \times 100' \text{/bldg.}}{2}$ = 3,500 lin. ft.

	= 18,500 lin. ft.
Plus 30%	6,200 lin. ft.
	24,700 lin. ft.
SAY	25,000 lin. ft.

Estimated Cost

Sewer & Water Lines	25,000	lin. ft. @ $12 /lin.ft.	=	$ 300,000
Paving	25,000	lin. ft. @ $30 /lin.ft.	=	750,000
Water Treatment Plant	2,000	people @ $200 /capita	=	400,000
Sewage Treatment	2,000	people @ $ 60 /capita	=	120,000
Homes	500	homes @ $25,000 each	=	12,500,000
Commercial Buildings	70	@ $100,000 each	=	7,000,000
Assembly Halls	2	@ $150,000 each	=	300,000
Motor Hotel	1	@ $150,000 each	=	150,000
Hotel	1	@ $150,000 each	=	150,000
Churches	6	@ $ 75,000 each	=	450,000
Schools	2	@ $250,000 each	=	500,000
Hospital	1	@ $250,000 each	=	250,000
Old Folks Home	1	@ $175,000 each	=	175,000
				$23,045,000
		SAY		23,000,000

Cost per capita of relocating = $\frac{\$23,000,000}{2,000 \text{ people}}$ = $11,500

TABLE C-3

COST OF RELOCATING TOWN OF MELITA, MANITOBA

Population: 1,200

No. of Homes: 1,200 people divided by 4 people /home
= 300 homes

No. of Commercial Buildings: 60

Lineal Feet of Street Required for:

Homes: $\frac{300 \text{ homes} \times 60' \text{/home}}{2}$ = 9,000 lin. ft.

Commercial Buildings: $\frac{60 \text{ bldgs.} \times 100' \text{/bldg.}}{2}$ = 3,000 lin. ft.

	= 12,000 lin. ft.
Plus 30%	3,600 lin. ft.
	15,600 lin. ft.
SAY	16,000 lin. ft.

Estimated Cost

Sewer & Water Lines	16,000 lin. ft.	@ $12 /lin.ft.	=	$ 192,000
Paving	16,000 lin. ft.	@ $30 /lin.ft.	=	480,000
Water Treatment Plant	1,200 people	@ $200 /capita	=	240,000
Sewage Treatment	1,200 people	@ $ 60 /capita	=	72,000
Homes	300 homes	@ $ 25,000 each	=	7,500,000
Commercial Buildings	60	@ $100,000 each	=	6,000,000
Assembly Halls	1	@ $150,000 each	=	150,000
Motor Hotel	2	@ $150,000 each	=	300,000
Hotel	2	@ $230,000 each	=	460,000
Churches	5	@ $ 75,000 each	=	375,000
Schools	2	@ $200,000 each	=	400,000
Hospital	1	@ $175,000 each	=	175,000
Old Folks Home	1	@ $175,000 each	=	175,000
				$16,519,000
		SAY		$17,000,000

Cost per capita of Relocating: $\frac{\$17,000,000}{1,200 \text{ people}}$ = $14,150

TABLE C-4

COST OF RELOCATING TOWN OF WAWANESA, MANITOBA

Population: 456

Cost of Relocating = $16,500 /capita (From Figure C-1)

Total Cost = $16,500 /capita x 456 people = $7,500,000

COST OF RELOCATING TOWN OF UPHAM, NORTH DAKOTA

Population: 333

Cost of Relocating = $17,000 /capita (From Figure C-1)

Total Cost = $17,000 /capita x 333 people = $5,650,000

COST OF RELOCATING TOWN OF VELVA, NORTH DAKOTA

Population: 1,330

Cost of Relocating = $13,600 /capita (From Figure C-1)

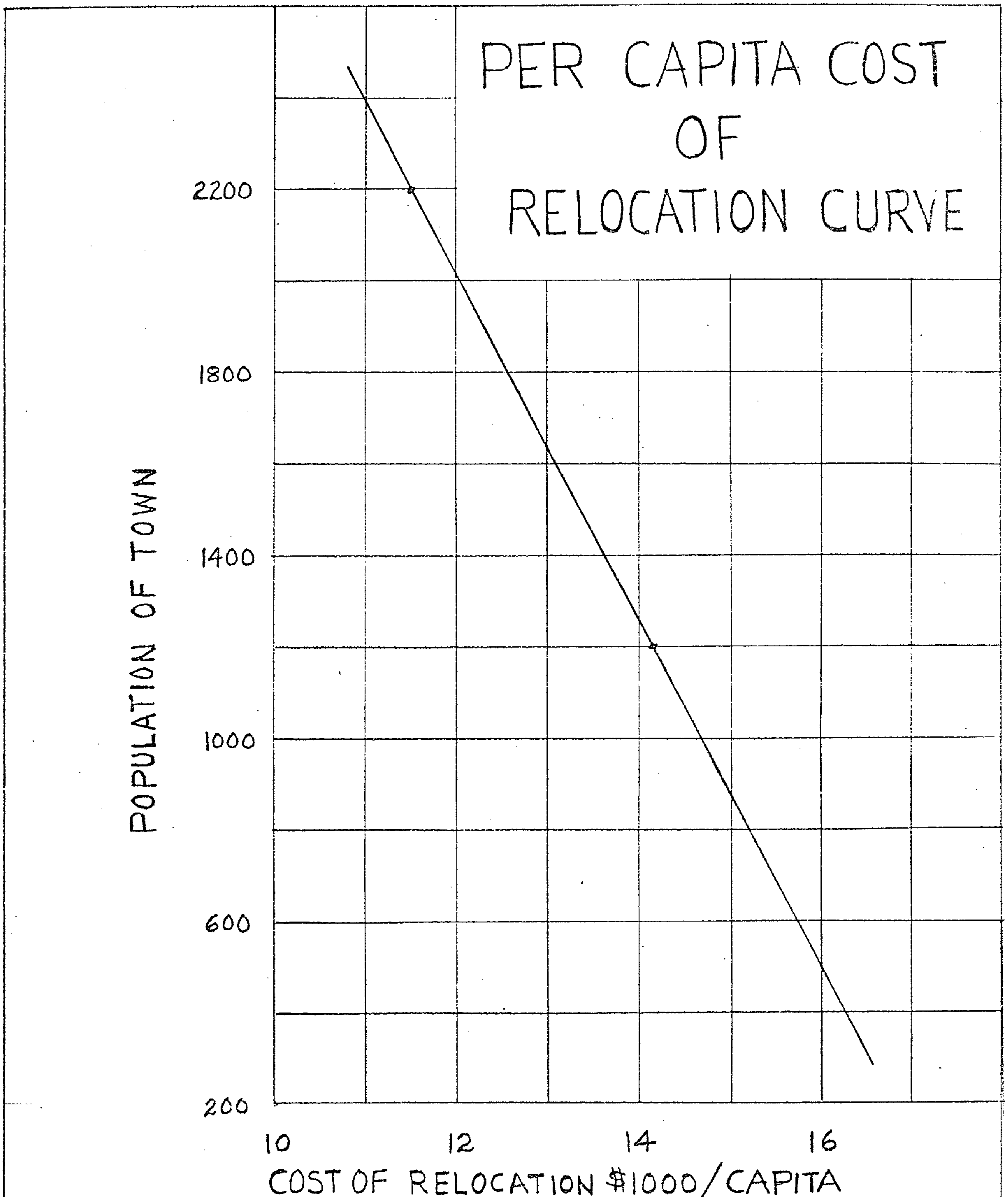
Total Cost = $13,600 /capita x 1,330 people = $18,000,000

COST OF RELOCATING TOWN OF SAWYER, NORTH DAKOTA

Population: 390

Cost of Relocating: $17,000 /capita (From Figure C-1)

Total Cost = $17,000 /capita x 390 people = $6,640,000



UNIVERSITY OF MANITOBA

FIGURE C-1

LAKE MANITOBA - GARRISON RESERVOIR

DIVERSION

A P P E N D I X D

CANALS

APPENDIX D

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CANALS

1. Introduction

A number of canals were investigated for this diversion. The purpose of this appendix is to cover the design aspects of these canals and to establish the capital cost of the canals.

2. Lake Manitoba - Assiniboine River Canal

The Lake Manitoba - Assiniboine River Canal is required to convey the diversion waters from Lake Manitoba to the reservoir behind Dam #1 on the Assiniboine River. The diversion water is lifted from elevation 812 on Lake Manitoba by a series of four pumping stations (two each with a lift of 25 feet and 33.5 feet respectively) to the elevation 925 behind Dam #1.

The Lake Manitoba - Assiniboine Canal is 20.5 miles in length including a 3 mile inlet channel from Lake Manitoba to the first pumping station.

3. Bunclody Canal

The Bunclody Canal was investigated as an option to using the Souris River as a conveyance system between a point downstream of the town of Souris near the Village of Bunclody and a point upstream of the Town of Melita.

The Bunclody Canal is essentially a contour canal. The water is lifted out of the "low reservoir" behind Dam #7 (FSL 1350) to elevation 1465 on the high bank of the Souris and gravity conveyed to the Blind Souris, an abandoned channel of the Souris River above Melita, and thus to the reservoir (FSL 1450) behind Dam #10.

4. Velva-Garrison Reservoir Canal

As an alternative to the Velva tunnels it would be possible to construct a canal from Reservoir #12 along a line drawn straight south of Velva to a point where a saddle occurs in the divide between the watersheds draining into the Hudson Bay and those draining to the Gulf of Mexico. The elevation of the top of the saddle is 2060. The length of this canal would be 20 miles from Velva to the top of the divide and 32 miles from the top of the divide down to the Garrison Dam. The canal would follow a route due south of Velva to the upper end of Camp Lake and Strawberry Lake in the Camp National Wildlife Refugee and thus to Long Lake and Crooked Lake. From this point the canal would flow south-southwest to enter the Garrison Reservoir at elevation 1850 at approximately the same point as the Velva tunnels.

The average slope of the ground along the Lake Manitoba-Assiniboine River Canal is 6 feet per mile. The average slope of the Velva-Garrison Dam Canal is 20.5 feet per mile from Velva to the top of the divide and then 6.5 feet per mile from the top of the divide to Garrison Dam.

It is expected that the cost per mile for the Velva-Garrison Dam Canal particularily that section from Velva to the divide to be much higher than on the Lake Manitoba-Assiniboine River Canal. The entire 20 miles would look much like that from Mile 16 to Mile 19 on the Lake Manitoba-Assiniboine River Canal except be much steeper. Pumping stations would be required every mile. This would necessitate the use of low megawatt pumping stations much similar to that used on the Lake Manitoba-Assiniboine River Canal.

A design was not carried out for this canal. Rather an estimate (and it is probably low for the reasons explained above) of capital cost was made based on unit cost per mile for the Lake Manitoba-Assiniboine River Canal. It was found that an additional head of 145 feet was inherent in the design of the canal over that required for the tunnels. Since additional generating stations would have to be provided an allowance for this was made. This estimate is contained in Table D-4.

For the purpose of estimating it was assumed that 20 miles of the 32 miles to Garrison Dam from the divide would be contained in similar canals as the Lake Manitoba-Assiniboine River Canal with the pump station replaced by drop structures. The remaining 12 miles would be contained in natural lakes such as Camp Lake, Strawberry Lake, Long Lake, and Crooked Lake and assorted interconnecting marshs.

5. Other Canals

It was found possible to construct a contour canal along the west or east high bank of the Souris from the vicinity of Dam #9 to either of the reservoirs behind Dam #11 or Dam #12. These contour canals would be in the order of 90 to 120 miles in length. Based on unit costs per mile for the Bunclody canal it was found that the capital cost of these canals would exceed the saving in dam costs, reservoir damages, and pumping station costs for Dam #10.

6. <u>Canal Design</u>

Although the allowable velocity for a concrete lined canal is in the order of 5.0 fps., the limiting velocity in this study was set at 3.0 fps. In order to increase the velocity from 3.0 fps. to 5.0 fps. additional head would be required at the pumping stations with the result that power and capital costs for the pumping stations would go up. On the other hand canal costs would probably decrease because of the smaller channel cross-sections required. To obtain an opitmum design a number of alternative designs would have to be examined. It was felt that such a study was beyond the scope of this report.

Foundation conditions along the Lake Manitoba - Assiniboine River Canal vary from fine sandy loam to silty clay, Red River clay and coarse textured sands.

Foundation conditions along the Bunclody Canal varied from gravelly till, weathered shale, gravel, clay loam, sandy loam and loamy sand.

With this type of foundation conditions, it is possible that a considerable amount of water could be lost.

The economics of whether to line a canal or not depends on two things - how much water you can expect to lose and secondly, what the water cost to get it to the point that it is lost at. Water for this diversion is not available free at Lake Manitoba. It is possible that a number of reaches on both canals could be unlined. However, without detailed knowledge of the permeability of the subsurface along the canal route it is impossible to make a judgement of what sections could be unlined. For the above reasons, both canals were assumed to be lined with concrete.

Design sections and gradients for the four levels of flow studied are indicated in Table D-1.

7. Capital Cost Estimates

Cost estimates were prepared for the Lake Manitoba-Assiniboine River Canal and Bunclody Canal and are contained in Tables D-2 and D-3.

TABLE D-1

DESIGN CROSS-SECTIONS FOR CANALS

(1) 70,000 cfs.

base = 790 ft.
side slopes = 1 vertical to 6 horizontal
depth of flow = 25 ft.
n = 0.015
slope of water surface = 0.0000135

(2) 52,500 cfs.

base = 550 ft.
side slopes = 1 vertical to 6 horizontal
depth of flow = 25 ft.
n = 0.015
slope of water surface = 0.0000140

(3) 35,000 cfs.

base = 310 ft.
side slopes = 1 vertical to 6 horizontal
depth of flow = 25 ft.
n = 0.015
slope of water surface = 0.0000146

(4) 17,500 cfs.

base = 80 ft.
side slopes = 1 vertical to 6 horizontal
depth of flow = 25 ft.
n = 0.015
slope of water surface = 0.0000168

Table D-2

LAKE MANITOBA - ASSINIBOINE RIVER

CANAL

70,000 cfs. Capacity

R.O.W.					
5000 acres @ $ 200 /acre			=	$ 1,000,000	$ 1,000,000
Earthwork					
Inlet Canal	- 12,000,000 cu.yds.	@ $0.60 /cu. yd.	=	$ 7,200,000	
Canal	- 42,000,000 cu.yds.	@ $0.35 /cu. yd.	=	14,700,000	
Overhaul	- 70,000,000 cu.yds.	@ $0.02 /sta. yds.	=	1,400,000	
Borrow	- 2,800,000 cu.yds.	@ $0.35 /cu. yd.	=	980,000	
				$24,280,000	$24,280,000
Canal Lining					
Mile 4 to Mile 20.5					
16.5 miles @ $1,925,000			=	$31,800,000	$31,800,000
Bridges					
Mile 6 Municipal Road	1150'	@ $600 /lin.ft.	=	$ 690,000	
Mile 6.5 C.N.R. (Single Track)	1150'	@ $900 /lin.ft.	=	1,030,000	
Mile 7 P.R. 227	1150'	@ $800 /lin.ft.	=	920,000	
Mile 11 P.R. 249	1150'	@ $800 /lin.ft.	=	920,000	
Mile 12.9 C.P.R. (2 track)	1150'	@ $1800/lin.ft.	=	2,070,000	
Mile 14.75 C.N.R. (Single track)	1150'	@ $900 /lin.ft.	=	1,030,000	
Mile 15.8 C.N.R. (Single Track)	1150'	@ $900 /lin.ft.	=	1,030,000	
Mile 16.0 P.T.H. #1 (East)	1150'	@ $1000/lin.ft.	=	1,150,000	
P.T.H. #1 (West)	1150'	@ $1000/lin.ft.	=	1,150,000	
Mile 16.5 C.P.R. (Double Track)	1150'	@ $1800/lin.ft.	=	2,070,000	
Mile 18.4 C.N.R. (Single track)	1150'	@ $900 /lin.ft.	=	1,030,000	
Mile 19.0 Municipal Road	1150'	@ $600 /lin.ft.	=	690,000	
				$13,780,000	$13,780,000

Table D-2 (continued)

LAKE MANITOBA - ASSINIBOINE RIVER

CANAL

70,000 cfs. Capacity

Raising Track Grade				
Mile 6.5 Single Track 4 miles	@ $150,000 /mile	=	$ 600,000	
Mile 12.9 Double Track 4 miles	@ $225,000 /mile	=	900,000	
Mile 14.75 Single Track 4 miles	@ $150,000 /mile	=	600,000	
Mile 15.8 Single Track 4 miles	@ $150,000 /mile	=	600,000	
Mile 16.5 Double Track 2 miles	@ $150,000 /mile	=	450,000	
Mile 18.4 Single Track 4 miles	@ $150,000 /mile	=	600,000	
			$3,750,000	$ 3,750,000
Farmstead Relocation				
Mile 4 - 1 Farmstead	@ $ 55,000 /each	=	$ 55,000	
Mile 9 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 9.5 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 11.5 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 12 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 14 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 14.5 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 15.0 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 18.0 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 18.5 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 19 - 1 Farmstead	@ $ 55,000 /each	=	55,000	
			$ 605,000	$ 605,000
Pumping Stations				
Mile 4.0 184 MW	@ $155,000 /MW	=	$28,500,000	
Mile 11.0 184 MW	@ $155,000 /MW	=	$28,500,000	
Mile 17.0 248 MW	@ $125,000 /MW	=	31,000,000	
Mile 18.5 248 MW	@ $125,000 /MW	=	31,000,000	
			$119,000,000	$ 119,000,000
	TOTAL			$ 194,735,000

Table D-2 (continued)

LAKE MANITOBA - ASSINIBOINE RIVER

CANAL

52,500 cfs. capacity

R.O.W.					
4,500 acres @ $200 / acre			=	$ 900,000	$ 900,000
Earthwork					
Inlet Canal	- 9,400,000 cu. yds.	@ $0.60/cu. yds.	=	$ 5,560,000	
Canal	- 31,500,000 cu.yds.	@ $0.35/cu. yds.	=	11,000,000	
Overhaul	- 70,000,000 sta. yds.	@ $0.02/cu.yds.	=	1,400,000	
Borrow	- 3,750,000 cu. yds.	@ $0.35/cu.yds.	=	1,300,000	
				$19,260,000	$19,260,000
Canal Lining					
Mile 4 to Mile 20.5					
16.5 miles @ $1,500,000 /mile			=	$25,000,000	$25,000,000
Bridges					
Mile 6 Municipal Road		910' @ $600 /lin.ft.	=	$ 550,000	
Mile 6.5 C.N.R. (Single Track)		910' @ $900 /lin.ft.	=	820,000	
Mile 7 P.R. 227		910' @ $800 /lin.ft.	=	730,000	
Mile 11 P.R. 249		910' @ $800 /lin.ft.	=	730,000	
Mile 12.9 C.P.R. (2 track)		910' @ $1800 /lin.ft.	=	1,650,000	
Mile 14.75 C.N.R. (Single track)		910' @ $900 /lin.ft.	=	820,000	
Mile 15.8 C.N.R. (Single Track)		910' @ $900 /lin.ft.	=	820,000	
Mile 16.0 P.T.H. #1 (East)		910' @ $1000 /lin.ft.	=	910,000	
P.T.H. #1 (West)		910' @ $1000 /lin.ft.	=	910,000	
Mile 16.5 C.P.R. (Double Track)		910' @ $1800 /lin.ft.	=	1,650,000	
Mile 18.4 C.N.R. (Single track)		910' @ $900 /lin.ft.	=	820,000	
Mile 19.0 Municipal Road		910' @ $600 /lin.ft.	=	550,000	
				$10,860,000	$10,860,000

Table D-2 (continued)

