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Optimal Operation of a Flood Control System

by

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Monique

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1.0

INTRODUCTION

OPTIMAL OPERATION OF A FLOOD CONTROL SYSTEM

1.0 INTRODUCTION

1.1 A Flood Control System

Two kinds of flood control works may be actively operated in order to alleviate flood damage, reservoirs and diversions. Reservoirs reduce flood damage by storing flood waters and releasing them at a later date so as to reduce the peak of the flood wave and lengthen its duration. Diversions simply divert flood waters away to an area less prone to flood damage. An operable flood control system as discussed in this thesis is composed of reservoirs and diversions in addition to passive flood control works such as dykes.

The object of operation of any flood control system is to minimize flood damage. This requirement defines the optimal operating schedule for each of the system components. The degree of complexity of the optimal operation of a flood control system is determined by the number of flood control reservoirs and/or diversions which comprise the system for each flood control component requires its own operating schedule. Since the operating schedules of the components of the system may be highly inter-related it may be appreciated that the difficulty in arriving at optimal operating schedules increases very rapidly as the number of components of the flood control system increases.

The optimal operating procedure is based on anticipated flows. The uncertainty in forecasting flows therefore adds a degree of uncertainty to the optimal operating procedure. It need not add to the complexity of the analysis if the uncertainty itself is not a factor in the objective of the system operation.

In this thesis all flow values have been treated as being deterministic and no allowance for stochastic variation has been included. Stochastic variation of flow values could be addressed by means of new estimates of flow values which would then be subject to another analysis. In an operational flood control context this might take the form of a high, best and low estimate of system in flows with each estimate requiring a separate analysis. In this manner any stochastic variation in flow estimates can be partially addressed within the deterministic framework of the model constructed in a manner acceptable for operational flood control purposes.

1.2 Simulation Analysis

Simulation analysis is a commonly accepted method of arriving at an operating schedule for a flood control system. In a simulation analysis, the river system is modelled so that movement in time and space of river flows throughout the river basin may be simulated. This is generally done by mathematical models of the river basin rather than by analog models and is carried out on an electronic computer.

Forecast inflows to the river basin are input to the simulation model of the system and an operating schedule is postulated for each system component. The output from the simulation model consists of discharges and water levels at various locations of interest in the river basin. Each run results in a calculated value of flood damage. Operating schedules for each system component are changed between runs so as to improve the performance and the simulation analysis is repeated. The results of individual simulation runs are compared and revised operating schedules are postulated until a best operating schedule for the system components is arrived at. No systematic search for optimal operating schedules of system components is necessarily implied in a simulation analysis although it can be incorporated therein.

The main difficulty with this technique lies in the revision of the operating schedules for individual system components so as to improve the performance. If the variables are changed one by one by small amounts, the amount of work required to achieve the optimum becomes prohibitive. If larger steps are taken or several variables changed at once, the analysis may well miss the optimum altogether. Therefore, simulation analysis works well to refine initial postulates of system component operating schedules. If the initial operation postulates are far from optimal simulation may give problems.

When the flood control system is not overly complex the limitations of simulation analysis are not severe. However, as the complexity of the system increases it may prove very difficult, if not impossible, to find the optimal operating schedule through simulation analysis.

1.3 Optimization Analysis

Optimization techniques differ from simulation in that a systematic search for the optimum operating schedule is incorporated in the technique. Theoretically, this would solve the problem.

However, in practice it is often found that the large number of variables involved makes an optimization technique much too laborious even with the aid of large electronic computers. It is possible in many cases to set the target in optimization somewhat lower and to aim for a solution that is not too far away from the optimum. The so called fine tuning can then be accomplished by means of simulation analysis.

In optimization, all the components of the flood control system must be analyzed simultaneously over their entire range of possible operating schedules. In addition, the technique must realistically reflect any operating schedule inter-relationships between individual system components. The time interval, however, can be increased substantially to reduce the number of variables.

An optimization technique known as linear programming was employed in this thesis to provide initial operating schedule postulates. It was decided to use a time interval of seven days in the optimization technique rather than the daily time interval generally used in flood control simulation analysis. This is acceptable when one keeps in mind that the primary function of the optimization technique is to provide initial system component operating schedule postulates, that are near optimal, for input to a simulation analysis which will then fine tune these postulates. The use of the seven day time period greatly reduces the computational burden of the optimization process.