LAKE MANITOBA - ASSINIBOINE RIVER

CANAL

52,500 cfs. Capacity

Raising Track Grade

Mile 6.5 Single Track 4 miles	@ $150,000 /mile	=	$ 600,000	
Mile 12.9 Double Track 4 miles	@ $225,000 /mile	=	900,000	
Mile 14.75 Single Track 4 miles	@ $150,000 /mile	=	600,000	
Mile 15.8 Single Track 4 miles	@ $150,000 /mile	=	600,000	
Mile 16.5 Double Track 2 miles	@ $150,000 /mile	=	450,000	
Mile 18.4 Single Track 4 miles	@ $150,000 /mile	=	600,000	
			$3,750,000	$ 3,750,000

Farmstead Relocation

Mile 4	- 1 Farmstead	@ $ 55,000 /each	=	$ 55,000	
Mile 9	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 9.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 11.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 12	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 14	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 14.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 15.0	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 18.0	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 18.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 19	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
				$ 605,000	$ 605,000

Pumping Stations

Mile 4.0	138 MW	@ $160,000 /MW	=	$22,000,000	
Mile 11.0	138 MW	@ $160,000 /MW	=	22,000,000	
Mile 17.0	186 MW	@ $155,000 /MW	=	29,000,000	
Mile 18.5	186 MW	@ $155,000 /MW	=	29,000,000	
				$102,000,000	$102,000,000
		TOTAL			$162,375,000

Table D-2 (continued)

LAKE MANITOBA - ASSINIBOINE RIVER

CANAL

35,000 cfs. capacity

R.O.W.					
3,500 acres	@ $200.00 /acre		=	$ 700,000	$ 700,000
Earthwork					
Inlet Canal	- 6,000,000 cu. yds.	@ $ 0.60 /cu.yd.	=	$ 3,600,000	
Canal	- 20,000,000 cu.yds.	@ $ 0.35 /cu.yd.	=	7,000,000	
Overhaul	- 70,000,000 sta. yds.	@ $0.02 /sta. yd.	=	1,400,000	
Borrow	- 4,200,000 cu.yds.	@ $ 0.35 /cu.yd.	=	1,500,000	
				$13,500,000	$ 13,500,000
Canal Lining					
Mile 4 to Mile 20.5	- 16.5 miles	@ $1,000,000 /mile	=	$16,500,000	$ 16,500,000
Bridges					
Mile 6 Municipal Road	670'	@ $ 600 /lin.ft.	=	$ 400,000	
Mile 6.5 C.N.R. (Single Track)	670'	@ $900 /lin.ft.	=	600,000	
Mile 7 P.R. 227	670'	@ $800 /lin.ft.	=	540,000	
Mile 11 P.R. 249	670'	@ $800 /lin.ft.	=	540,000	
Mile 12.9 C.P.R. (2 track)	670'	@ $1800 /lin.ft.	=	1,200,000	
Mile 14.75 C.N.R. (Single track)	670'	@ $900 /lin.ft.	=	600,000	
Mile 15.8 C.N.R. (Single Track)	670'	@ $900 /lin.ft.	=	600,000	
Mile 16.0 P.T.H. #1 (East)	670'	@ $1000 /lin.ft.	=	670,000	
P.T.H. #1 (West)	670'	@ $1000 /lin.ft.	=	670,000	
Mile 16.5 C.P.R. (Double Track)	670'	@ $1800. /lin.ft.	=	1,200,000	
Mile 18.4 C.N.R. (Single track)	670'	@ $900.00/lin.ft.	=	600,000	
Mile 19.0 Municipal Road	670'	@ $600.00 /lin.ft.	=	400,000	
				$8,020,000	$ 8,020,000

Table D-2 (continued)

LAKE MANITOBA - ASSINIBOINE RIVER

CANAL

35,000 c.f.s. capacity

Raising Track Grade

Mile 6.5 Single Track 4 miles	@ $150,000 /mile	=	$ 600,000	
Mile 12.9 Double Track 4 miles	@ $225,000 /mile	=	900,000	
Mile 14.75 Single Track 4 miles	@ $150,000 /mile	=	600,000	
Mile 15.8 Single Track 4 miles	@ $150,000 /mile	=	600,000	
Mile 16.5 Double Track 2 miles	@ $150,000 /mile	=	450,000	
Mile 18.4 Single Track 4 miles	@ $150,000 /mile	=	600,000	
			$3,750,000	$ 3,750,000

Farmstead Relocation

Mile 4	- 1 Farmstead	@ $ 55,000 /each	=	$ 55,000	
Mile 9	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 9.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 11.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 12	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 14	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 14.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 15.0	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 18.0	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 18.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 19	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
				$ 605,000	$ 605,000

Pumping Stations

Mile 4.0	92 MW	@ $180,000 /MW	=	$16,500,000	
Mile 11.0	92 MW	@ $180,000 /MW	=	16,500,000	
Mile 17.0	124 MW	@ $170,000 /MW	=	21,100,000	
Mile 18.5	124 MW	@ $170,000 /MW	=	21,100,000	
				$75,200,000	$ 75,200,000
			TOTAL		$118,275,000

Table D-2 (continued)

LAKE MANITOBA - ASSINIBOINE RIVER

CANAL

17,500 cfs. capacity

R.O.W.			
3,500 acres @ $200 /acre	=	$ 700,000	$ 700,000
Earthwork			
Inlet Canal - 3,000,000 cu. yds. @ $0.60 /cu. yd.	=	$ 1,800,000	
Canal - 10,000,000 cu.yd. @ $0.35 /cu. yd.	=	3,500,000	
Overhaul - 70,000,000 Sta. Yds. @ $0.02 /sta. yd.	=	1,400,000	
Borrow - 9,000,000 cu. yds. @ $0.35 /cu. yd.	=	3,100,000	
		$ 9,800,000	$ 9,800,000
Canal Lining			
Mile 4 to Mile 20.5 - 16.5 miles @ $675,000 /mile	=	$11,100,000	$11,100,000
Bridges			
Mile 6 Municipal Road 440' @ $600.00 /lin.ft.	=	$ 260,000	
Mile 6.5 C.N.R. (Single Track) 440' @ $900.00 /lin.ft.	=	400,000	
Mile 7 P.R. 227 440' @ $800.00 /lin.ft.	=	350,000	
Mile 11 P.R. 249 440' @ $800.00 /lin.ft.	=	350,000	
Mile 12.9 C.P.R. (2 track) 440' @ $1800.00/lin.ft.	=	800,000	
Mile 14.75 C.N.R. (Single track) 440' @ $900.00 /lin.ft.	=	400,000	
Mile 15.8 C.N.R. (Single Track) 440' @ $900.00 /lin.ft.	=	400,000	
Mile 16.0 P.T.H. #1 (East) 440' @ $1000.00 /lin.ft.	=	440,000	
P.T.H. #1 (West) 440' @ $1000.00 /lin.ft.	=	440,000	
Mile 16.5 C.P.R. (Double Track) 440' @ $1800.00 /lin.ft.	=	800,000	
Mile 18.4 C.N.R. (Single track) 440' @ $900.00 /lin.ft.	=	400,000	
Mile 19.0 Municipal Road 440' @ $600.00 /lin.ft.	=	260,000	
		$5,700,000	$ 5,700,000

Table D-2 (continued)

LAKE MANITOBA - ASSINIBOINE RIVER

CANAL

17,500 cfs. capacity

Raising Track Grade					
Mile 6.5 Single Track 4 miles		@ $150,000 /mile	=	$ 600,000	
Mile 12.9 Double Track 4 miles		@ $225,000 /mile	=	900,000	
Mile 14.75 Single Track 4 miles		@ $150,000 /mile	=	600,000	
Mile 15.8 Single Track 4 miles		@ $150,000 /mile	=	600,000	
Mile 16.5 Double Track 2 miles		@ $150,000 /mile	=	450,000	
Mile 18.4 Single Track 4 miles		@ $150,000 /mile	=	600,000	
				$3,750,000	$ 3,750,000
Farmstead Relocation					
Mile 4	- 1 Farmstead	@ $ 55,000 /each	=	$ 55,000	
Mile 9	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 9.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 11.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 12	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 14	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 14.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 15.0	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 18.0	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 18.5	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
Mile 19	- 1 Farmstead	@ $ 55,000 /each	=	55,000	
				$ 605,000	$ 605,000
Pumping Stations					
Mile 4.0	46 MW	@ $200,000 /MW	=	$ 9,200,000	
Mile 11.0	46 MW	@ $200,000 /MW	=	9,200,000	
Mile 17.0	62 MW	@ $200,000 /MW	=	12,400,000	
Mile 18.5	62 MW	@ $200,000 /MW	=	12,400,000	
				$43,200,000	$ 43,200,000
			TOTAL		$ 74,855,000

Table D-3

BUNCLODY CANAL

70,000 cfs. Capacity

R.O.W.				
16,500 acres	@ $150 /acre	=	$ 2,475,000	$ 2,475,000
Earthwork				
Canal -	105,000,000 cu. yds. @ $0.35 /cu.yd.	=	$36,800,000	
Overhaul -	NIL sta. yds. @ $0.02 /sta. yd.	=	Nil	
Borrow -	9,000,000 cu. yds. @ $0.35 /cu.yd.	=	3,100,000	
			$39,900,000	$39,900,000
Canal Lining				
Mile 0 to Mile 47				
47.0 miles	@ $1,925,000 /mile	=	$90,000,000	$90,000.000
Bridges				
Mile 4.3 Municipal Road	1150' @ $600 /lin.ft.	=	$ 690,000	
Mile 5.5 Municipal Road	1150' @ $600 /lin.ft.	=	690,000	
Mile 7.2 P.T.H. #22	1150' @ $1000/lin.ft.	=	1,150,000	
Mile 10.5 Municipal Road	1150' @ $600 /lin.ft.	=	690,000	
Mile 11.0 Municipal Road	1150' @ $600 /lin.ft.	=	690,000	
Mile 11.5 P.R. #347	1150' @ $800 /lin.ft.	=	920,000	
Mile 17.2 Municipal Road	1150' @ $600 /lin.ft.	=	690,000	
Mile 18.9 Municipal Road	1150' @ $600 /lin.ft.	=	690,000	
Mile 19.8 C.N.R. (Single Track)	1150' @ $900 /lin.ft.	=	1,040,000	

Table D-3 (continued)

BUNDLOCY CANAL

70,000 cfs. Capacity

Mile 20.4 P.T.H. #21	1150' @ $1000/lin.ft.	=	$ 1,150,000		
Mile 24.5 Municipal Road	1150' @ $600 /lin.ft.	=	690,000		
Mile 27.5 C.P.R. (Single Track)	1150' @ $900 /lin.ft.	=	1,040,000		
Mile 29.0 Municipal Road	1150' @ $600 /lin.ft.	=	690,000		
Mile 30.1 P.R. #345	1150' @ $800 /lin.ft.	=	920,000		
Mile 31.5 C.P.R. (Single Track)	1150' @ $900 /lin.ft.	=	1,040,000		
Mile 32.0 Municipal Road	1150' @ $600 /lin.ft.	=	690,000		
Mile 35.5 Municipal Road	1150' @ $600 /lin.ft.	=	690,000		
Mile 36.1 C.P.R. (Single Track)	1150' @ $900 /lin.ft.	=	1,040,000		
Mile 37.5 P.R. #447	1150' @ $800 /lin.ft.	=	920,000		
Mile 39.0 Municipal Road	1150' @ $600 /lin.ft.	=	690,000		
Mile 39.0 C.P.R. (Single Track)	1150' @ $900 /lin.ft.	=	1,040,000		
Mile 40.0 P.R. #452	1150' @ $800 /lin.ft.	=	920,000		
Mile 44.8 P.T.H. #3	1150' @ $1000/lin.ft.	=	1,150,000		
Mile 46.0 P.R. #588	1150' @ $800 /lin.ft.	=	920,000		
			$19,690,000	$19,690,000	

Raising Railway Grades

Mile 19.8 C.N.R. (Single Track)	4 miles @ $150,000/mile	=	$ 600,000	
Mile 27.5 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 31.5 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 36.1 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 39.0 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
			$3,000,000	$ 3,000,000

Waterway Conduits (or Siphons)

Mile 2.0 Creek	2500'	@ $300 /ft.	=	$ 750,000
Mile 4.2 Creek	1500'	@ $200 /ft.	=	300,000
Mile 5.0 Creek	1500'	@ $200 /ft.	=	300,000
Mile 5.5 Creek	1500'	@ $200 /ft.	=	300,000

Table D-3 (continued)

BUNCLODY CANAL

70,000 cfs. Capacity

Mile 6.5 Creek	1500'	@ $200 /ft.	=	$300,000	
Mile 7.8 Elgin Creek	2000'	@ $300 /ft.	=	600,000	
Mile 15.5 Creek	1500'	@ $200 /ft.	=	300,000	
Mile 20.5 Creek	1500'	@ $200 /ft.	=	300,000	
Mile 21.5 Creek	1500'	@ $200 /ft	=	300,000	
Mile 23.0 Creek	1500'	@ $300 /ft.	=	450,000	
Mile 24.1 Creek	1500'	@ $200 /ft.	=	300,000	
Mile 24.5 Creek	1500'	@ $200 /ft.	=	300,000	
Mile 25.0 Creek	1500'	@ $200 /ft.	=	300,000	
Mile 30.0 Creek	1500'	@ $200 /ft.	=	300,000	
Mile 37.0 Creek	1500'	@ $200 /ft.	=	300,000	
Mile 38.0 Creek	1500'	@ $200 /ft.	=	300,000	
Mile 41.5 Creek	1500'	@ $200 /ft.	=	300,000	
Mile 44.5 Creek	1500'	@ $200 /ft.	=	300,000	
				$5,800,000	$5,800,000

Farmstead Relocation

Mile 3	- 1 Farmstead	@ $ 55,000 / each	=	$ 55,000	
Mile 4.5	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 5.5	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 21.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 23.7	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 38.0	- 2 Farmstead	@ $ 55,000 / each	=	110,000	
Mile 40.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 43.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 43.2	- 1 Farmstead	@ $ 55,000 / each	=	55.000	
Mile 45.0	- 1 Farmstead	@ 55,000 / each	=	55,000	
				$ 605,000	$ 605,000

Pumping Station

Mile 0	855 MW	@ $72,000 / MW	=	$61,500,000	$ 61,500,000
				TOTAL	$222,970,000

Table D-3 (continued)

BUNCLODY CANAL

52,500 cfs. Capacity

R.O.W.				
15,000 acres @ $150 /acre		=	$ 2,250,000	$ 2,250,000
Earthwork				
Canal -	76,250,000 cu. yds. @ $0.35 /cu. yd.	=	$26,700,000	
Overhaul -	8,000,000 sta. yds.@ $0.02 /sta. yd.	=	160,000	
Borrow -	9,500,000 cu. yds. @ $0.35 /cu. yd.	=	3,300,000	
			$30,160,000	$30,160,000
Canal Lining				
Mile 0 to Mile 47				
47.0 miles @ $1,500,000 /mile		=	$70,500,000	$70,500,000
Bridges				
Mile 4.3 Municipal Road	910' @ $600 /lin.ft.	=	$ 550,000	
Mile 5.5 Municipal Road	910' @ $600 /lin.ft.	=	550,000	
Mile 7.2 P.T.H. #22	910' @ $1000/lin.ft.	=	910,000	
Mile 10.5 Municipal Road	910' @ $600 /lin.ft.	=	550,000	
Mile 11.0 Municipal Road	910' @ $600 /lin.ft.	=	550,000	
Mile 11.5 P.R. #347	910' @ $800 /lin.ft.	=	730,000	
Mile 17.2 Municipal Road	910' @ $600 /lin.ft.	=	550,000	
Mile 18.9 Municipal Road	910' @ $600 /lin.ft.	=	550,000	
Mile 19.8 C.N.R. (Single Track)	910' @ $600 /lin.ft.	=	550,000	

Table D-3 (continued)

BUNDLOCY CANAL

52,500 cfs. Capacity

Mile 20.4 P.T.H. #21	910' @ $1000/lin.ft.	=	$ 910,000		
Mile 24.5 Municipal Road	910' @ $600 /lin.ft.	=	550,000		
Mile 27.5 C.P.R. (Single Track)	910' @ $900 /lin.ft.	=	820,000		
Mile 29.0 Municipal Road	910' @ $600 /lin.ft.	=	550,000		
Mile 30.1 P.R. #345	910' @ $800 /lin.ft.	=	730,000		
Mile 31.5 C.P.R. (Single Track)	910' @ $900 /lin.ft.	=	820,000		
Mile 32.0 Municipal Road	910' @ $600 /lin.ft.	=	550,000		
Mile 35.5 Municipal Road	910' @ $600 /lin.ft.	=	550,000		
Mile 36.1 C.P.R. (Single Track)	910' @ $900 /lin.ft.	=	820,000		
Mile 37.5 P.R. #447	910' @ $800 /lin.ft.	=	730,000		
Mile 39.0 Municipal Road	910' @ $600 /lin.ft.	=	550,000		
Mile 39.0 C.P.R. (Single Track)	910' @ $900 /lin.ft.	=	820,000		
Mile 40.0 P.R. #452	910' @ $800 /lin.ft.	=	730,000		
Mile 44.8 P.T.H. #3	910' @ $1000/lin.ft.	=	910,000		
Mile 46.0 P.R. #588	910' @ $800 /lin.ft.	=	730,000		
			$15,440,000	$ 15,440,000	

Raising Railway Grades

Mile 19.8 C.N.R. (Single Track)	4 miles @ $150,000/mile	=	$ 600,000	
Mile 27.5 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 31.5 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 36.1 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 39.0 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
			$ 3,000,000	$ 3,000,000

Waterway Conduits (or Siphons)

Mile 2.0 Creek	2200' @ $300 /ft.	=	$ 660,000
Mile 4.2 Creek	1200' @ $200 /ft.	=	240,000
Mile 5.0 Creek	1200' @ $200 /ft.	=	240,000
Mile 5.5 Creek	1200' @ $200 /ft.	=	240,000

Table D-3 (continued)

BUNCLODY CANAL

52,500 cfs. Capacity

Mile 6.5 Creek		1200'	@ $200 /ft.	=	$ 240,000	
Mile 7.8 Elgin Creek		1700'	@ $300 /ft.	=	510,000	
Mile 15.5 Creek		1200'	@ $200 /ft.	=	240,000	
Mile 20.5 Creek		1200'	@ $200 /ft.	=	240,000	
Mile 21.5 Creek		1200'	@ $200 /ft	=	240,000	
Mile 23.0 Creek		1200'	@ $300 /ft.	=	360,000	
Mile 24.1 Creek		1200'	@ $200 /ft.	=	240,000	
Mile 24.5 Creek		1200'	@ $200 /ft.	=	240,000	
Mile 25.0 Creek		1200'	@ $200 /ft.	=	240,000	
Mile 30.0 Creek		1200'	@ $200 /ft.	=	240,000	
Mile 37.0 Creek		1200'	@ $200 /ft.	=	240,000	
Mile 38.0 Creek		1200'	@ $200 /ft.	=	240,000	
Mile 41.5 Creek		1200'	@ $200 /ft.	=	240,000	
Mile 44.5 Creek		1200'	@ $200 /ft.	=	240,000	
					$5,130,000	$5,130,000
Farmstead Relocation						
Mile 3	-	1 Farmstead	@ $ 55,000 / each	=	$ 55,000	
Mile 4.5	-	1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 5.5	-	1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 21.0	-	1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 23.7	-	1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 38.0	-	2 Farmstead	@ $ 55,000 / each	=	110,000	
Mile 40.0	-	1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 43.0	-	1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 43.2	-	1 Farmstead	@ $ 55,000 / each	=	55.000	
Mile 45.0	-	1 Farmstead	@ 55,000 / each	=	55.000	
					$ 605,000	$ 605,000
Pumping Station						
Mile 0		640 MW	@ $78,000 / MW	=	$50,000,000	$ 50,000,000
					TOTAL	$177,085,000

Table D-3 (continued)

BUNCLODY CANAL

35,000 cfs. Capacity

R.O.W.					
12,500 acres @ $150/acre			=	$ 1,875,000	$ 1,875,000
Earthwork					
Canal -	56,000,000 cu. yds.	@ $0.35 /cu. yd.	=	$19,600,000	
Overhaul -	1,500,000 cu. yds.	@ $0.02 /cu. yd.	=	30,000	
Borrow -	11,000,000 cu. yds.	@ $0.35 /cu. yd.	=	3,850,000	
				$23,480,000	$23,480,000
Canal Lining					
Mile 0 to Mile 47					
47.0 miles @ $1,000,000 /mile			=	$47,000,000	$47,000,000
Bridges					
Mile 4.3 Municipal Road	670'	@ $600 /lin.ft.	=	$ 402,000	
Mile 5.5 Municipal Road	670'	@ $600 /lin.ft.	=	402,000	
Mile 7.2 P.T.H. #22	670'	@ $1000/lin.ft.	=	670,000	
Mile 10.5 Municipal Road	670'	@ $600 /lin.ft.	=	402,000	
Mile 11.0 Municipal Road	670'	@ $600 /lin.ft.	=	402,000	
Mile 11.5 P.R. #347	670'	@ $800 /lin.ft.	=	536,000	
Mile 17.2 Municipal Road	670'	@ $600 /lin.ft.	=	402,000	
Mile 18.9 Municipal Road	670'	@ $600 /lin.ft.	=	402,000	
Mile 19.8 C.N.R. (Single Track)	670'	@ $900 /lin.ft.	=	603,000	

Table D-3 (continued)

BUNDLOCY CANAL

35,000 cfs. Capacity

Mile 20.4 P.T.H. #21	670' @ $1000/lin.ft.	=	$ 670,000	
Mile 24.5 Municipal Road	670' @ $600 /lin.ft.	=	402,000	
Mile 27.5 C.P.R. (Single Track)	670' @ $900 /lin.ft.	=	603,000	
Mile 29.0 Municipal Road	670' @ $600 /lin.ft.	=	402,000	
Mile 30.1 P.R. #345	670' @ $800 /lin.ft.	=	536,000	
Mile 31.5 C.P.R. (Single Track)	670' @ $900 /lin.ft.	=	603,000	
Mile 32.0 Municipal Road	670' @ $600 /lin.ft.	=	402,000	
Mile 35.5 Municipal Road	670' @ $600 /lin.ft.	=	402,000	
Mile 36.1 C.P.R. (Single Track)	670' @ $900 /lin.ft.	=	603,000	
Mile 37.5 P.R. #447	670' @ $800 /lin.ft.	=	536,000	
Mile 39.0 Municipal Road	670' @ $600 /lin.ft.	=	402,000	
Mile 39.0 C.P.R. (Single Track)	670' @ $900 /lin.ft.	=	603,000	
Mile 40.0 P.R. #452	670' @ $800 /lin.ft.	=	536,000	
Mile 44.8 P.T.H. #3	670' @ $1000/lin.ft.	=	670,000	
Mile 46.0 P.R. #588	670' @ $800 /lin.ft.	=	536,000	
			$11,524,000	$ 11,524,000

Raising Railway Grades

Mile 19.8 C.N.R. (Single Track)	4 miles @ $150,000/mile	=	$ 600,000	
Mile 27.5 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 31.5 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 36.1 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 39.0 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
			$ 3,000,000	$ 3,000,000

Waterway Conduits (or Siphons)

Mile 2.0 Creek	1800'	@ $300 /ft.	=	$ 540,000
Mile 4.2 Creek	800'	@ $200 /ft.	=	160,000
Mile 5.0 Creek	800'	@ $200 /ft.	=	160,000
Mile 5.5 Creek	800'	@ $200 /ft.	=	160,000

Table D-3 (continued)

BUNCLODY CANAL

35,000 cfs. Capacity

Mile 6.5 Creek	800'	@ $200 /ft.	=	$ 160,000	
Mile 7.8 Elgin Creek	1200'	@ $300 /ft.	=	360,000	
Mile 15.5 Creek	800'	@ $200 /ft.	=	160,000	
Mile 20.5 Creek	800'	@ $200 /ft.	=	160,000	
Mile 21.5 Creek	800'	@ $200 /ft.	=	160,000	
Mile 23.0 Creek	800'	@ $300 /ft.	=	240,000	
Mile 24.1 Creek	800'	@ $200 /ft.	=	160,000	
Mile 24.5 Creek	800'	@ $200 /ft.	=	160,000	
Mile 25.0 Creek	800'	@ $200 /ft.	=	160,000	
Mile 30.0 Creek	800'	@ $200 /ft.	=	160,000	
Mile 37.0 Creek	800'	@ $200 /ft.	=	160,000	
Mile 38.0 Creek	800'	@ $200 /ft.	=	160,000	
Mile 41.5 Creek	800'	@ $200 /ft.	=	160,000	
Mile 44.5 Creek	800'	@ $200 /ft.	=	160,000	
				$3,540,000	$3,540,000

Farmstead Relocation

Mile 3	- 1 Farmstead	@ $ 55,000 / each	=	$ 55,000	
Mile 4.5	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 5.5	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 21.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 23.7	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 38.0	- 2 Farmstead	@ $ 55,000 / each	=	110,000	
Mile 40.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 43.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 43.2	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 45.0	- 1 Farmstead	@ 55,000 / each	=	55,000	
				$ 605,000	$ 605,000

Pumping Station

Mile 0	420 MW	@ $95,000 / MW	=	$39,900,000	$39,900,000
				TOTAL	$130,924,000

Table D-3 (continued)

BUNCLODY CANAL

17,500 cfs. Capacity

R.O.W.					
10,500 acres @ $150.00 /acre			=	$ 1,575,000	$ 1,575,000
Earthwork					
Canal –	30,100,000 cu. yds.	@ $0.35 /cu. yd.	=	$10,500,000	
Overhaul –	19,500,000 Sta. yds.	@ $0.02 /sta. yd.	=	390,000	
Borrow –	8,200,000 cu. yds.	@ $0.35 /cu. yds.	=	2,870,000	
				$13,760,000	$13,760,000
Canal Lining					
Mile 0 to Mile 47					
47.0 miles @	$675,000 /mile		=	$31,725,000	$31,725,000
Bridges					
Mile 4.3 Municipal Road	440'	@ $600 /lin.ft.	=	$ 260,000	
Mile 5.5 Municipal Road	440'	@ $600 /lin.ft.	=	260,000	
Mile 7.2 P.T.H. #22	440'	@ $1000/lin.ft.	=	440,000	
Mile 10.5 Municipal Road	440'	@ $600 /lin.ft.	=	260,000	
Mile 11.0 Municipal Road	440'	@ $600 /lin.ft.	=	260,000	
Mile 11.5 P.R. #347	440'	@ $800 /lin.ft.	=	350,000	
Mile 17.2 Municipal Road	440'	@ $600 /lin.ft.	=	260,000	
Mile 18.9 Municipal Road	440'	@ $800 /lin.ft.	=	350,000	
Mile 19.8 C.N.R. (Single Track)	440'	@ $900 /lin.ft.	=	410,000	

Table D-3 (continued)

BUNDLOCY CANAL

17,500 cfs. Capacity

Mile 20.4 P.T.H. #21	440' @ $1000/lin.ft.	=	$ 440,000	
Mile 24.5 Municipal Road	440' @ $600 /lin.ft.	=	260,000	
Mile 27.5 C.P.R. (Single Track)	440' @ $900 /lin.ft.	=	410,000	
Mile 29.0 Municipal Road	440' @ $600 /lin.ft.	=	260,000	
Mile 30.1 P.R. #345	440' @ $800 /lin.ft.	=	350,000	
Mile 31.5 C.P.R. (Single Track)	440' @ $900 /lin.ft.	=	410,000	
Mile 32.0 Municipal Road	440' @ $600 /lin.ft.	=	260,000	
Mile 35.5 Municipal Road	440' @ $600 /lin.ft.	=	260,000	
Mile 36.1 C.P.R. (Single Track)	440' @ $600 /lin.ft.	=	260,000	
Mile 37.5 P.R. #447	440' @ $800 /lin.ft.	=	350,000	
Mile 39.0 Municipal Road	440' @ $600 /lin.ft.	=	260,000	
Mile 39.0 C.P.R. (Single Track)	440' @ $900 /lin.ft.	=	410,000	
Mile 40.0 P.R. #452	440' @ $800 /lin.ft.	=	350,000	
Mile 44.8 P.T.H. #3	440' @ $1000/lin.ft.	=	440,000	
Mile 46.0 P.R. #588	440' @ $800 /lin.ft.	=	350,000	
			$10,870,000	$ 10,870,000

Raising Railway Grades

Mile 19.8 C.N.R. (Single Track)	4 miles @ $150,000/mile	=	$ 600,000	
Mile 27.5 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 31.5 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 36.1 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
Mile 39.0 C.P.R. (Single Track)	4 miles @ $150,000/mile	=	600,000	
			$ 3,000,000	$ 3,000,000

Waterway Conduits (or Siphons)

Mile 2.0 Creek	1600' @ $300 /ft.	=	$ 480,000
Mile 4.2 Creek	600' @ $200 /ft.	=	120,000
Mile 5.0 Creek	600' @ $200 /ft.	=	120,000
Mile 5.5 Creek	600' @ $200 /ft.	=	120,000

Table D-3 (continued)

BUNCLODY CANAL

17,500 cfs. Capacity

Mile 6.5 Creek	600'	@ $200 /ft.	=	$ 120,000	
Mile 7.8 Elgin Creek	1100'	@ $200 /ft.	=	220,000	
Mile 15.5 Creek	600'	@ $200 /ft.	=	120,000	
Mile 20.5 Creek	600'	@ $200 /ft.	=	120,000	
Mile 21.5 Creek	600'	@ $200 /ft.	=	120,000	
Mile 23.0 Creek	600'	@ $300 /ft.	=	180,000	
Mile 24.1 Creek	600'	@ $200 /ft.	=	120,000	
Mile 24.5 Creek	600'	@ $200 /ft.	=	120,000	
Mile 25.0 Creek	600'	@ $200 /ft.	=	120,000	
Mile 30.0 Creek	600'	@ $200 /ft.	=	120,000	
Mile 37.0 Creek	600'	@ $200 /ft.	=	120,000	
Mile 38.0 Creek	600'	@ $200 /ft.	=	120,000	
Mile 41.5 Creek	600'	@ $200 /ft.	=	120,000	
Mile 44.5 Creek	600'	@ $200 /ft.	=	120,000	
				$2,680,000	$2,680,000

Farmstead Relocation

Mile 3	- 1 Farmstead	@ $ 55,000 / each	=	$ 55,000	
Mile 4.5	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 5.5	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 21.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 23.7	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 38.0	- 2 Farmstead	@ $ 55,000 / each	=	110,000	
Mile 40.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 43.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 43.2	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
Mile 45.0	- 1 Farmstead	@ $ 55,000 / each	=	55,000	
				$ 605,000	$ 605,000

Pumping Station

Mile 0	210 MW	@ $135,000/ MW	=	$28,350,000	$ 28,350,000
				TOTAL	$ 92,565,000

TABLE D-4

CAPITAL COST COMPARISON BETWEEN
BUNCLODY CANAL AND SOURIS RIVER CHANNEL
DAM #7 to DAM #10

(1) BUNCLODY CANAL

	70,000 cfs.	52,500 cfs.	35,000 cfs.	17,500 cfs.
Dam #7 FSL 1350	9,600,000	9,600,000	9,600,000	9,600,000
Pumping Station at Dam #7	38,400,000	31,600,000	28,400,000	16,500,000
Channel Improvements Upstream of Dam #7 FSL 1350	1,500,000	1,320,000	680,000	400,000
Reservoir Damages Upstream of Dam #7 FSL 1350	4,250,000	4,300,000	4,400,000	4,660,000
Bunclody Canal	161,470,000	127,085,000	91,024,000	64,215,000
Bunclody Pumping Station	61,200,000	49,000,000	40,400,000	28,400,000
Total Estimated Capital cost	276,420,000	222,905,000	174,504,000	123,775,000

(2) SOURIS RIVER CHANNEL

	70,000 cfs.	52,500 cfs.	35,000 cfs.	17,500 cfs.
Dam #7 FSL 1400	10,600,000	10,600,000	10,600,000	10,600,000
Dam #7A FSL 1400	7,100,000	7,100,000	7,100,000	7,100,000
Pumping Station at Dam #7 FSL 1400	56,000,000	45,500,000	38,000,000	28,400,000
Channel Improvements Upstream of Dam #7 FSL 1400	6,700,000	5,400,000	Nil	Nil
Dyking Upstream of Dam #7 FSL 1400	nil	nil	nil	nil
Reservoir Damages for Dam #7 FSL 1400	39,468,000	39,900,000	40,775,000	41,340,000
Dam #8 FSL 1410	1,575,000	1,575,000	1,575,000	1,575,000
Pumping Station at Dam #8	14,720,000	11,000,000	7,300,000	3,700,000
Channel Improvements Upstream of Dam #8	9,700,000	8,400,000	nil	nil

TABLE D-4 (continued)

CAPITAL COST COMPARISON BETWEEN
BUNCLODY CANAL AND SOURIS RIVER CHANNEL
DAM # 7 to DAM # 10

(2) SOURIS RIVER CHANNEL

	70,000 cfs.	52,500 cfs.	35,000 cfs.	17,500 cfs.
Dyking Upstream of Dam #8	nil	nil	nil	nil
Reservoir Damages for Dam #8	3,181,000	3,961,000	4,546,000	4,741,000
Dam #9 FSL 1440	6,300,000	6,300,000	6,300,000	6,300,000
Pumping Station at Dam #8	29,300,000	25,800,000	19,000,000	11,000,000
Channel Improvements Upstream of Dam #9	nil	nil	nil	nil
Dyking Upstream of Dam #9	86,000	86,000	86,000	86,000
Reservoir Damages for Dam #9	21,836,000	21,956,000	22,816,000	22,991,000
Pumping Station at Dam #10	14,720,000	11,000,000	7,300,000	3,700,000
	$214,986,000	$198,578,000	$165,398,000	$141,533,000

TABLE D-5

CAPITAL COST OF VELVA-GARRISON RESERVOIR CANAL

(1) Statistics

Average cost/mile for Lake Manitoba-Assiniboine River Canal

17,500 cfs. flow = \$1,920,000
35,000 cfs. flow = \$2,630,000
52,500 cfs. flow = \$3,640,000
70,000 cfs. flow = \$4,600,000

Velva-Garrison Reservoir Canal
Static Lift = 2060 - 1550
= 510 feet

Length: 20 miles Velva to the top of the divide
31 miles top of the divide to Garrison Reservoir

Top of divide to Garrison Reservoir
= 2060 - 1850
= 210 feet

Drop structures required: $\frac{\text{210 ft. drop}}{\text{30 ft. drop/each}} = 7.0$

Maximum Elevation of Energy Line

Velva-Garrison Reservoir Canal	= 2150
Tunnel Scheme	= 2005
Increase in Energy Line	145 ft.

Total head from Lake Manitoba to Garrison Dam
= (2005 - 830)
= 1175 feet

Increase in total head due to 145 feet additional head
$= \frac{145 \text{ ft.}}{1175 \text{ ft.}} \times 100$

= 10% (approximately)

Additional Capital Cost of Generating Station for Velva-Garrison Reservoir Canal should be equal to 10% of the total Generating Capital Cost. This is a capital cost chargeable to the Velva-Garrison Reservoir Canal.

Table D-5 (continued)

(2) 70,000 cfs. Capacity Estimate

Additional Generating Capacity	
10% of $1,700,000,000	= $170,000,000
Canal: 40 miles @ $4,600,000 /mile	= $184,000,000
Pumping Stations:	
3700 MW @ $155,000 /MW	= $574,000,000
Drop Structures:	
7 @ $1,800,000 each	= $ 12,600,00
	$940,600,000

(3) 52,500 cfs. Capacity Estimate

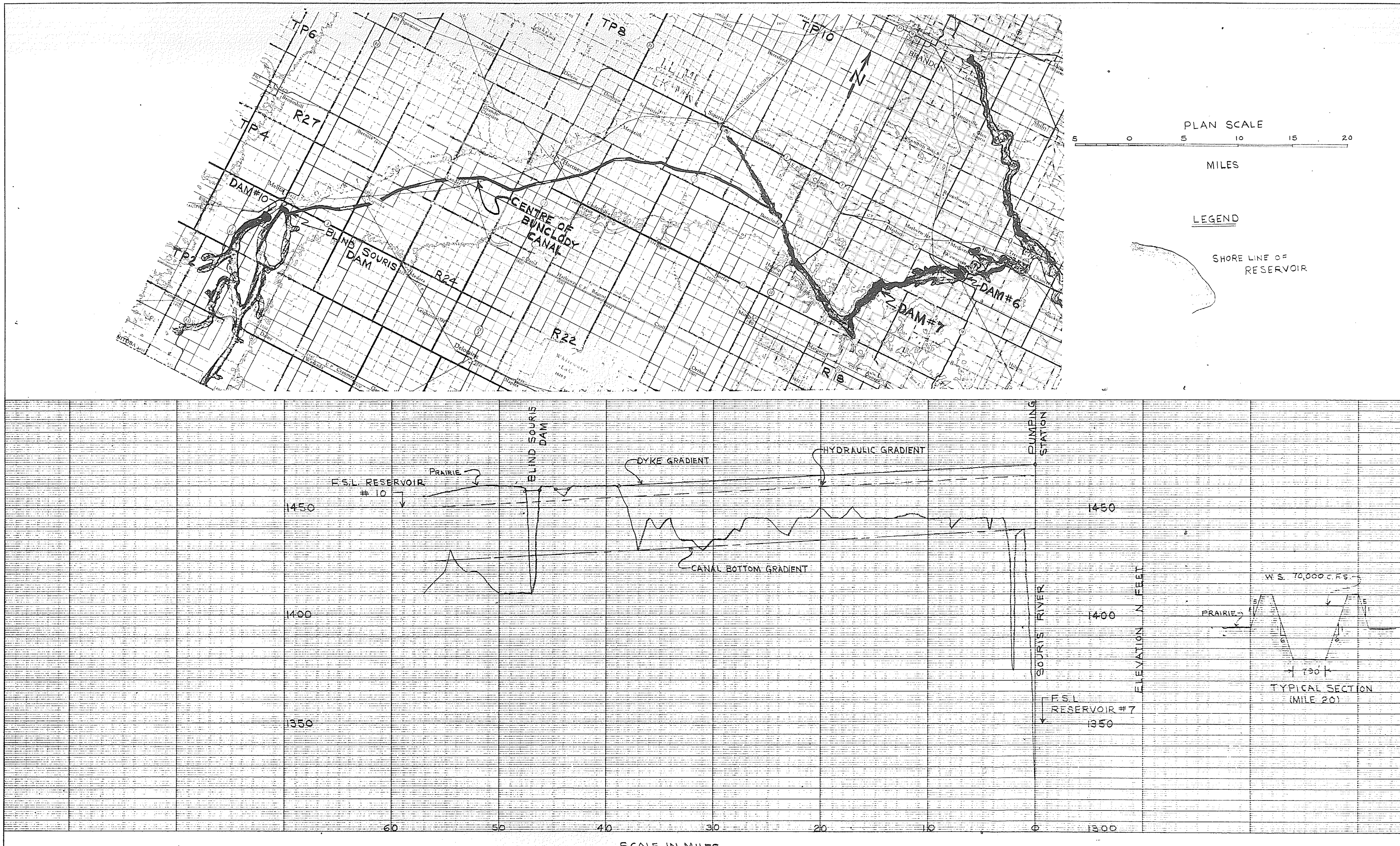
Additional Generating Capacity	
10% of $1,240,000,000	= $124,000,000
Canal: 40 miles @ $3,640,000 /mile	= $145,000,000
Pumping Stations:	
2820 MW @ $160,000 /MW	= $450,000,000
Drop Structures:	
7 @ $1,400,000	= $ 9,800,000
	$728,800,000

(4) 35,000 cfs. Capacity Estimate

Additional Generating Capacity	
10% of $867,500,000	= $ 86,750,000
Canal: 40 miles @ $2,630,000 / mile	= $105,000,000
Pumping Stations:	
1850 MW @ $180,000 /MW	= $333,000,000
Drop Structures:	
7 @ $1,000,000 each	= $ 7,000,000
	$531,750,000

(5) 17,500 cfs. Capacity Estimate

Additional Generating Capacity	
10% of $432,000,000	= $ 43,200,000
Canal: 40 miles @ $1,920,000 /mile	= $ 77,000,000
Pumping Stations:	
920 MW @ $200,000 /MW	= $184,000,000
Drop Structures:	
7 @ $600,000 each	= $ 4,200,000
	$308,400,000



UNIVERSITY OF MANITOBA			
LAKE MANITOBA - GARRISON RESERVOIR DIVERSION			
BUNCLODY CANAL			
SCALE AS SHOWN	DATE JULY 70	SHEET 1 OF 1	FIGURE D-1

LAKE MANITOBA - GARRISON RESERVOIR

DIVERSION

A P P E N D I X E

VELVA TUNNELS

APPENDIX E

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APPENDIX E

VELVA TUNNELS

1. Introduction

The Velva tunnels are intended to convey the water from the reservoir behind Dam #12 to Garrison Dam with a total lift of 325 feet.