1.4 Optimization-Simulation Comparison

A comparison of the optimization and simulation processes is in order. Optimization tends to look at the overall picture with respect to operating schedules of individual flood control system components. In an optimization analysis the entire physically feasible range of operating schedules for operating system components is analyzed. Generally, the flood control system is not modelled in great detail with respect to either the time step employed in the analysis or the degree of exact modelling of the system under consideration.

Simulation analysis, on the other hand, tends to look at a very limited picture with respect to operating schedules of the individual flood control system components. In simulation analysis a narrow range of operating schedules for individual system components is analysed. Generally, the system is modelled in considerable detail with respect to the time step employed and the degree of exact modelling of the system.

It may be appreciated that a trade off in terms of computational burden and exactness of results is involved in simulation and optimization analysis.

A point may be made that the optimization and simulation analysis processes are always carried out together in the determining of optimal operating schedule for flood control components. For the case of less complex flood control systems the optimization analysis takes the form of intuitive reasoning by the person responsible for the analysis. For more complex flood control systems, a more formal optimization process, together with the all important intuitive reasoning of the person responsible for the analysis, is felt to be more appropriate.

1.5 The Optimization Model Selected in this Thesis

A linear programming technique was selected as the optimization model in this thesis. It is intended to optimize operation of flood control works so as to minimize damage caused by flooding. Flood damage is represented by flooded area in this context. Implicit in this statement is the assumption that all flooded areas in the model have the same dollar value per acre with regard to flood damage for a given time of year. This assumption may be relaxed quite easily should a particular river system require different dollar per acre values of flood damage. The linear programming model constructed herein produces optimal mean seven day operating schedules for each of a flood control system's control works on the basis of minimizing total flooded area as a function of peak mean seven day discharges at selected damage centres throughout the flood control system. Peak mean seven day discharges at each damage centre in the analysis, together with their corresponding damage coefficients, form the objective function in the analysis. The total value of this objective function is to be minimized.

No limitation as to the number of flood control reservoirs or diversions in the flood control system is implied by the model although in reality the computational capacity of the electronic computer employed in the analysis or the cost factor of the analysis itself would be the limiting factor as to the size of the system which could be optimized and/or the detail to which the system could be modelled in the optimization.

The optimization model is formulated to address river basins in which the predominant damages due to flooding are agricultural in nature. In this respect the phenomenon that agricultural flood damages are time dependent is addressed in the model. This feature is an extension rather than a restriction to the use of the model as non-agricultural damages, such as flooding of buildings or loss of bridges are non time dependent and may be addressed directly by the model constructed.

The general optimization model constructed in this thesis was applied to the Assiniboine River in Manitoba to assess its applicability. It should be noted that the flood control system in existence on the Assiniboine River system may be treated as one in which acceptable postulates for a simulation analysis may be obtained by intuitive reasoning rather than requiring the use of an optimization model. However, it should also be noted that it is this very non-complexity of the flood control system in terms of the number of operable system components that allows a reasonable check of the applicability of the optimization model as compared to intuitive reasoning.

The linear programming optimization model constructed in this thesis effectively reflects the inter-relationships of the flood control system on the Assiniboine River in Manitoba and produces acceptable starting postulates for a simulation analysis.

2.0

THE ASSINIBOINE RIVER SYSTEM

2.0 THE ASSINIBOINE RIVER SYSTEM

2.1 History

Since the beginning of the settlement of the west the Assiniboine River has had a record of destructive floods. On several occasions during the 1800's floods did occur but much of this information is very sketchy. Detailed records have been kept since 1913. In the latter period there were seventeen years in which major flooding occurred.

The Assiniboine River flows in a valley from Kamsack to Portage la Prairie. Flooding in this reach would generally affect the river valley bottem land only. Downstream of Portage la Prairie the Assiniboine enters the flat prairie which once comprised the bottem of Lake Agassis. In this reach the adjacent land falls away from the river banks which have been raised by silt deposits. Once the banks are overtopped the water cannot return to the river channel when the flood peak has passed. The flood waters eventually drain via old creeks and channels to Lake Manitoba to the north and into the La Salle River to the south. However, drainage is generally poor and flood waters may remain on the land for several weeks.