2. Precedence

Mechanical and highly automated tunnel machines, usually referred to as "moles", have been employed successfully in the past on both large and small diameter tunnels. In 1965, on the Mangla Dam Project (13) five diversion tunnels were constructed with moles with a bore diameter of 36'-8" to give a finished reinforced concrete lined tunnel with an external diameter of 30'-0". The five diversion tunnels were each 1,650 feet long. On the San Juan-Chama Project (14) in New Mexico, a "mole" was used to drive the 12.8 mile long Azotea tunnel. The project was completed in 1967. Moles have been used to construct tunnels of 25'-8" on the South Saskatchewan Dam (13) in Saskatchewan and of 29'-6" on the Oake Dam (15) in South Dakota. It was proposed that a similar "mole" would be used to construct the Velva tunnels.

3. Geology

Existing information (10) as to the geology of the proposed route of the Velva tunnels is very general in nature and based upon several dozen drill holes putdown either in connection of petroleum or ground water exploration. The bedrock in the area is known to consist of Fort Union Formation, which is similar to the Turtle Mountain formation in Manitoba. The Fort Union Formation is fairly "new" rock formation overlain by glacial drift. The Fort Union Formation consists of beds of sandstone, sand, siltstone, shaly clay and lignite.

Depth to the top of the Fort Union Formation varies from 50 to 150 feet below the surface. At Velva the formation is within 50 feet of the surface and at a few points is exposed. In the vicinity of Garrison Reservoir the formation is within 100 feet of the surface. In between Velva and the Garrison Reservoir the formation is located 100 to 150 feet below the surface.

Except for the last three or four miles of the tunnels, where the tunnels are expected to be located in glacial drift, the tunnels will be located in the Fort Union Formation.

Generally the tunnels will be located 50 to 150 feet below the top of the formation. Since the Fort Union Formation is relatively "young", "soft" moling should be relatively easy. However because the formation is relatively "young" it is not expected to be highly consolidated, particularily within 75 feet of the surface of the bedrock. This feature may present problems in that the formation may not be strong enough along some sections of the tunnels to support itself even with tunnel bracing spaced every 5'-0". It is expected that it may take up to three months after completion of "moling" before the tunnel is lined with concrete. However this aspect cannot be determined without more detailed information. This detailed information can only be obtained by actually field drilling of the proposed tunnel locations.

The existing geological information for the proposed tunnel route in no way precludes the construction of the tunnel. However it is apparent that from the general geological nature of the bedrock in which the tunnels are located that problems of stability of the tunnel walls prior to the placing of the reinforced concrete lining may develope along certain portions of the route.

4. <u>Physical Dimensions of the Velva Tunnels</u>

The Velva tunnels would be 31 miles in length with each having an internal diameter of 40'-0". Each tunnel would convey 17,500 cfs. at a velocity of 14fps. Other dimensions relating to the tunnels are listed in Table E-1.

5. <u>Selection of Size and Number of Tunnels</u>

It was felt that the tunnels should be as large as possible so as to reduce the friction loss in the tunnel to as low amount as possible so as to keep energy costs down.

It was felt that at the present time that technologically it is possible to construct a 40 foot diameter tunnel as indicated in Section 2 of this Appendix.

To determine whether the tunnel was too large economically it was decided to compare the incremental cost in using a smaller diameter tunnel versus the 40 foot diameter tunnel. A 35 foot diameter was assumed and it was found as indicated in Table E-2 that the friction loss in the tunnel increased to 300 feet versus 155 feet for the 40 foot tunnel. The increased capital cost in electrical generating and pumping capacity was found to be $50,000,000. The reduction in the capital cost of the pipe was calculated by assuming the cost of the tunnel is a function of the raduis. This is true to a large extent particularily in relation to the number of cubic yards of concrete, pounds of reinforcing and tunnel bracing used in tunnel construction. Excavation varies as the square of the radius. However moling costs probably don't vary directly as the radius. It was assumed for the purpose of this study that the cost of the tunnel varied as the raduis.

In reducing the size of the tunnel from 40 foot diameter to 35 foot diameter the cost of the tunnel reduced 14%. On this basis the saving in tunnel construction costs amounted to $32,600,000.

It should be apparent from this that the economical size of the proposed tunnel was about 40 feet in diameter.

It should be noted that to get a head loss of 300 feet in a 40 foot conduit the velocity would have to be increased from 14 fps. to 19.5 fps. At this velocity, the conduit could accomodate 24,500 cfs. It would appear from this that it could be possible to reduce the number of tunnels for 70,000 cfs. capacity flow from four to three with an increase in the cost in pumping and generating equipment of $50,000,000 versus a saving of $236,150,000 in the construction of one less tunnel for a net saving of $176,150,000. However with velocities in the order of 19.5 fps., the volume of flows being considered, considerable study would have to be given to water hammer and strength of the tunnel liner. It was felt that the study required to justify the reduction in the number of tunnels to be used was beyond the scope of this report particularily in view of the fact that the design and cost estimates given in this report were based on preliminary information as to the geological nature of the bedrock in the area.

6. <u>Hydraulic Transients</u>

Water hammer can develop a design pressure far in excess of the static head and friction loss in the pipeline. Water hammer occurs where there is a sudden change in the velocity of flow in a pipeline penstock, or tunnel. For example, water hammer can develop when a pump is suddenly shut off or started up or if a valve is suddenly opened or closed. It can be shown that if the flywheet effect of the pump will slow down slow enough that there is no appreciable water hammer effect.

However, this is rarely the case. Usually the flywheel effect is small in relation to that required to carry the pump on to suppress any possibility of severe water hammer occuring. Therefore if the pump stops rotating within $\frac{2L}{a}$ seconds of power failure a negative pressure of magnitude $DH = \frac{a}{g} DV$ occurs where:

L = length of conduit, feet

a = water hammer wave velocity, fps.

g = acceleration of gravity, feet per second

If this negative surge is greater than the static head plus 32 feet a vacuum will occur in the pipeline causing the steady state continuous water column to degenerate to several flow reaches moving under ill-defined, independent boundary conditions. The system static head and the resistance would eventually overcome the original kenetic energy of flow at which point the water within the conduit would reverse and accelerate back towards the pumping plant. Severe pressure rises would result as the independent moving columns rejoin, thus subjecting the system to water-hammer pressure peak loading substantially in excess of normal operating pressures. Consequently protection components provided to control pressure rise following water column reversal could not be selected on adequately rigorous terms.

Numerous methods are available to control water hammer and these include slow opening and closing discharge valves, conventional surge tanks, and large hydro-pneumatic surge tanks. The surge tanks are designed to dampen any possible water hammer effects and to keep the column of water in the pipeline from separating.

The Velva tunnel would require seven service vertical shafts along its 31 mile length leading from the tunnel vertically to the ground surface. These shafts would be approximately 40 feet in diameter to accomodate ventilation ducting, hoist equipment for the removal of excavation, and elevators for workers. It is proposed that these shafts be converted into surge tanks to prevent the possibility of water hammer pressure developing to a magnitude that would cause damage to the pumps and tunnel.

No design of the surge tanks was undertaken for this report.

7. Structural Design of Tunnel Walls

The tunnels will be required to work against a static head of 300 feet with a friction head at the pumphouse of 150 feet (plus what ever water hammer may develope). This total head of 450 feet is equivalent to 200 psi. Since the concrete is usually pumped into the forms under a slight pressure it may be possible to take up some of this stress in the supporting rock foundation. However without having more specific data on the bedrock formation it is impossible to conduct any design.

The design used for estimating cost of the concrete lining and ring beam support system is a copy of the design used for the 30'-0" Mangla Diversion Tunnels (see Figure E-1 for a cross-section of a tunnel).

8. Cost Estimate

A cost estimate for one of the four Velva Tunnels is given in Table E-1. This estimate was based on unit costs for concrete, steel, and labour that have been experienced in the Manitoba area. The cost of the moles were based on prices quoted in various technical advertisements and articles. The volume of material involved was based upon the tunnel section illustrated in Figure E-1. On this basis the capital cost of a sigle Velva tunnel was estimated at $236,150,000.

In order to check the above estimate, another estimate based on the costs experienced on the Azotea tunnel, shown in Table E-4, was made. The capital cost of the Velva tunnel by this method was estimated to be $335,000,000. However it was felt that this estimate is high since the volumes of excavation, concrete, etc. on the Azotea Tunnel Project was considerably lower than that for the Velva tunnel and therefore would reflect a higher unit price. For example, the excavation and concrete yardages for the Velva tunnel are 10,000,000 cubic yards and 2,480,000 cubic yards respectively. Excavation and concrete yardages for the Azotea tunnel were 350,000 cubic yards and 27,300 cubic yards respectively.

Azotea Tunnel unit prices would have to be reduced 30% to give the same total capital cost for the Velva tunnel. It would seem reasonable that this reduction in unit cost would occur if yardage as required for the Velva tunnels were experienced.

TABLE E-1

COST ESTIMATE FOR ONE VELVA TUNNEL

Tunnel Features:

Diameter = 40 ft. internal diameter
Length = 31 miles (170,000 ft.)
Bore Diameter of Mole = 46 ft.
Tunnel Lining = three foot thick Reinforced Concrete Walls
= 12" WF 75 lb. @ 5'-0" on centres
Tunnel Advancement = 2000 ft. /month Average

Hydraulic Characteristics:

Flow = 17,500 cfs.
Velocity = 14 fps.
Head at Pumphouse =

Contract Quantities:

(a) Excavation /ft. = 62 cu. yds.
Excavation /mile = 327,000 cu. yds.
Excavation for Tunnel = 10,000,000 cu. yds.

(b) Volume of Concrete (Lining) /ft. = 15.1 cu. yds.
Volume of Concrete (Lining) /mile = 80,000 cu. yds.
Volume of Concrete (Lining) for Tunnel = 2,480,000 cu. yds.

(c) Reinforcing Steel: (See Figure E-1)
#11 @ 1'-0" c.c. = 680* /ft. of tunnel
8 @ 1'-5" c.c. = 234* /ft. of tunnel
Total 914* /ft. of tunnel
Reinforcing Steel /mile = 4,800,000*
Reinforcing Steel for Job = 150,000,000*

(d) Weight of 12" WF 75 lb. Supports:
Weight /ft. = 2200 lbs.
Weight /mile = 11,500,000 lbs.
Weight for Tunnel = 360,000,000 lbs.

(e) Shafts:
- One approximately every 4 miles for a total of seven
- $1,000,000 each

(f) Tunnel Railroad:
- 14 miles of track, hopper case and electric locomotive
- Lump Sum = $1,000,000

(g) Ventilation Equipment:
- $1,000,000 @ each shaft

TABLE E-1 (continued)

Labor Cost in "Moling":

60 men /day (20 men /shift) @ \$40 /man - day =	\$2400 /day
Supervision 25%	\$ 600 /day
	\$3000 /day

Cost /month = 30 days X \$3000 /day = \$90,000

Time Required to Complete Job:

Tunnel Advancement: 2000 ft. /month Average
Time Required for Job:
(31 miles x 5280 ft. /mile) ÷ 200 ft. /month = 82 months
Say 85 months

Total Construction Cost:

Labour: \$90,000 /month X 85 months	\$ 7,650,000
Moles: 2 @ \$1,000,000 each	2,000,000
Concrete: 2,480,000 cu. yds. @ \$30 /cu. yd.	74,000,000
Reinforcing Steel: 150,000,000 lbs. @ \$0.15 /lb.	30,000,000
WF Supports: 360,000,000 lbs. @ \$0.25 /lb.	90,000,000
7 Shafts @ \$1,000,000 each	7,000,000
Tunnel Railroad @ \$1,000,000	1,000,000
Ventilating System - Lump Sum	7,000,000
Disposal of Excavation at Surface: 10,000,000 cu. yds. @ \$0.35 /cu. yd.	3,500,000
Modification to Shafts for Water Hammer: 7 @ \$2,000,000 each	14,000,000
TOTAL	\$236,150,000

TABLE E-2

TUNNEL SIZE SELECTION

(1) 40' diameter Tunnel

Static Lift = 1850 - 1550
= 300 ft.

Q = 17,500 cfs.

$A = \quad (20)^2$
= 1256 sq. ft.

V = Q/A
= 17,500 cfs. /1256 sq. ft.
= 14.0 fps.

Length = 31 miles
= 170,000 ft.

Friction Loss = f L/D V^2 /2g

Friction Loss = f 170,000 ft./40 ft. $(v)^2$ /64.4
= 66 F $(v)^2$

Calculate f

$$e = \frac{0.001 + 0.010}{2} = 0.0055$$

$$\frac{e}{D} = 0.0055 /40$$
$$= 1.37 \times 10{-}4$$

$$Re = \frac{VD}{v}$$

VD = 14 x 480
= 6730

f = 0.012

Friction Loss = 66 x 0.012 $(14)^2$
= 155 ft.

Total Lift = Static Lift and Friction Loss
= 300 feet + 155 feet
= 455 feet

MW Rating for Powerhouse and Pumphouse

$$= \frac{455 \text{ ft.} \times 17{,}500 \text{ cfs.} \times 62.4 \text{ lbs/cu. ft.}}{550 \text{ ft. lbs.} \times 0.8 \text{ efficiency}} \times 736 \text{ watts/h.p.}$$

= 830 MW

TABLE E-2 (continued)

Capital Cost /MW Pumping Stations	= \$ 72,000
Capital Cost /MW Generating Stations	= \$122,000
	\$194,000

Capital Cost of Pumping Stations and Generating Stations
= \$194,000 /MW x 830 MW
= \$160,000,000

Capital Cost of Tunnel: \$236,150,000

(2) 35 Foot Diameter Tunnel

Static Lift = 1850 - 1550
= 300 feet

Q = 17,500 cfs.

$$A = (17.5)^2$$
$$= 962$$

V = Q/A
= 17,500 cfs. /962 sq. ft.
= 18.2 fps.

$$\text{Friction Loss} = 155 \text{ ft. X } \left(\frac{18.2}{14}\right)^2 \text{ X } \frac{40}{35}$$
$$= 300 \text{ ft.}$$

Total Lift = Static Lift and Friction Loss
= 300 ft. + 300 ft.
= 600 ft.

MW Rating for Powerhouse and Pumphouse

$$= \frac{600 \text{ ft. X } 17{,}500 \text{ cfs. X } 62.416 \text{ /cu. ft.}}{550 \text{ ft. lbs. X } 0.8 \text{ efficiency}} \text{ X } 736 \text{ watts/ h.p.}$$

= 1100 MW

Capital Cost /MW of Pumping Stations	= \$ 70,000
Capital Cost /MW of Generating Stations	= \$120,000
Capital Cost of Total MW	= \$190,000

Capital Cost of Pumping Stations and Generating Stations
= \$190,000 X 1100 MW
= \$210,000,000

TABLE E-2 (continued)

Incremental Cost of Pumping Stations and Generating Stations over that required for the 40 foot Diameter Tunnel

$$= \$210,000,000 - \$160,000,000$$
$$= \$50,000,000$$

Saving in tunnel cost over that required for 40 foot diameter tunnel

$$\% \text{ decrease} = \left(\frac{40}{35} - 1.0\right) 100$$
$$= 14\%$$

$$\text{Capital Saving} = \$236,150,000 \times 0.14$$
$$= \$32,600,000$$

TABLE E-3

AZOTEA TUNNEL

(1) Statistics

Bore Diameter = 13 ft. - 3 inches
Finished Diameter = 10 ft. - 11 inches
Length = 12.8 miles
Reinforced Concrete Lining = 1'-2" thick
Cost of Contract =$13 million
Bid Price for Excavation = $23.60 /cu. yd.

(2) Contract Quantities

Excavation /foot of Tunnel = 5.2 cu. yds.
Excavation /mile of Tunnel = 27,300 cu. yds.
Total Excavation for Tunnel = 350,000 cu. yds.

Concrete /foot of Tunnel = 1.7 cu. yds.
Concrete /mile of Tunnel = 9,000 cu. yds.
Total Concrete for Tunnel = 115,000 cu. yds.

(3) Unit Prices

Bid Price for Excavation = $23.60 /cu. yd.
Total Cost of Excavation = $23.60 /cu. yd. x 350,000 cu. yds.
= $8,250,000

Cost of Concrete Lining Including Steel and 6" WF Ring Beams
=$13,800,000 - $8,250,000
= $5,550,000

Cost /yard of Concrete Including Reinforcing Steel and 6" W F Ring Beams
= $5,550,000 ÷ 115,000 cu. yds.
= $48.40

TABLE E-4

COST ESTIMATE FOR VELVA TUNNEL BASED ON

AZOTEA TUNNEL UNIT PRICES

(1) Statistics of Velva Lining

Bore Diameter - 46'-0"
Finished Diameter - 40'-0"
Length - 31 miles
Reinforced Concrete Lining - 3'-0" thick

(2) Contract Quantity

Total Excavation for Tunnel: 10,000,000 cubic yards
Total Volume of Concrete : 2,480,000 cubic yards

(3) Cost of Tunnel Based on Azotea Tunnel Unit Prices

Cost of Excavation: $23.60 /cu. yd. X 10,000,000 cu. yds.
= $236,000,000

Cost of Concrete : $48.40 /cu. yd. X 2,480,000 cu. yds.
= $119,000,000

TOTAL $355,000,000

VELVA TUNNEL CROSSECTION

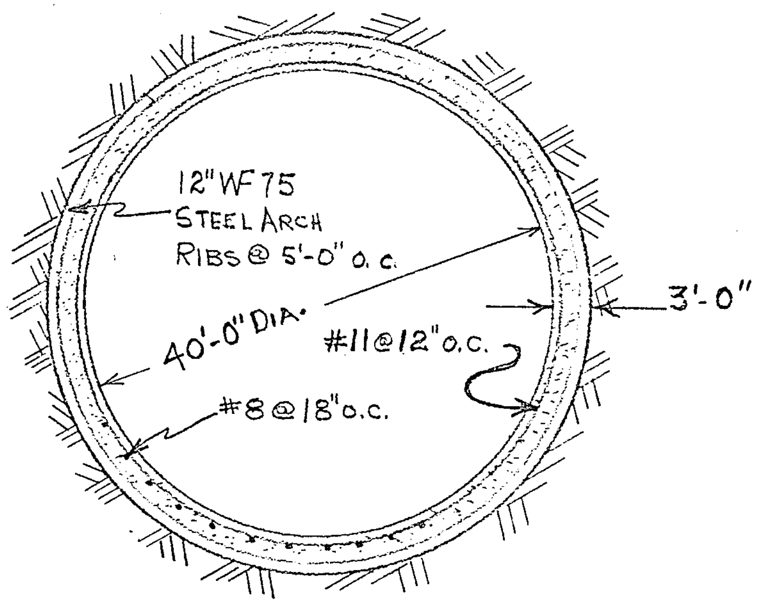

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FIGURE E-1

LAKE MANITOBA - GARRISON RESERVOIR

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PIPELINES

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PIPELINES

1. Introduction

Pipelines were considered as alternatives to the Lake Manitoba-Assiniboine River Canal, the Bunclody Canal and the Velva-Garrison Canal.

Although there are numerous water conveying tunnels of the diameter required for this diversion, there are no water conveying pipelines as such. However, there are many vehicular "pipelines" of this size so it does not seem impractical that water conveying pipelines of this diameter could not be constructed.

This chapter will deal with some of the general features associated with the pipelines and their method of design.

2. Lake Manitoba-Assiniboine River Pipeline

The Lake Manitoba-Assiniboine River Pipeline would convey water from Lake Manitoba to the reservoir behind Dam #1 on the Assiniboine River. The pipeline would operate against a static head of 113 feet. The pipeline would be 16.5 miles long.

3. Bunclody Pipeline

The Bunclody pipeline would convey water from a point near the Village of Bunclody on the reservoir behind the "low level" Dam #7 (FSL 1350) south-south west to the Blind Souris which forms part of the reservoir behind Dam #10. The pipeline would be 47 miles in length. The pipeline would operate against a static head of 0 feet.

4. Velva-Garrison Dam Pipeline

This pipeline would convey water from the reservoir behind Dam #12 (FSL 1550) to the divide between the Souris and Mississippi Watersheds. The divide is located at elevation 2060. From the divide the water would flow by canal and natural channel to the Garrison Reservoir as described in Appendix D. The pipeline would be 20 miles in length and would operate against a static head of 510 feet.

5. Size Limitations

It was assumed that the maximum velocity that could be tolerated in the pipline was 10-15 fps. and that the maximum size that could be economically constructed was a forty-foot diameter pipeline. This criteria resulted in each conduit being able to carry 17,500 cfs. at 14 fps.

It is possible that each conduit could carry flow at a higher velocity and, therefore, carry more water. But the increase in velocity would result in higher friction heads and higher design pressures both from the point of view of water hammer and pump head. The economical limit to increased velocity would be reached when the incremental capital cost of higher head pumping stations, larger generating stations, and heavier wall pipe equalled the capital saving either in the reduction of the number of conduits or the size of the conduits.

However, before a study of the above nature was carried out it was decided to investigate the economic feasibility of the pipelines versus the other alternatives available. It was decided for the purpose of the feasibility study that a 40 foot conduit conveying 17,500 cfs. would be investigated.

6. Design

Of the three pipelines under consideration, the Bunclody Pipeline would operate under the lowest head (see Table F-1). It was decided to carry out a preliminary design on this pipeline to determine the relative cost of the pipelines.

The design pressure for the pipeline was based upon the static head plus 50% for water hammer allowance. It is possible that with adequate water hammer dampening devices, such as surge tanks, that the allowance for water hammer could be lower. However, this could only be determined by carrying out a series of water hammer analysis with different sizes of water hammer dampening devices until an economical balance was reached between the incremental capital cost of providing adequate water hammer dampening devices and the incremental saving in the capital costs of the pipe resulting from the lower design head. It was felt that such a study as described above was beyond the scope of this report.

The Bunclody Pipeline wall was designed using the hoop stress method. This method is valid only if the pipeline is small in diameter and thin walled. If the pipe is substantially larger than 3 to 4 feet in diameter, the method will yield low design stresses and therefore an unsafe pipe design. Since the design in this report was only for estimating purposes, it was concluded that the "hoop stress" method of design would suffice. The design method used is outlined in Table F-2. The design is illustrated in Figure F-1.

7. Economic Feasibility of Constructing Pipelines

The average capital cost per mile for the 17,500 cfs. Bunclody pipeline was estimated at $7,300,000 per mile (less the cost of right-of-way, railroad, vehicular bridges, and earth moving).

The Bunclody Canal was estimated to cost $1,365,000 per mile and $4,336,000 per mile for the 17,500 cfs. and 70,000 cfs. flows respectively (see Appendix D, Table D-3). The pumping station for the Bunclody Pipeline would of course be more costly than the Bunclody Canal Pumphouse because of the increased Megawatt rating of the pipeline pumphouse caused by the pipe friction. It is obvious from the above figures that the Bunclody Pipeline is not an economical alternative for the Bunclody Canal.

The average cost per mile (not including the cost of the pumping stations) for the Lake Manitoba-Assiniboine River Canal was estimated to be $1,920,000 and $4,600,000 for the 17,500 cfs. and 70,000 cfs. flows respectively (see Appendix D, Table D-5) which is considerably lower than the average per mile cost of the pipeline. The pumping station costs for the canal for the 17,500 cfs. and 70,000 cfs. flows was estimated to be $42,000,000 and $119,000,000 respectively. (see Appendix G, Table G-2).

The pumping station costs for the pipeline for the 17,500 cfs. and 70,000 cfs. flows were estimated to be $33,000,000 and $83,500,000 respectively. It was interesting to note that with the consolidation of the pumping at one station on the pipeline rather than four stations on the canal the cost of the pumping station for pipelines was less than that for the canal even with a higher pump head on the pipeline. However, because of the increased head (and therefore MW rating) of the pumping station of the pipeline over that required for the canal, the power generating capital costs will go up $14,000,000 and $57,000,000 for the 17,500 cfs. and 70,000 cfs. flows. The increase in the power generating costs would erase any saving made in the pump station capital costs. Therefore it can be seen from the above figures that the pipeline is not an economical alternative to the Lake Manitoba-Assiniboine River Canal.

With the design pressure of the Velva-Garrison Pipeline being approximately 3.7 time higher than the Bunclody

Pipeline, and the average cost of the Velva-Garrison Canal being about equal to the Lake Manitoba-Assiniboine Diversion, it is apparent that the pipeline in this case also would be an uneconomical choice.

In the above discussions on economic feasibility of constructing pipelines, the discussion was limited to 17,500 cfs. and 70,000 cfs. Be inference the comments applicable to these flows are true for the 35,000 cfs. and 52,500 cfs. flows.

TABLE F-1

PIPELINES

(1) Statistics

Internal Diameter Pipeline	-- 40' 0"
Flow Velocity	-- 14 fps
Flow/conduit	-- 17,500 cfs

(2) Operating Head-(Static Head & Friction Head) 1.5

Pipeline	Static head	Friction Head	Design Head
Lake Manitoba-Assiniboine River	113 ft	54 ft	250 ft
Bunclody	0 ft	154 ft	231 ft
Velva-Garrison Reservoir	510 ft	65 ft	860 ft

(3) Megawatt Rating of Pump Stations

	70,000 cfs	52,500 cfs	35,000 cfs	17,500 cfs
Lake Manitoba-Assiniboine River	1230 MW	930 MW	610	306
Bunclody	1980 MW	1500 MW	985	492
Velva-Garrison Reservoir	4250 MW	3200	2100	1050

TABLE F-2

BUNCLODY PIPELINE

```
Assumed design head = (Static Head & Friction Head) 1.5
                    = (0 + 154) 1.5
                    = 231 ft.
                    = 100 psi

Hoop stress/ft      = Pressure x Radius of Pipe x 12"
                    = 100 psi x (20 ft.x12 in.) x 12 in.
                    = 288,000#/ft.

Hoop Steel Req'd.   = 288,000#/ft/40,000 psi
                    = 7.0 sq.in.

No. of #11 Bars/ft. required for hoop stress =
                    = 7.0 sq.in./1.56 sq.in. /#11 bar
                    = 4.5 say 5.0
```

Longitudinal Steel Assume #6 bar @ 1' 0" c.c.
Base steel #11 Top and Bottom @ 12# c.c.
Concrete Wall thickness: Assume as shown in Figure #F-1

Materials/ft. of Pipe

Steel:	#11 bars - 165 ft. x 5 bars x 5.313 #/ft.	= 4,400 lbs.
	# 6 bars (outside) 152 bars x2.36#/fs	= 360 lbs.
	# 6 bars (inside) 130 bars x 2.36#/fs	= 306 lbs.
	#11 bars (base) 2 bars x 42 ft x5.13#/fs	= 430 lbs.
	Total Steel	5496 lbs.

Concrete: 16 cubic yards.

Cost Estimate/ft of Pipe

Steel: 5496 lbs. @$0.15/lb. =	$820
Concrete: 16 cu. yds @$35/cu.yd.	560
	$1380

Cost/mile = $1380 /ft. x 5280 ft/mile
= $7,300,000/mile

BUNCLODY PIPELINE CROSSECTION

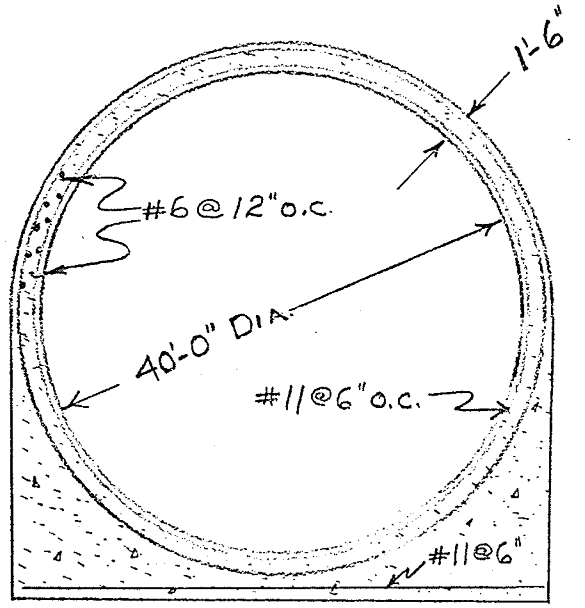

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FIGURE F-1

LAKE MANITOBA - GARRISON RESERVOIR

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PUMPING STATIONS

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PUMPING STATIONS

1. Introduction

The pumping stations,which form a significant portion of the capital cost of this project, are required to lift the diversion water from Lake Manitoba at an elevation of 812 to the Garrison Reservoir at elevation 1852.

Although the pumping stations were not actually designed, it was found that there were a number of features of the pumping stations that would influence the location of other works on the diversion. This section covers these features and describes how the capital cost for the pumping stations was estimated.

2. Submergence Requirements for the Pumping Stations

It was assumed that a minimum of thirty five of water (8) must be available over the pump station intakes to prevent unnecessary intake loss. It was found that this criteria required that the intake channel of some of the pumphouses be depressed below the natural channel bottom. This feature of the channel design is covered in Appendix A.

3. Foundations for Pumping Stations

The foundation conditions available at each pumping station location are covered in Appendix B.

The construction of the pumping stations in conjunction with the earth dams will present some problems related to differential settlement. It is expected that settlement under the earth dams will occur due to consolidation of the dam foundation. Because of the heavy loads associated with the pumping stations and the inflexible nature of the pumping stations, the pumping stations will have to be constructed on a pile foundation in order to transmit the high loads to a suitable bearing layer and so as to keep settlement to a minimum. The pumping stations will therefore not be subject to the same settlement as will the dams.

Because of this, the pumping stations and discharge conduits will probably have to be completely disassociated from the dam embankment. The pumping stations would be located downstream of the dams with the discharge conduits constructed through a dam abutment in virgin material.

4. Civil, Mechanical and Electrical Works

In general other than the considerations for submergence of the pump units and general considerations for foundation conditions no attempt was made to size or design any portion of the civil, mechanical or electrical works associated with the pumping stations.

For the purpose of estimating the electrical imput into the pumping stations, it was assumed that the overall efficiency of the pumping stations was 80%.

5. Capital Cost of Pumping Stations

C. W. Hubbard (18) developed a cost per kilowatt versus size of installation curve for pumped storage plants in the size range from 300 to 2,000 megawatts for heads of 350 feet or more.

Since pumping station sizes in this study ranged from 18 to 3,350 megawatts, it was necessary to try and extend the Hubbard curve over these ranges. To do this and also to verify the Hubbard curve, capital costs for proposed hydro generating stations on the Nelson River (19) were obtained courtesy of Manitoba Hydro. It was assumed that the capital costs of the hydro generating stations would be essentially the same as the capital cost of pumping stations of the same size range. These figures are tabulated in Table G-1. It was found that the figures for the hydro generating station spanned the size range of 257 to 1610 megawatt well within the range being considered for pumping stations in the report.

Although it was possible to draw a curve through the hydro generating points, it was decided to use the Hubbard curve for estimating the capital cost of the pumping stations for the pump station size range of 300 to 2000 megawatts. In order to estimate capital costs for pumping stations less than 300 megawatts in size, it was decided to extend the Hubbard curve by setting the cost of a 50 megawatt station at $200,000 per megawatt and joining this point by a straight line with the last point on Mr. Hubbard's curve. For pumping stations in excess of 2,000 MW rating the capital costs per megawatt was taken as the same value for the 2,000 MW station (See Figure G-2).

It was felt that the capital cost per megawatt would vary with the head and discharge pumped. An attempt was made to establish capital cost per megawatt versus size of installation curves for 10 foot, 50 foot and 100 foot pump discharge heads. However, sufficient information was not available to do this.

The Hubbard curve reflects the total cost of a pumped storage plant (percentage of total cost indicated in brackets) including land and rights (3%); reservoirs; dams and waterways (40%); powerhouse (7%); major and auxillary equipment (33%); and transmission line (2%); administration and engineering (15%). It was possible, with these figures to reduce the capital costs per megawatt figures by 40% at least since essentially the information required for this study is the cost of powerhouse and major and auxillary equipment.

However on reviewing the plot of the Hubbard curve on Figure G-2 in relation to the points of the Manitoba Hydro generating stations it was felt that if this reduction was carried out that the Hubbard curve would yield per MW costs well below that experienced by Manitoba Hydro. Therefore, it was decided not to reduce the Hubbard curve.

The estimated capital cost of the pumping stations are listed in Table G-2.

TABLE G-1

CAPITAL COST OF NELSON RIVER HYDRO ELECTRIC GENERATING STATIONS

Station	Flow	Head	MW Rating	Capital Cost	Cost /MW
Upper Gull Project	75,000 cfs.	45'	257	$35,310,000	$133,000
	125,000 cfs.	45'	428	56,750,000	134,000
Lower Gull Project	75,000 cfs.	43.5'	248	44,590,000	180,000
	125,000 cfs.	43.5'	414	55,860,000	135,000
Kettle Rapids	75,000 cfs.	98.5'	562	44,500,000	80,000
	125,000 cfs.	98.5	936	70,000,000	75,000
Long Spruce	75,000 cfs.	78	445	39,910,000	90,000
	125,000 cfs.	78	742	63,540,000	86,000
Limestone	75,000 cfs.	169.5	966	54,050,000	56,000
	125,000 cfs.	169.5	1610	88,520,000	55,000
Gillam	75,000 cfs.	80.5	459	41,570,000	90,000
	125,000 cfs.	80.5	765	67,200,000	88,000

TABLE G-2

CAPITAL COST OF PUMPING STATIONS

A. 70,000 cfs Capacity

(1) Lake Manitoba-Assiniboine River Canal Pumping Stations

Mile 4.0 -	25 ft. lift -	184 MW	@ $155,000/MW	=	$ 28,500,000
Mile 11.0 -	25 ft. lift -	184 MW	@ $155,000/MW	=	$ 28,500,000
Mile 17.0 -	33 5 ft. lift -	248 MW	@ $125,000/MW	=	$ 31,000,000
Mile 18.5 -	33.5 ft. lift -	248 MW	@ $125,000/MW	=	$ 31,000,000
		Total Capital Cost			$ 119,000,000

(2) Assiniboine River Dams Pumping Stations

Dam # 1 - FSL 925 -	0 ft. lift -	-- MW	@ $-- MW	=	$ --
Dam # 2 - FSL 950 -	25 ft. lift -	184 MW	@ $155,000/MW	=	$ 28,500,000
Dam # 3 - FSL 1050-	100 ft. lift -	735 MW	@ $ 76,000/MW	=	$ 56,000,000
Dam # 4 - FSL 1150-	100 ft. lift -	735 MW	@ $ 76,000/MW	=	$ 56,000,000
		Total Capital Cost			$ 140,500,000

(3) Souris River Dams Pumping Stations

Dam #5 FSL 1200-	50 ft. lift -	368 MW	@ $104,000/MW	=	$ 37,200,000
Dam #6 FSL 1300-	100 ft. lift -	735 MW	@ $ 76,000/MW	=	$ 56,000,000
		Total Capital Cost			$ 93,200,000
Dam #7 FSL 1350-	50 ft. lift	368 MW	@ $ 76,000/MW	=	$ 38,400,000
		Total Capital Cost			$ 38,400,000

70,000 cfs. continued

TABLE G-2 continued

CAPITAL COST OF PUMPING STATIONS

(3) Souris River Dams Pumping Stations

Dam #7	FSL 1400	100 ft. lift	- 736 MW @ $76,000/MW	=	$ 56,000,000
Dam #8	FSL 1410	10 ft. lift	- 736 MW @$200,000/MW	=	$ 14,720,000
Dam #9	FSL 1440	30 ft. lift	- 220 MW @$133,000/MW	=	$ 29,300,000
			Total Capital Cost		$ 100,020,000
Dam #10	FSL 1450	10 ft. lift	- 736 MW @$200,000/MW	=	$ 14,720,000
Dam #11	FSL 1500	50 ft. lift	- 368 MW @$104,000/MW		37,200,000
Dam #12	FSL 1550	50 ft. lift	- 368 MW @$104,000/MW		37,200,000
			Total Capital Cost		$ 89,120,000

(4) Velva Tunnels Pumping Station

At Reservoir 12 FSL 1550 - 455 ft. lift - 3350 MW @$65,000/MW = $218,000,000

(5) Bunclody Canal Pumping Station

At Reservoir 7 FSL 1350 - 115 ft. lift - 850 MW @$72,000/MW = $ 61,200,000

Table G-2 continued

(c) 52,500 cfs

(1) Lake Manitoba - Assiniboine River Canal Pumping Stations

Mile 4.0	- 25 ft. lift	- 138 MW	@ $160,000/MW	=	$ 22,000,000
Mile 11.0	- 25 ft. lift	- 138 MW	@ $160,000/MW	=	$ 22,000,000
Mile 17.0	- 33.5 ft. lift	- 186 MW	@ $155,000/MW	=	$ 29,000,000
Mile 18.5	- 33.5 ft. lift	- 186 MW	@ $155,000/MW	=	$ 29,000,000
		Total Capital Cost		=	$102,000,000

(2) Assiniboine River Dams Pumping Stations

Dam #1	FSL 925	0 ft. lift	- -- MW	@ $ -- /MW	=	$ ---
Dam #2	FSL 950	25 ft. lift	138 MW	@ $160,000/MW	=	$ 22,000,000
Dam #3	FSL 1050	100 ft. lift	555 MW	@ $ 82,000/MW	=	$ 45,500,000
Dam #4	FSL 1150	100 ft. lift	555 MW	@ $ 82,000/MW	=	$ 45,500,000
			Total Capital Cost			$113,000,000

(3) Souris River Dam Pumping Stations

Dam #5	FSL 1200	50 ft. lift	277.5 MW	@ $115,000/MW	=	$ 31,600,000
Dam #6	FSL 1300	100 ft. lift	555 MW	@ $ 82,000/MW	=	$ 45,500,000
			Total Capital Cost			$ 77,100,000
Dam #7	FSL 1350	50 ft. lift	277.5 MW	@ $115,000/MW	=	$ 31,600,000
			Total Capital Cost			$ 31,600,000
Dam #7	FSL 1400	100 ft. lift	555 MW	@ $ 82,000/MW	=	$ 45,500,000
Dam #8	FSL 1410	10 ft. lift	55.5 MW	@ $200,000/MW	=	$ 11,000,000
Dam #9	FSL 1440	30 ft. lift	166.5 MW	@ $155,000/MW	=	$ 25,800,000
			Total Capital Cost			$ 82,300,000
Dam 10	FSL 1450	10 ft. lift	55.5 MW	@ $200,000/MW	=	$ 11,000,000
Dam 11	FSL 1500	50 ft. lift	277.5 MW	@ $115,000/MW	=	$ 31,600,000
Dam 12	FSL 1550	50 ft. lift	277.5 MW	@ $ 82,000/MW	=	$ 31,600,000
			Total Capital Cost			$ 74,200,000

Table G-2 continued

(c) 52,500 cfs continued.