2.2 Flood Control Investigations

Following the 1950 flood, measures were studied for both the Assiniboine River and the Red River. In 1958 the Royal Commission on Flood Cost Benefit recommended specific flood control works.

With respect to the Assiniboine River, the Royal Commission investigated storage as well as diversion proposals. For every principal tributary investigations were conducted to assess the feasibility of flood control storage; each analysis, however, showed that tributary contribution was insufficient to warrant the construction of a major flood control dam.

It was finally decided that a substantial storage reservoir on the main stem of the Assiniboine was required in order to achieve the desired level of flood control. Three sites for a major dam were thoroughly investigated; the first at St. Lazare, the second west of Russell and the third below the confluence of the Shell and Assiniboine Rivers. All three sites were found to be economically feasible. The Shellmouth site was finally chosen because of more satisfactory foundation conditions, a smaller acreage of agricultural land in the reservoir area and a better source of construction materials.

Extensive investigations to divert flood waters into Lake Manitoba were conducted. Several different locations and diversion capacities were examined. Several alternative diversion routes were found which is not surprising since areal photographs clearly show that the Assiniboine at one time flowed north to Lake Manitoba. It followed several different routes to the lake before it broke through to its present course eastward to the Red River.

The diversion route finally selected has its beginning two miles west of Portage la Prairie. From there the channel runs almost due north to Lake Manitoba.

The length of river between Portage la Prairie and Winnipeg has been dyked.

The drainage basin of the Assiniboine River in Manitoba together with the location of the above noted flood control works are shown on Figure II-1. Both the Shellmouth Reservoir and the Portage Diversion will be discussed in more detail below.

2.3 Shellmouth Reservoir

The Shellmouth Reservoir, on the Assiniboine River, is located approximately two miles north and two miles east of the Village of Shellmouth in an area where the Assiniboine River Valley is wide, with high banks.

The earth dam is 75 feet high and 4000 feet long. It is equipped with a concrete conduit to control releases from the reservoir. An uncontrolled concrete spillway passes flows in excess of the conduit capacity. The storage capacity is used for water conservation as well as flood control. The conservation pool is up to an elevation of 1391.0, representing 165,000 acre-feet of storage, while combined conservation and flood control capacity is between elevations 1391.0 and 1402.5 resulting in a storage of 136,000 acre-feet. A further 87,000 acre-feet of flood storage capacity is available between elevation 1402.5 and 1408.5, the elevation of the uncontrolled spillway.

The location of the dam is shown on Figure II-2.

The prime purpose of Shellmouth Reservoir is to reduce the flood damage along the Assiniboine River and in Winnipeg by storing the majority of the flood runoff that originates upstream from the Shellmouth Reservoir in the Assiniboine River Basin. A secondary benefit that can be achieved by operation of the reservoir is that of augmenting low flows on the Assiniboine River during dry periods.

The Water Resources Division of the Department of Mines, Resources and Environmental Management of the Government of Manitoba has determined the following principles of operation.

In order that the full capacity of the reservoir for flood control purposes be available in the spring the reservoir is lowered from a summer level of 1402.5, to 1391.0 over the period November 1 to March 31.

The lowering is carried out at as uniform rate of release as is possible based on an early winter forecast of the inflow to the reservoir during the winter period and recognizing the amount of water in storage that must be released. In years with evidence of a high spring runoff the reservoir may be drawn down below 1391.0 by March 31.

In order that storage spece be available in the reservoir subsequent to the spring runoff to reduce flood damage from summer floods on the Assiniboine River, the water level in the reservoir is lowered to 1402.50 immediately after the spring runoff at a rate which does not cause downstream flooding. The reservoir is then maintained at 1402.50 throughout the summer and early fall until November 1 when releases begin to lower the reservoir for spring flood control as noted earlier. If drought conditions plus high water supply demands prevail, these elevations may be impossible to obtain.