(4) Velva Tunnels Pumping Stations

At Reservoir 12 FSL 1550 455 ft. lift - 2560 MW @ $65,000/MW = $ 166,500,000

$ 166,500,000

(5) Bunclody Canal Pumping Stations

At Reservoir 7 FSL 1350 - 115 ft. lift 635 MW @ $77,000/MW = $ 49,000,000

$ 49,000,000

TABLE G-2 continued

(c) 35,000 cfs.

(1) Lake Manitoba-Assiniboine River Canal Pumping Stations

Mile 4.0	25 ft. lift	92 MW @ $ 180,000/MW	=	$ 16,500,000
Mile 11.0	25 ft. lift	92 MW @ $ 180,000/MW	=	16,500,000
Mile 17.0	33.5 ft. lift	124 MW @ $ 170,000/MW	=	21,100,000
Mile 18.5	33.5 ft. lift	124 MW @ $ 170,000/MW	=	21,100,000
		Total Capital Cost		$ 75,200,000

(2) Assiniboine River Dams Pumping Stations

Dam #1	FSL 925	0 ft. lift	- @ --	=	--
Dam #2	FSL 950	This dam is not used in this scheme--			
Dam #3	FSL 1050	125 ft. lift	458 MW @ $ 92,000/MW	=	$ 42,000,000
Dam #4	FSL 1100	50 ft. lift	183 MW @ $155,000/MW	=	$ 28,400,000
Dam 4A	FSL 1150	50 ft. lift	183 MW @ $155,000/MW	=	$ 28,400,000
			Total capital cost		$ 98,800,000

(3) Souris River Dams Pumping Stations

Dam #5	FSL 1200	50 ft. lift	183 MW @ $155,000/MW	=	$ 28,400,000
Dam #6	FSL 1300	100 ft. lift	366 MW @ $104,000/MW	=	$ 38,000,000
			Total capital cost	=	$ 66,400,000
Dam #7	FSL 1350	50 ft. lift	183 MW @ $155,000/MW	=	$ 28,400,000
			Total Capital cost	=	$ 28,400,000
Dam #7	FSL 1400	100 ft. lift	366 MW @ $104,000/MW	=	$ 38,000,000
Dam #8	FSL 1410	10 ft. lift	36.6 MW @ $200,000/MW	=	$ 7,300,000
Dam #9	FSL 1440	30 ft. lift	110 MW @ $172,000/MW	=	$ 19,000,000
			Total capital cost		$ 64,300,000
Dam 10	FSL 1450	10 ft. lift	36.6 MW @ $200,000/MW	=	$ 7,300,000
Dam 11	FSL 1500	50 ft. lift	183 MW @ $155,000/MW	=	$ 28,400,000
Dam 12	FSL 1550	50 ft. lift	183 MW @ $155,000/MW	=	$ 28,400,000
			Total capital cost		$ 64,100,000

Table G-2 continued

(c) 35,000 cfs. continued.

(4) Velva Tunnels Pumping Station

At Reservoir 12 FSL 1550 455 ft. lift - 1675 MW @ $66,000/MW	=	$111,000,000
Total Capital Cost	=	$111,000,000

(5) Bunclody Canal Pumping Station

At Reservoir #7 FSL 1350 - 115 ft. lift - 425 MW @ $95,000/MW	=	$ 40,400,000
		$ 40,400,000

Table G-2 continued

(c) 17,500 cfs

(1) (1) Lake Manitoba-Assiniboine River Canal Pumping Station

Mile 4.0 -	25 ft. lift -	46MW @ $200,000/MW =	$ 9,200,000
Mile 11.0 -	25 ft. lift -	46MW @ $200,000/MW =	$ 9,200,000
Mile 17.0 -	33.5 ft. lift -	62MW @ $190,000/MW =	$11,800,000
Mile 18.5 -	33.5 ft. lift -	62MW @ $190,000/MW =	$11,800,000
		Total Capital Cost	$42,000,000

(2) Assiniboine River Dams Pumping Stations

Dam # 1 - FSL 925	0 ft. lift	--MW --- ----	---
Dam # 2 - FSL 950	This dam not used in this scheme		---
Dam # 3 - FSL 1050	125 ft. lift	230 MW @$127,000/MW =	$29,200,000
Dam # 4 - FSL 1100	50 ft. lift	91.5 MW @$180,000/MW=	16,500,000
Dam #4A - FSL 1150	50 ft. lift	91.5 MW @$180,000/MW=	16,500,000
		Total Capital cost	$62,200,000

(3) Souris River Dams Pumping Station

Dam # 5 - FSL 1200	50 ft. lift	91.5 MW @$180,000/MW	$16,500,000
Dam # 6 - FSL 1300	100 ft. lift	183 MW @$155,000/MW	$28,400,000
		Total Capital Cost	$44,900,000
Dam # 7 - FSL 1350	50 ft. lift	91.5 MW @$180,000/MW	$16,500,000
		Total capital cost	$16,500,000
Dam # 7 - FSL 1400	100 ft. lift	183 MW @$155,000/MW	$28,400,000
Dam # 8 - FSL 1410	10 ft. lift	18.3MW @$200,000/MW	$ 3,700,000
Dam # 9 - FSL 1440	30 ft. lift	55.0MW @$200,000/MW	$11,000,000
		Total Capital Cost	$43,100,000

Table G-2 continued

(c) 17,500 cfs

(3) continued.

Dam # 10 FSL 1450	10 ft. lift	18.3 MW	@ $200,000/MW	=	$ 3,700,000
Dam # 11 FSL 1500	50 ft. lift	91.5 MW	@ $180,000/MW	=	$16,500,000
Dam # 12 FSL 1550	50 ft. lift	91.5 MW	@ $180,000/MW	=	$16,500,000
			Total Capital Cost	=	$36,700,000

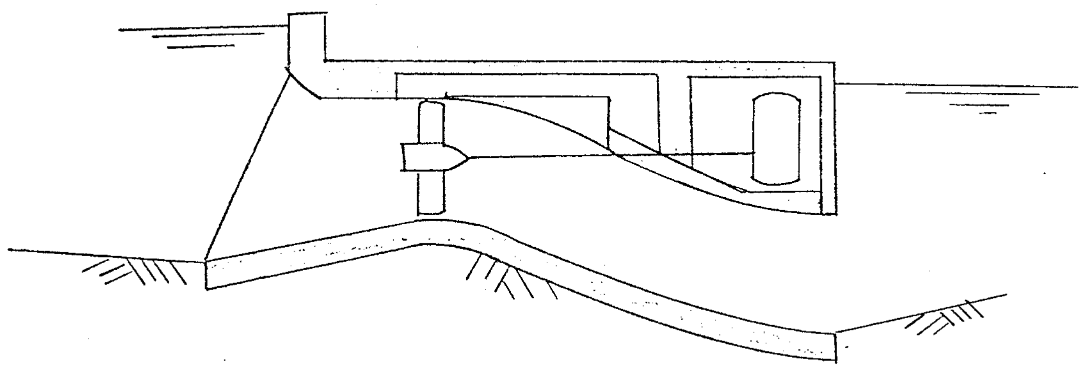
(4) Velva Tunnels Pumping Station

At Reservoir 12 FSL 1550	455 ft. lift	835 MW	@ $73,000/MW	$ 61,000,000
			Total Capital Cost	$ 61,000,000

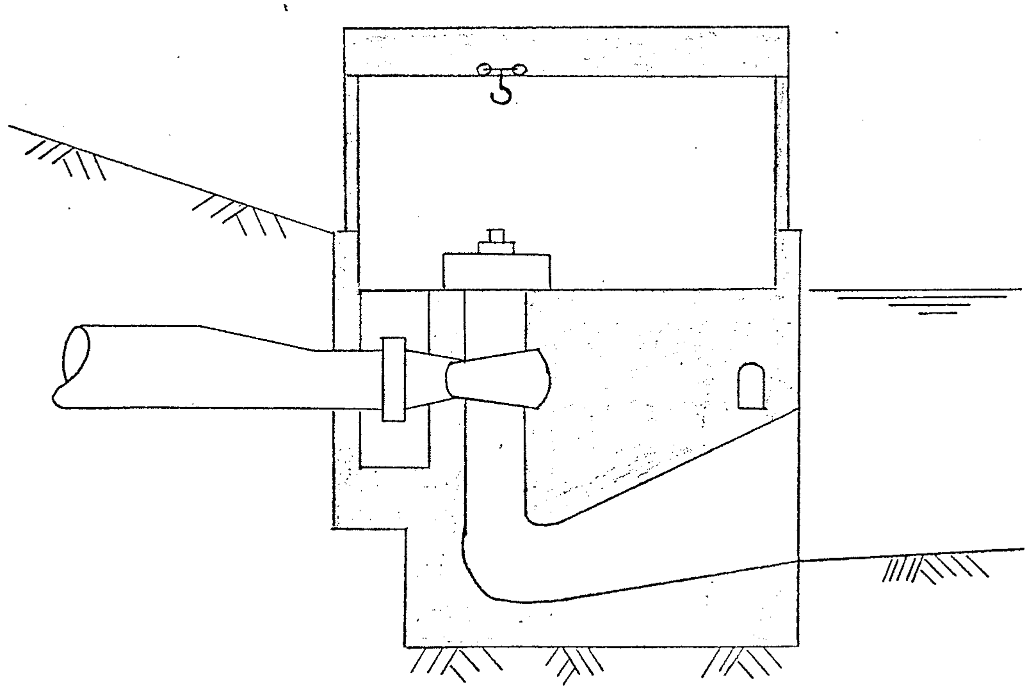
Bunclody Canal Pumping Station

At Reservoir 7 FSL 1350	115 ft. lift	210 MW	@ $135,000/MW	$ 28,400,000
			Total Capital Cost	$ 28,400,000

TYPICAL PUMPING STATIONS



HEADS TO 50 FEET



HEADS 50 TO 450 FEET

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FIGURE G-1

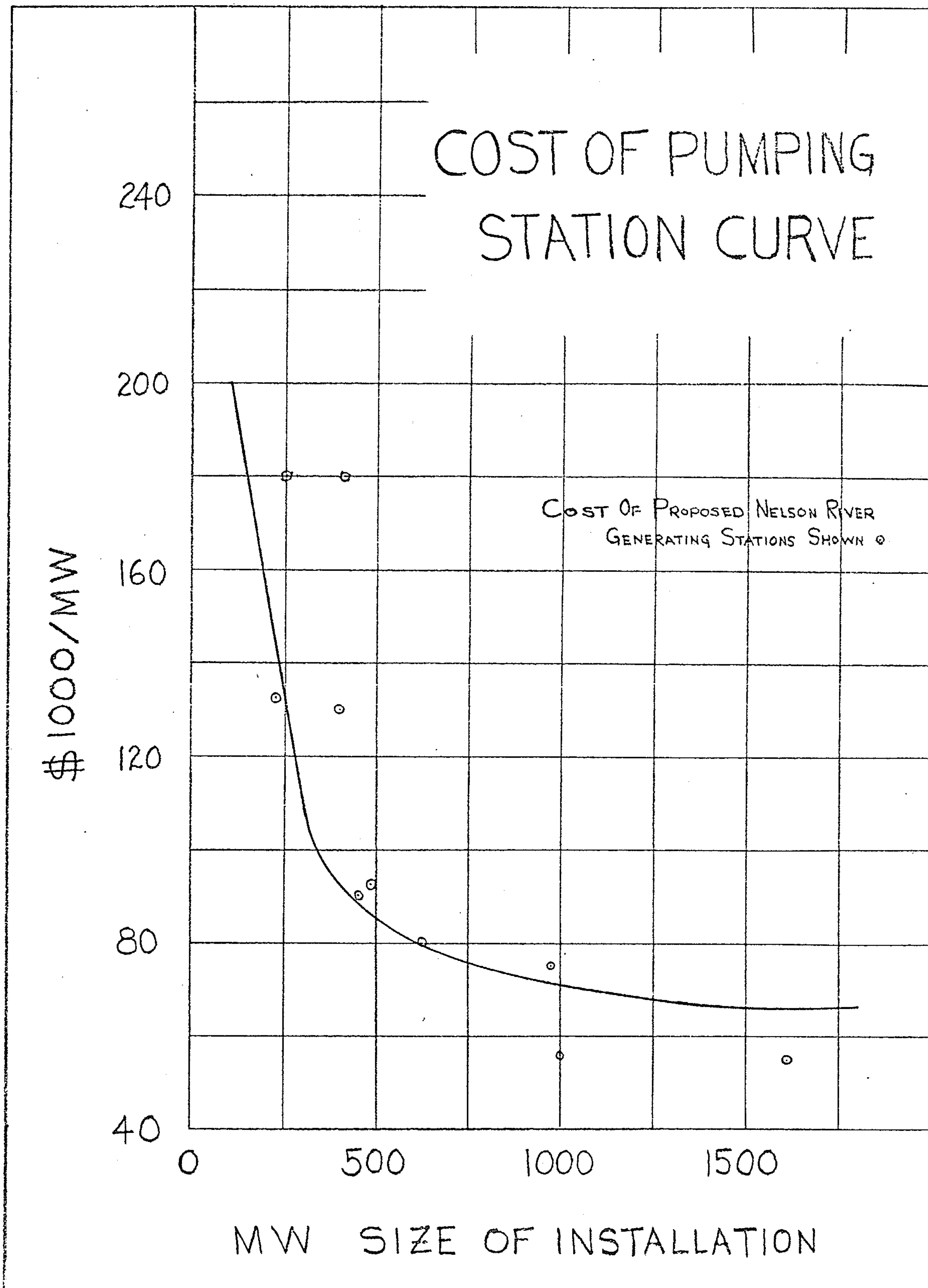
COST OF PUMPING
STATION CURVE
COST OF PROPOSED NELSON RIVER
GENERATING STATIONS SHOWN ⊙
$1000/MW
240
200
160
120
80
40
0
500
1000
1500
MW SIZE OF INSTALLATION

FIGURE G-2

LAKE MANITOBA - GARRISON RESERVOIR

DIVERSION

A P P E N D I X H

POWER

APPENDIX H

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APPENDIX H

LIST OF TABLES

APPENDIX H

POWER

1. Introduction

Approximately 2,650 MW and 10,560 MW of electrical power will be required for the 17,500 cfs and 70,000 cfs diversion flows respectively.

Presently the combined thermal, gas turbine, and hydro generated output of the Manitoba Hydro and Winnipeg Hydro is 1,640 MW. A potential exists for the developments of another 5,000 MW of hydro generated electrical power.

Assuming a constant increase in electrical consumption of 10% over the next two decades, which would result in an electrical demand of 5,000 MW by 1985-1990, it is apparent from the above figures that electrical power input for the diversion could not be supplied from the existing electrical generating system nor does the potential exist for developing the power required from presently undeveloped hydro electrical generating sites.

This appendix covers the selection of an electrical generating system to supply the electrical power required for the diversion, location of plants, and capital cost of the generating units and distribution system.

2. Electrical Generating System

It was assumed that the large block of electrical power required for this project could be best produced by atomic powered generating stations.

Since the unit cost of power generating decreases (20) with the size of the nuclear plant, it would be advantageous to make the units as large as possible. Presently the largest plants under consideration are 1,000 MW capacity (20).

Practical considerations such as the availability of standby power would to a certain extent govern the size and number of power plants built. Further it is apparent from todays technology that a nuclear unit cannot be shut down for repairs without a delay of some 2 to 3 months.

For these reasons it was felt that it would be unrealistic to consider no less than three plants with an installed capacity of 120% the demand load. Since the nuclear plants would be constructed with two units per plant there would always be one unit in reverse.

Although it would appear at first glance that the cost of distributing the power would have an influence on the locations of the nuclear plants it should be noted that to ensure adequate standby power in event that one unit or one of the nuclear plants has to be shut down adequate transmission facilities must be available to interconnect the nuclear plants.

3. <u>Location of Nuclear Plants</u>

Since large volumes of cooling water will be required to operate the nuclear plants, it will be necessary to construct the plants near the large bodies of water.

Locations meeting this requirement would be the shore of Lake Manitoba, upstream of Dam #3 and #4 in the Assiniboine, upstream of Dam #10 on the Souris River and adjacent to Garrison Dam. Except for the Lake Manitoba and Garrison Dam locations, the plants would largely depend upon cooling water being supplied from the diversion itself.

4. Distribution System

Presently the largest capacity transmission lines being built in Manitoba are 250 MW (230,000 volt) (21) lines. The capital cost of these lines is approximately $35,000 per mile (21).

The distance paralleling the diversion from the Garrison Reservoir to the shore of Lake Manitoba is approximately 350 miles. The total estimated capital cost for transmission lines is shown in Table H-1.

5. Capital Cost of Generating Stations

The capital cost for the nuclear power generating station was obtained from Figure 9 contained in an article "Nuclear Power is Competitive" by J.O. Holt, published in October 1966 issue of the E. I. C. Engineering Journal. The total estimated capital cost of the generating stations is contained in Table H-2. A copy of Mr. Holt's article is appended to this appendix.

6. Operating Cost of Generating Stations

The total unit energy costs, including amortization, fueling costs, and other operating costs per kilowatt hour, was obtained from Figure 12, contained in J.O. Holt's article mentioned above. The total estimated annual energy charge is contained in Table H-3.

APPENDIX H

TABLE H-1

CAPITAL COST OF GENERATING STATIONS

(1) Pumping Station Loads	70,000 cfs	52,500 cfs	35,000 cfs	17,500 cfs
Lake Manitoba-Assiniboine River Pumping Station				
Mile 4.0	184 MW	138 MW	92 MW	46 MW
Mile 11.0	184 MW	138 MW	92 MW	46 MW
Mile 17.0	240 MW	186 MW	124 MW	62 MW
Mile 18	248 MW	186 MW		
Assiniboine River				
Dam #1 FSL 925	--	--	--	--
Dam #2 ESL 950	184 MW	138 MW	--	--
Dam #3 FSL 1050	736 MW	555 MW	458 MW	230 MW
Dam #4 FSL 1150	736 MW	555 MW	--	--
Dam #4 FSL 1100	--	--	183 MW	92 MW
Dam 4A FSL 1150	--	--	183 MW	92 MW
Souris River				
Dam #5 FSL 1200	368 MW	278 MW	183 MW	93 MW
Dam #6 FSL 1300	736 MW	555 MW	366 MW	183 MW
Dam #7 FSL 1400	736 MW	555 MW	366 MW	183 MW
Dam #8 FSL 1410	74 MW	56 MW	37 MW	19 MW
Dam #9 FSL 1440	220 MW	167 MW	110 MW	55 MW
Dam 10 FSL 1450	74 MW	56 MW	37 MW	19 MW
Dam 11 FSL 1500	368 MW	278 MW	183 MW	92 MW
Dam 12 FSL 1550	368 MW	278 MW	183 MW	92 MW
Velva Tunnels	3350 MW	2560 MW	1675 MW	835 MW
Total MW Pumping Capacity:	8814 MW	6679 MW	4396 MW	2200 MW

Table H-1 continued

(2) Estimated Capital Cost of Generating Stations

(a) 70,000 cfs

Generating Capacity Required = 8814 MW x 1.20
= 10,600 MW
say 11,000 MW

Power supplied by 11 - 1000 MW Stations
Capital Cost = 11 stations x 1000 MW /stations x \$155,000 /MW
= \$1,700,000,000

(b) 52,500 cfs

Generating Capacity Required = 6679 MW x 1.20 =
= 8100 MW
= Say 8000 MW

Power supplied by 8 - 1000 MW Stations

Capital Cost = 8 stations x 1000 MW/Station x \$155,000/MW
= \$1,240,000,000

(c) 35,000 cfs

Generating Capacity Required = 4396 MW x 1.20
= 5280 MW
Say 5500 MW

Power Supplied by 5 - 1000 MW Stations plus one 500 MW Station

Table H-1 (continued)

(c) 35,000 cfs

Capital Cost = (5 stations @ 1000 MW/station x $155,000/MW) + (1 station @500 MW/station x $185,000/MW)

= $775,000,000 + 92,500,000

= $867,500,000

(d) 17,500 cfs

Generating Capacity Required = 2200 MW x 1.2

= 2640 MW

Say 2700 MW

Power supplied by 2 - 1000 MW Stations plus 1 - 700 MW Station

Capital Cost =(2 stations @ 1000 MW/Station x $155,000/MW) + (1 station @700 MW/station x $175,000/MW

= $310,000,000 + 122,000,000

= $432,000,000

TABLE H-2

ANNUAL ENERGY CHARGES

(1) 70,000 cfs

Installed Pumping Capacity	=	8814 MW
Megawatt hour demand/year	=	8814 MW x 365 days x 24 hours/day
	=	77,200,000 MW --hr.

Cost/MW hr. using 0.90 capacity factor and 7% interest (See Figure 12, in Table G-1, Appendix G-) for 1000 MW Stations

Annual Energy Charge	=	77,200,000 kw. hr. @ \$2.60 MW/hr.
	=	\$200,000,000

(2) 52,500 cfs

Installed Pumping Capacity	=	6679 MW
Megawatt hour Demand/year	=	6679 MW x 365 days x 24 hours/day
	=	58,500,000 MW/hr.

Cost/MW hr. obtained from Figure 12 in Table G-1 Appendix G using 0.90 Capacity factor and 7% interest for 1000 MW stations.

Annual Energy Charge	=	58,500,000 MW-hrs. @\$2.60 MW-hr.
	=	\$152,000,000

(3) 35,000 cfs

Installed Pumping Capacity	=	4396 MW
Megawatt-hour demand/year	=	4396 MW x 365 days x 24 hours/day
	=	38,500,000 MW

Power supplied by 1000 MW stations $= \frac{5000 \text{ MW}}{5500 \text{ MW}}$ of total power required

$= 0.90$ of total power required

Power supplied by 500 MW station $= \frac{500}{5500}$ of total power required

$= 0.10$ of total power required

Cost/MW hr. obtained from Figure 12 in Table G-1, Appendix G, using 0.90 Capacity Factor and 7% interest for 1000 MW stations and 500 MW stations.

Table H-2 continued

Cost of power supplied by 1000 MW stations = 38,500,000 MW hrs. x 0.90 x $2.60 MW hr.

= 90,000,000

Cost of power supplied by 500 MW Stations = 38,500,000 MW hrs. x 0.10 x $3.00 MW hr.

= $11,500,000

Annual Energy Charge = $90,000,000 + $11,300,000

= $101,300,000

(4) 17,500 cfs

Installed Pumping Capacity = 2200 MW
Megawatt-hour demand/year = 2200 MW x 365 days x 24 hours/day
= 19,300,000 MW hrs.

Power supplied by 1000 MW Stations = $\frac{2000}{2700}$ of total power required

= 0.74 of total power required

Power supplied by 500 MW Stations = $\frac{700}{2700}$ of total power required

= 0.26 of total power required

Cost of power supplied by 1000 MW station = 19,300,000 MW hrs. x 0.74 x $2.60 MW hr.
= $37,200,000

Cost of power supplied by 700 MW station = 19,300,000 MW hrs. x 0.26 x $2.70 MW hr.
= $13,500,000

Annual Energy Charge = $37,200,000 + $13,500,000
= $50,700,000

APPENDIX G

TABLE H-3

CAPITAL COST OF POWER DISTRIBUTION SYSTEM

(1) Statistics

Capital Cost for 250 MW (230,000 volt line) = \$35,000 /mile
Capital cost for 1 - 350 mile line = 350 miles x \$35,000/mile
= \$12,200,000

Assume a power distribution system having a capacity of 40% the generating capacity.

(2) 70,000 cfs Capacity

Generating Capacity =11,000 MW
Line Capacity Required =11,000 MW x 0.40
=4400 MW
Number of lines required =4400 MW/250 MW per line
=18 lines

Capital Cost for 18 lines = \$12,200,000 / line x 18 lines
= \$220,000,000

Table H-3 continued
Capital Cost of Power Distribution System

(3) 52,500 cfs Capacity

Generating Capacity	= 8000 MW
Line Capacity Required	= 8000 MW x 0.40
	= 3200 MW
Number of Lines Required	= 3200 MW/250 MW per line
	= 13 lines
Capital Cost for 13 lines	= $12,200,000/line x 13 lines
	= $160,000,000

(4) 35,000 cfs Capacity

Generating Capacity	= 5500 MW
Line Capacity Required	= 5500 MW x 0.40
	= 2200 MW
Number of Lines Required	= 2200 MW/250 MW per line
	= 9 lines
Capital Cost for 9 lines	= $12,200,000/line x 9 lines
	= $110,000,000

(5) 70,000 cfs Capacity

Generating Capacity	= 2700 MW
Line Capacity Required	= 2700 MW x 0.40
	= 1080 MW
Number of lines required	= 1080 MW /250 MW per line
	= 5 lines
Capital Cost for 5 lines	= $12,200,000/line x 5 lines
	= $61,000,000

Table H-4

Nuclear Power is Competitive

J. O. Holt
Atomic Power Department
Canadian General Electric Company Limited
Peterborough, Ontario

Paper presented to 11th Maritime Professional Engineers' Conference, Digby, N.S., September, 1966.

EIC-66-THERM & NUC 2

The past two years have seen a striking change in the nature of commitments for electrical generating plant throughout the world. The early promise of nuclear power, which seemed for some years so slow in materializing, has now shown the proof of its substance. This period has been marked by a pronounced upsurge in nuclear power plant orders placed by utilities in many countries, and by the large number of bid submissions and tender negotiations under consideration and in progress. All this activity is clear evidence that nuclear power is now firmly established as a major production source to meet the ever growing demand for electrical energy.

This world wide swing to nuclear power is of impressive amplitude. In the first six months of 1966, U.S. utilities placed orders for nearly 9,000 megawatts of nuclear power compared with about 4,800 MW in 1965. Some of the largest orders have been placed by utilities that have access to coal burning plants with fuel costs of less than 21 cents per million BTU's. As of August 1, 1966, over one-third of all large turbine-generator sets ordered this year in the United States were destined for nuclear plants, and this proportion is likely to increase over the balance of the year.

Britain earlier displayed a similar trend. With much of her original program of 5,000 MW in gas-cooled, graphite-moderated, natural uranium-fuelled reactors in service or nearing completion, she has recently initiated an even larger program of construction for advanced gas cooled reactors (AGR) using slightly-enriched uranium as a fuel. As we write this we note that France will all but cease to build coal-fired stations by 1973, and from that date will rely almost exclusively on nuclear power.

Turning now to the Canadian scene, Ontario Hydro has Douglas Point at 200-MWe scheduled for operation later this year but, more significantly, has committed two 500-MWe units at Pickering, near Toronto, with plans for expansion to possibly 6,000 MWe on the same site. Hydro-Quebec, despite a continuing program of large hydro-electric projects, has plans for a 250-MWe prototype station near Trois Rivières, which will undoubtedly be the forerunner of a series of large scale plants for service in the seventies.

Thus, we find that almost every industrialized country in the world, and indeed many developing countries, are now actively planning for nuclear power generation; there is no doubt that all expanding utilities must carefully compare the cost of nuclear power generation with all other available sources before committing new power generation projects. Nevertheless, we in the nuclear industry do not believe that nuclear power will completely displace conventional sources. Applications and economic environment vary so widely that hydro, fossil fuel and nuclear power generation must complement each other for many years to provide reliable and low cost electrical energy over the range from peaking to base load operation.

Development of Competitive Reactor Systems

The sharply competitive position now enjoyed by nuclear base load generation derives from several sources. One, of course, is the technology gained from experience in the pioneer installations such as NPD in Canada, Dresden and Yankee in the United States, various plants in Europe and the long line of MAGNOX plants in Britain. Another is the growth of power systems and the spread of interties to the point where ever larger units can be added; nuclear power plant capital and unit energy costs are particularly sensitive to the economics of increasing sale. Finally, as nuclear plant construction grows to a level comparable with that for conventional plants, the costs of equipment manufacture and fuel processing are reduced because of the benefits of experience and larger volume.

Even though nuclear power may be an obvious choice, utilities in many countries still face the problem of selecting a suitable reactor concept to meet their needs. To reach a decision they must consider such factors as:

(i) Initial investment

Fig. 1.

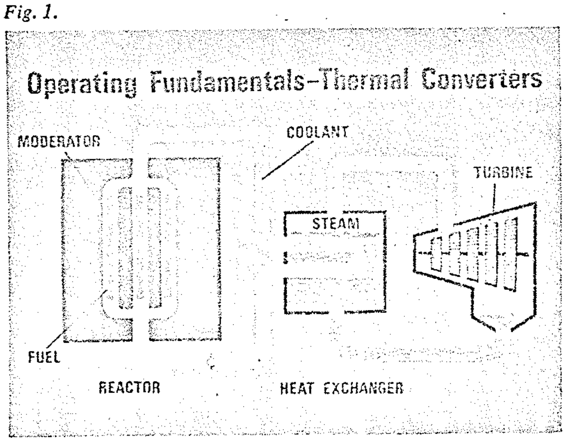


Fig. 2.

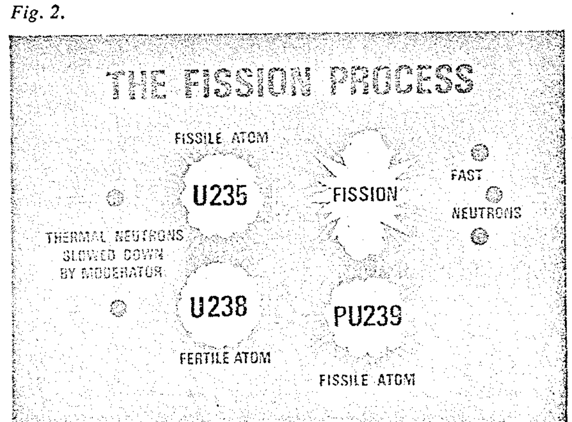


Table H-4 (Continued)

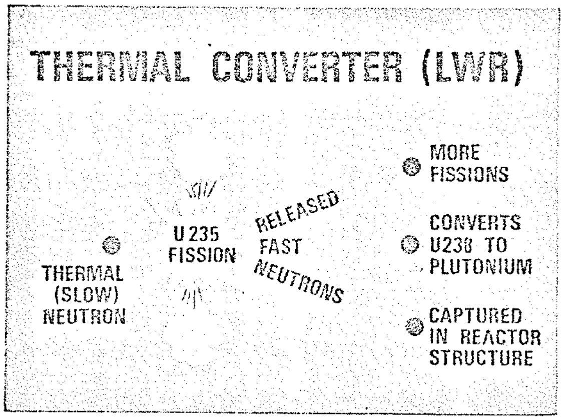


Fig. 3.

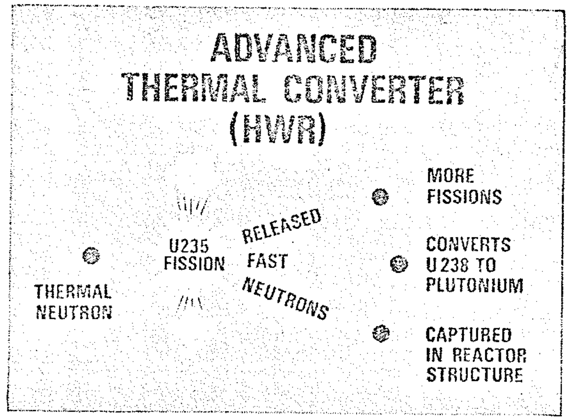


Fig. 4.

(ii) Fuelling cost
(iii) Other operating costs
(iv) Risk of economic obsolescence
(v) Stability of production costs
(vi) Availability of fuel
(vii) Ease of repair
(viii) Load following flexibility
(ix) Simplicity of design features.

Several reactor types are now commercially available on the world market. The immediate choice lies between:

—Graphite moderated, gas-cooled reactors using either natural uranium or slightly enriched uranium fuel (Britain and France).
—Boiling light water reactors using enriched fuel (USA and Germany).
—Pressurized light water reactors using enriched fuel (USA and Germany).
—Heavy water moderated and cooled reactors using natural uranium fuel (Canada).

Although only heavy water or graphite moderated reactors can use natural uranium fuel, all these reactors may be described as thermal converters (Fig. 1). They are called thermal because the nuclear chain reaction is sustained by slowing down the fast or high energy neutrons released by fission to low or "thermal" velocities by means of a moderator such as graphite or water. They are termed converters because, while burning the fissile isotope uranium 235, they generate fissile plutonium through neutron capture in fertile isotope uranium 238 (Fig. 2). Some of the plutonium is burned in turn to produce energy, but the unburned (or unfissioned) portion remaining in the spent fuel may be recovered for other purposes. This process is typical of the light water reactors (Fig. 3).

Heavy water moderated reactors are called "advanced converters" because they "convert" with great efficiency (Fig. 4). They use considerably less natural uranium for a given output of energy than do the other reactors listed, because they produce and burn more plutonium.

The advanced converters use only about one percent of the total potential energy in the fuel if there is no recovery and recycling of the residual plutonium in the spent fuel. With plutonium recycling it is possible to convert up to about three per cent of the potential energy. Low though this utilization may seem, the fuelling cost of the heavy water reactors is only about one mill per kilowatt hour using the "once through" cycle. Higher utilization does not of course necessarily result in lower unit fuelling costs because of the costs associated with reprocessing spent fuel for plutonium separation and recovery.

It is worth noting that it seems possible to use over 50% of the theoretical energy content of natural uranium in "breeder" reactors (Fig. 5). The reactor is designed in such a way that more fissile atoms are produced than are used in the fission process. There are, however, many technical problems to be solved before such reactors can be regarded as commercially feasible. Present estimates suggest that 10 to 15 years of development, prototype construction and experience will be necessary to make such reactors commercially competitive. When breeders are proved and available, they will not, however, make the advanced converter reactors obsolete. The two types will be complementary, for the fissile material required for the initial fuelling of the breeders can be supplied most economically in the form of plutonium generated in advanced converters. A comparison of the three conversions is shown in Table 1, from which

Fig. 5.

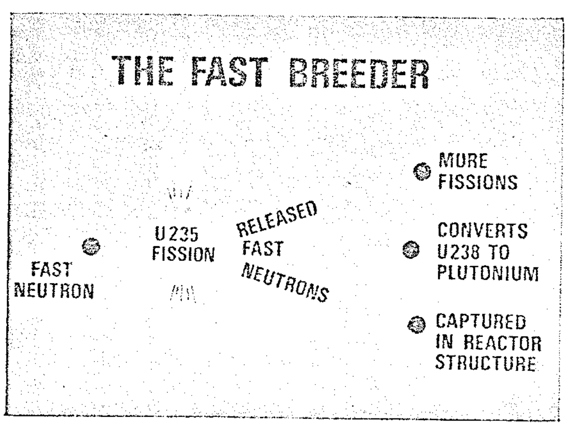


Fig. 6.

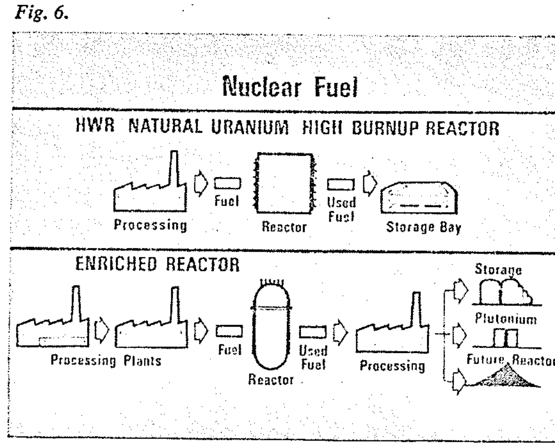


Table H-4 (continued)

Table 1
Conversion Comparisons

Distribution of Released Neutron	LWR	HWR	Breeder
Fission	40%	40%	34%
Conversion to Plutonium	26%	32%	39%
Conversion Rate	0.65	0.80	1.16

more fissile material than it consumes. it is seen that the breeder produces

The Canadian Program

Canada has many sound and excellent reasons for concentrating on the development of heavy water moderated reactors capable of burning natural uranium fuel effectively and efficiently. Because of the low investment in natural uranium and the unique properties of the heavy water moderator, the fuelling cost is less than one mill/kWh — by far the lowest fuelling cost of any commercial reactor. This fuelling cost is all inclusive and can be accurately predicted now — the costs of the once through system are not dependent on the variability of reprocessing costs or long term estimates of the value of recovered plutonium. (Fig. 6).

Canadian reactors now being designed are the world's most efficient converters. For a given energy output they use about 25% less uranium feed than do the light water enriched reactors, and about 45% less than do the graphite moderated reactors. Even greater reductions in feed are possible with fuel recycling. Because of their high conversion rate and low natural uranium feed requirements, the fuelling cost of heavy water reactors is less sensitive to possible increases in the price of natural uranium than are the fuelling costs of other reactors, so that production costs will be much more stable over the life of the HWR station.

The "once through" system does not, however, preclude the posibility of plutonium recovery and fuel recycling, for the plutonium content in the discharged fuel averages about 3 gm/kgU or 1 gm/MWD. Normally fuel consumption averages about 100 kgU/MWe/year, but economic plutonium recovery costs are dependent on a volume equivalent to an installed capacity of not less than 2,000 MWe or 200,000 kgU/year. At the current price of $8-$9/gm, it is obvious that this plutonium has a large potential value; some years hence, when a stable market is established, operators of heavy water systems may be able either to obtain revenue from their spent fuel, or, by recycling plutonium, reduce their uranium requirements by about 50%. Another possibility for these neutron economical reactors is their promise as "near breeders" using the thorium-uranium 233 cycle. Thorium is a fertile material which, as in the generation of plutonium from uranium 238, can be transformed by neutron capture into the fissile isotope uranium 233.

The inherent low fuelling cost of the heavy water power reactor has a significant effect on long term station economics; in any system, those stations having the lowest operating costs will always be loaded in preference to others. The spectre of economic obsolescence is largely banished if future technological improvements can bring only marginal reductions in operating costs. The full benefits of low fuelling cost can come of course only if the station offers high availability. Canadian HWR stations have on-power refuelling; off-power refuelling, common to light water reactors, can result in the loss of at least 19½ days a year according to British studies. This loss of availability must probably be made good from other less efficient stations held in reserve.

With all these advantages, Canada has committed herself confidently to the continuing development of heavy water moderated power reactors using natural uranium fuel. This confidence has been underlined by the decisions of the Federal Government to underwrite the construction in the Maritimes of two heavy water production plants, by contracting for the purchase of at least 700 tons of heavy water per year over a ten-year period. This production corresponds with a station construction rate approaching 1,000 MWe per year.

Nevertheless, the designers of heavy power reactors must seek continuously to reduce the cost of construction by improved engineering and general simplification of design. Many advantages have been made as the result of experience with NDP and Douglas Point. For example, in June 1966, Canadian General Electric announced a simplified version of the Canadian heavy water moderated and cooled, natural uranium fuelled reactor, which has a vertical rather than a horizontal configuration (Fig. 7).

All the advantages of the earlier horizontal design are retained and many new features are added. A lower capital investment results from shorter construction times, simplified nuclear components including a single-ended on-power fuelling system, fewer but larger steam generator units, a smaller reactor building of prestressed concrete construction, and a reduction in the initial inventories of heavy water and uranium fuel.

Capital Investment in Nuclear Generating Stations

There is a widespread but mistaken belief that the capital investment in heavy water power reactor systems is higher than that of other systems. While this may have been true in the case of earlier stations, this is no longer true of stations being designed for installation in the early seventies. In making comparisons one must remember that one has the choice in reactor design of using natural uranium fuel with heavy water moderation ("enrichment" of water), or of using enriched uranium fuel with a less efficient and less costly moderator (Fig. 8). In the consideration of capital investment it can be shown that the total cost of the first charge of natural uranium fuel and heavy water moderator is about the same or possibly a little less than the cost of the first charge of enriched uranium fuel for a power reactor system using a less efficient but lower cost moderator.

Fig. 7.

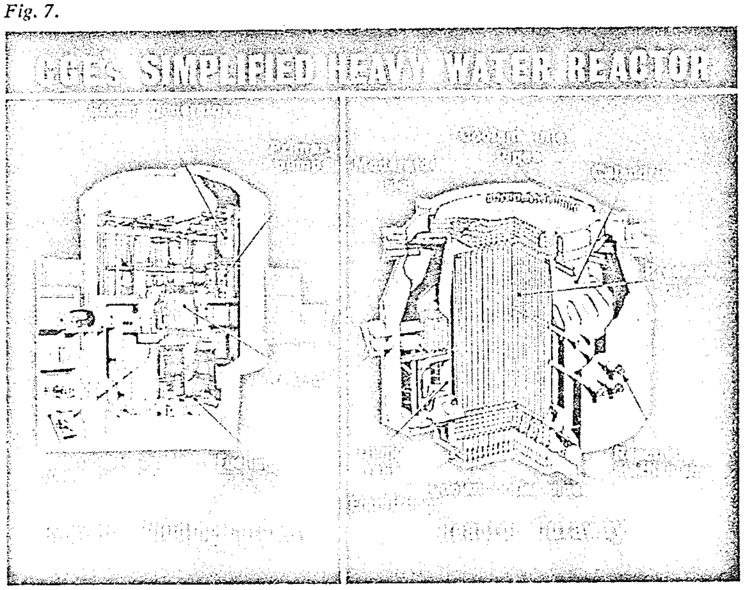


Table H-4 (continued)

If one now examines the balance of the physical plant, one finds only nominal differences which in nearly every case are handsomely offset by the lower fuelling cost of the heavy water reactor.

Contract Prices for Physical Plant

In comparing the relative costs of generating stations, one must clearly understand what is, or is not, included in construction cost. Here construction cost is defined as the total cost of building a station: it consists of physical plant costs and indirect costs. The indirect costs include interest during construction, commissioning, training, and consultants' fees; many of these costs are associated with the economic environment and requirement of a particular utility, and may vary widely. For this reason we will restrict our discussion to the physical plant and consider estimated contract prices covering the main structures, power generation equipment, and basic site improvements within the immediate station area.

Estimated contract prices for physical plant, fuel and heavy water are presented in Tables 2 and 3, and Fig. 9. Estimates are based on current (1966) Canadian dollars for stations coming into operation in the early seventies, but they do not include taxes, duties or escalation, and apply to average Canadian supply and construction conditions.

Trends in Heavy Water Prices

In the ninteeen-fifties the price of heavy water from US production plants was \$30.25/lb. (US \$28.00) but by 1962 the price had fallen to \$26.50 (US \$24.50). Within the past two years, Canadian heavy water production projects have been committed which will make heavy water available at \$20.50/lb. in 1967 with further reductions in later years to \$16/lb. (Fig. 10).

Table 2

Physical Plant—Estimated Contract Prices—\$/kW

Unit Size (MWe)	100	150	200	250	300	400	500	600	800	1000
Single Units	267.0	232.0	207.5	193.0	181.9	164.0	152.0	142.0	133.7	128.1
Two Units	242.7	210.9	188.6	175.4	165.4	149.1	138.2	129.1	121.5	116.4

Table 3

Heavy Water and First Fuel Charge—\$/kW

Unit Size (MWe)	100	150	200	250	300	400	500	600	800	1000
Heavy Water @ \$20.50/lb	35.0	33.4	32.1	30.6	30.1	29.2	28.5	27.9	26.7	25.8
Fuel @ \$62.50/kgU	10.9	10.7	10.6	10.5	10.3	10.2	10.1	10.0	9.9	9.8

This history of the Canadian projects began in 1963 when Atomic Energy of Canada Limited invited Canadian industry to submit proposals on the understanding that AECL would purchase not less than 200 tons/year over a five-year period. The winning bid came from Deuterium of Canada with an offer of \$20.50/lb. from a plant now under construction at Glace Bay, N.S.

In 1964 AECL issued a second invitation to industry; an offer made by Canadian General Electric was accepted in March 1966 for the supply of 5,000 tons at up to 500 tons/year over a maximum period of 12½ years at a starting price of \$20.50/lb. and a sliding scale to \$16/lb. at the end of the period. This second plant will be located at Port Hawkesbury, N.S.

Fuelling Costs

For any given HWR station operating on a "once through" fuel cycle, the equilibrium refuelling cost is proportional to the delivered price of the fuel (including all uranium and fabrication costs). The forecast trend in natural uranium fuel prices is shown in Fig. 11. The curve begins at \$74/kg of contained uranium in 1964 (the price of the first fuel charge for Douglas Point) and falls to a level of \$45/kgU or less towards the end of the seventies. This reduction in price is based on an increase in production volume, and the availability of U_3O_8 feed at less than \$11/kg.

In recent years there has been a growing trend in the utility industry to base economic assessments on the "present-worth" technique which translates all future economic commitments to their "present-worth". The results permit a direct comparison between schemes which show a marked difference in variation of their economic commitments with time. There are large variations in such commitments between nuclear and conventional plants, and indeed between various designs of nuclear plants, so that there is a strong case for the application of present worth techniques in making economic comparisons. The area of greatest interest is, of course, that of fuelling cost, since variations in both price of fuel and station output may be expected over the life of the station.

Typical fuelling cost estimates calculated by this method for a 20 year life at 7½% simple interest and an average capacity factor of 0.75 are presented in Table 4.

Operating and Maintenance Costs

Operating and maintenance costs include all salaries and wages for operating and maintenance personnel, an appropriate

Fig. 8.

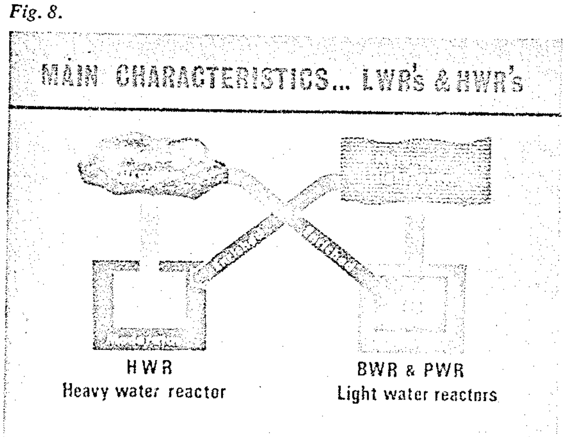
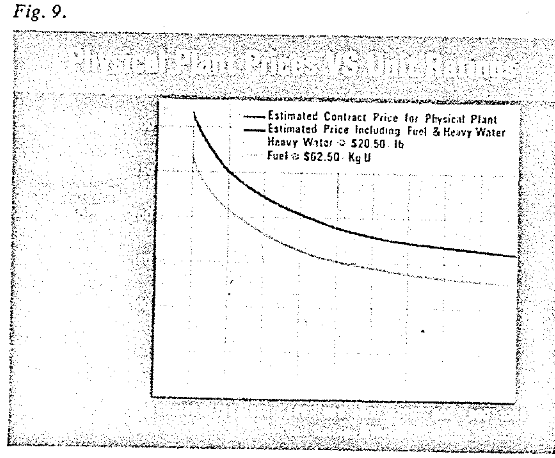


Fig. 9.



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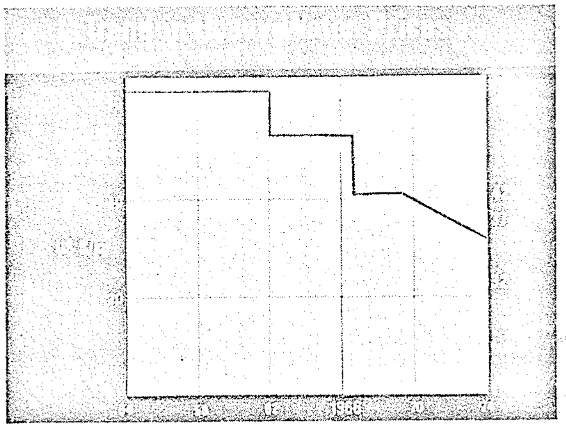

Fig. 10.

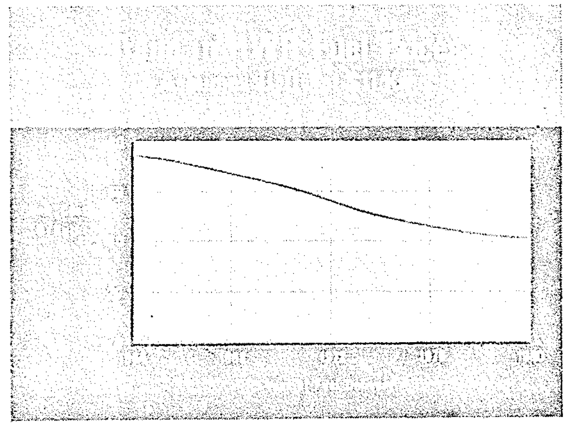

Fig. 11.

overhead or burden charge, supplies, purchased services, replacement materials, heavy water makeup and upgrading, and insurance.

In comparison with other nuclear generating stations, the question of heavy water makeup and upgrading must be examined. Adequate control of heavy water losses and downgrading is inherent in the design of HWR stations, and systems have been developed to the point where the added cost of operation is estimated not to exceed 0.03 to 0.1 mill/kWh depending on the unit size, the cost increasing as the size decreases.

Unit Energy Costs

Many factors influence total unit energy cost, and a detailed study is required to establish costs appropriate to any given physical and economic environment. However, we have calculated the total unit energy costs for a range of HWR station ratings and capital charge rates using reasonable figures for the customer costs associated with a nuclear project in Canada. We believe the resulting costs are typical of stations constructed on Canadian sites with adequate fresh-water cooling supplies, and committed for services in the early seventies.

The ground rules for these calculations are as follows:

1. Unit energy cost at generator bus;
2. 48-month construction;
3. Straight line interest during construction;
4. Customer costs \$10/kW;
5. No escalation;
6. 8% allowance on physical plant for purchase and sales tax, etc.:
7. Nominal expenditures for training and commissioning;
8. O & M include D_2O makeup and upgrading, and nuclear insurance at \$1/kW;
9. Fuelling costs on a Present Worth — 20 year basis.

The unit energy costs thus calculated are shown in Fig. 12.

Comparison of Power Generation Systems

The title of our paper "Nuclear Power Is Competitive" really needs qualification, for there is no one system of power generation that is competitive under all conditions and circumstances; again we would emphasize that we in the nuclear industry believe that hydro, fossil fuel and nuclear power generation must complement each other for many years to provide minimum cost electrical energy over the operating range from peaking to base load. Nevertheless, nuclear power generation is now competitive for base load operation in many locations and will become so in many more locations

Table 4

Fuelling Costs — Present Worth Method

(Using Fuel Price Trends from Figure 11)
0.75 Capacity Factor — 20 year life — 7½% int.

Unit Size (MWe)	100	150	200	250	300	400	500	600	800	1000
First Charge $/kW	10.9	10.7	10.6	10.5	10.3	10.2	10.1	10.0	9.9	9.8
20 Year Replacement Fuel $/kW	59.4	54.7	52.6	50.5	49.5	46.8	45.6	45.0	44.1	43.3
20 Year Total Fuelling Cost $/kW*	70.3	65.4	63.2	61.0	59.8	57.0	55.7	55.0	54.0	53.1
Unit Fuelling Cost Mills/kWh	1.05	0.97	0.94	0.91	0.89	0.85	0.83	0.82	0.80	0.79

* *These figures represen the capital required, at startup, to finance the fuelling of the station over 20 years at 0.75 capacity factor operation.*

Fig. 12.

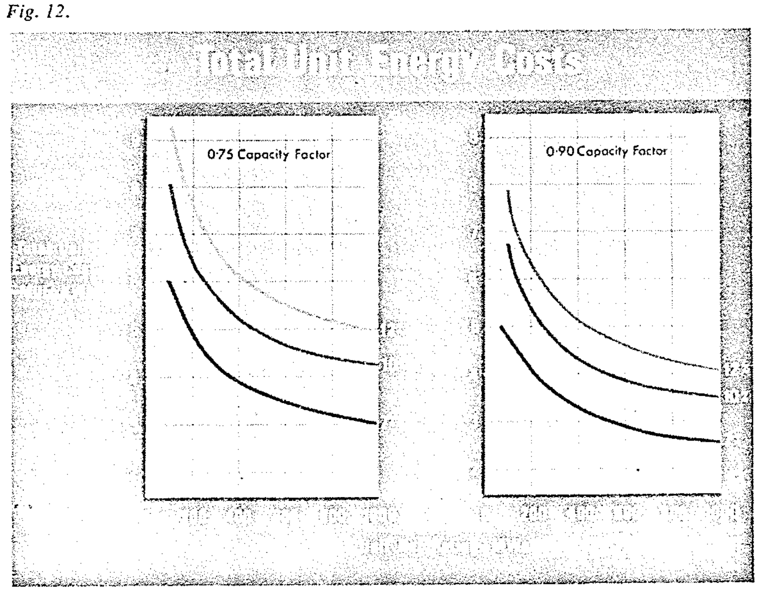

Table H-4 (continued)

Table 5

Energy Cost Comparison of Coal Fired and Nuclear Plants Initial 12 Year Period

	US Mills/kWh			
	BWR	*PWR*	*Coal*	*HWR*
	Published by TVA			*Estimate*
Interest and Depreciation on Plant Investment	0.89	0.93	0.90	1.01
Interest and Depreciation on Heavy Water	—	—	—	0.19
Average Fuel Cost	1.25(1)	1.39(1)	1.69	0.69(1)
Operations and Maintenance	0.19	0.18	0.24	0.21
Nuclear Insurance	0.04	0.04	—	0.04
Total Bus Bar Cost	2.37	2.54	2.83	2.14

Note: (1) Includes interest and depreciation on first fuel charge.

with the passage of time. To present comparative figures one must consider a specific set of conditons which are applicable to all sources of generation considered.

By their commitment of 1,000 MWe at Pickering, Ontario Hydro are obviously satisfied that nuclear power is competitive with fossil fuels in Southern Ontario; commitments by other utilities are also supported by detailed and exhaustive studies.

One of the most detailed economic comparisons yet published is that by the Tennessee Valley Authority which compares power generation by BWR (boiling water reactor), PWR (pressurized water reactor) and a coal fired plant. In each case the station consisted of two 1,000 MWe units. The TVA operation is characterized by rather low capital charge rates (4½% and 35 year lifetime) and the availability of coal at U.S. ¢ 18.9 per million BTU's.

Table 5 shows the published TVA estimates for the BWR, PWR and coal fired plants, and our estimate for the equivalent HWR station. First, to quote TVA: "It is evident from the results of the evaluation that the nuclear alternatives have a decided advantage over the coal fired plant, and that either a BWR or PWR would be a decided economic choice over a coal fired plant." While we do not have access to all the data and ground rules of the TVA study, and therefore cannot claim complete accuracy for our estimates, we believe that these figures show that the Canadian heavy water power reactor can offer real competition for any other power reactor system and for fossil-fuelled plant.

Conclusions

Nuclear power is now competitive with other energy sources in many locations, and current Canadian designs are priced competitively with other reactor types, assuming that comparisons are made on the basis of total initial investment, including physical plant, first fuel charge and heavy water.

Heavy water power reactors promise low, stable production costs over their lifetime through the simplicity and efficiency of the natural uranium fuel cycle. No other commercial reactor design can approach the low operating cost of the heavy water power reactor or offer the flexibility of its fuel cycle.

LAKE MANITOBA - GARRISON RESERVOIR

DIVERSION

A P P E N D I X   I

UNIT COSTS

APPENDIX I

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APPENDIX I

UNIT COSTS

1. Introduction

Although it is anticipated that costs will vary from area to area along the diversion depending upon terrain, working conditions and availability of materials, it was assumed that the following unit prices would be applicable to the entire project. All costs are in Canadian dollars.

2. Common Excavation

Common excavation and overhaul costs were obtained from Portage Diversion Contractsand similar large earth excavation projects undertaken recently in the Province of Manitoba by the Water Control and Conservation Branch. Common excavation costs used in this study were as follows:

Common Excavation	- Good Working Conditions	- $0.35 /cu. yd.
Common Excavation	- Poor Working Conditions	- $0.60 /cu. yd.
Overhaul	-	- $0.02 /sta. yd.

3. Bridges

Railroad bridge costs were obtained from the Portage Diversion, highway bridge costs from the Highways Branch, Department of Transport, Province of Manitoba. Provincial Road and municipal bridge costs were obtained from the Water Control and Conservation Branch, Province of Manitoba.

Railroad Bridges - 2 track	\$1800 per lineal foot
Railroad Bridge - 1 track	\$ 900 per lineal foot
Provincial Highway Bridge - 40 feet wide	\$1000 per lineal foot
Provincial Road Bridge - 32 feet wide	\$800-\$1000 per lineal foot
Municipal Road - 24 feet wide	\$600-\$1000 per lineal foot

4. <u>Highways</u>

Highway construction costs were obtained from the Highways Branch, Department of Transport, Province of Manitoba.

Concrete Surfaced - 2 lanes	\$125,000 per mile
Asphalt Surfaced - 2 lanes	\$ 70,000 per mile

5. <u>Railroads</u>

Railroad construction costs were obtained from the Canadian National Railways.

Single Track	\$150,000 per mile
Double Track	\$225,000 per mile

6. <u>Municipal Services</u>

Municipal services were estimated on the following basis:

Water Distribution System	\$ 7.00 per lineal foot
Sewage Collection System	\$ 5.00 per lineal foot
Water Treatment Plant	\$200.00 per Capita
Waste Treatment	\$ 60.00 per Capita
Street (Grading and 6" Pavement) - 24 feet wide	\$ 30.00 per lineal foot

The above costs were obtained from the Manitoba Water Supply Board and the City of Winnipeg.

7. <u>Canal Lining</u>

Canal Lining (6" thick concrete)	\$ 3.00 per square yard

8. <u>Concrete</u>

Formed One Face	\$30.00 per cubic yard
Formed Two Faces	\$35.00 per cubic yard

9. <u>Steel</u>

Reinforcing Steel	\$ 0.15 per pound
Structural Steel	\$ 0.25 per pound