This system of allocating the available storage to the various purposes makes it possible to provide sufficient storage to reduce peak flows along the Assiniboine River downstream of the Shellmouth Reservoir and at the same time make it possible to maintain a flow of 250 c.f.s. in the Assiniboine River at Brandon compared to the recorded minimum of 7 c.f.s.

2.4 Assiniboine River Diversion

The Assiniboine River Diversion channel begins two miles west of Portage la Prairie and runs almost due north to Lake Manitoba. It is 18 miles long and is designed to carry up to 25,000 c.f.s. away from the Assiniboine River. The removal of water through the Diversion gives flood protection to the cities of Portage la Prairie and Winnipeg and the areas between them.

An earthfill dam across the Assiniboine River with a concrete spillway control structure creates a small reservoir with a storage capacity of 14,600 acre-feet. North and west of the dam at the upper end of the diversion channel an inlet control structure regulates flow to Lake Manitoba. The diversion channel has three drop structure along its route so as to keep water velocities below those which would cause erosion.

For economic reasons approximately the last 3 miles of the diversion, which are located in the Delta Marsh, have been designed to carry only 15,000 c.f.s. The excess flow, which at full design discharge could be up to 10,000 c.f.s. is spilled over into the west Delta Marsh. A section of the west dyke of the diversion channel in the vicinity of Cram Creek was designed and constructed at a lower elevation than the remaining portion of the dykes through the marsh. This particular reach of lower designed dyking concentrates the overflow and reduces the probability of an extended failure along the dyke.

The location of the diversion and details of its layout are shown on Figure II-3 and Figure II-4.

The purpose of the Assiniboine River Diversion is to provide flood protection to Winnipeg and the area from Portage la Prairie to Winnipeg. The diversion will accommodate and regulate the Assiniboine River flow up to a maximum of 45,000 c.f.s. At this design flood flow, 25,000 c.f.s. is diverted into Lake Manitoba, while the remaining 20,000 c.f.s. passes downstream into the Assiniboine River. At Assiniboine River flows of greater than 45,000 c.f.s. flood damage will occur either along the Diversion or the Assiniboine River depending on whether the flow is diverted or allowed to flow down the Assiniboine. The following points illustrate the procedures now being followed by the Water Resources Division in the operation of the Diversion.

1) While there is ice on the Assiniboine River downstream of the Portage Diversion it is desirable to maintain flows less than 5,000 c.f.s. in the river because of the possibility of ice jams.

2) After the ice has gone from the Assiniboine River downstream of the Portage Diversion it is desirable to maintain flows less than 10,000 c.f.s. in the river. Flows greater than 10,000 c.f.s. are above the natural bank stage of the river and backup of local streams which outlet into the Assiniboine may occur at this level. There also may be seepage problems through dykes, leakage through gated through-dyke culverts and flooding of cultivated land between dykes.

3) The bankfull capacity of the Assiniboine River downstream of the Assiniboine River Diversion is 20,000 c.f.s.

4) The overflow section of the west dyke of the Portage Diversion which allows flows in excess of 15,000 c.f.s. to spill out into the west marsh of Delta Marsh should only be overtopped when dictated by an extreme condition on the main stem of the Assiniboine.

5) The design capacity of the Portage Diversion is 25,000 c.f.s.

6) If possible flows on the Assiniboine River downstream of the Diversion while ice is still present should only exceed 5,000 c.f.s. if the Winnipeg James Avenue stage is below 745.57. The level of Lake Manitoba should not be taken into account while there is ice on the Assiniboine River, as the period during which there is ice on the river during the sprin runoff is only a few days, and diverted flows for this short period of time would have a negligible effect on the level of Lake Manitoba.

7) For Assiniboine River inflows to the Portage Reservoir in the 25,000 to 35,000 c.f.s. range, the diverted flow may in some instances be limited to 15,000 c.f.s. to prevent overtopping of the west dyke overflow section. Thus flows in the 10,000 to 20,000 c.f.s. range would occur on the river. In this instance the James Avenue stage would be the deciding factor as to how much water should be sent down the river and how much diverted. Flows in excess of 10,000 c.f.s. in the river should only be permitted if Lake Manitoba is high and the James Avenue level is low. If both the lake and the James Avenue levels are high, presumably flows would be diverted to the lake rather than down the river.

8) The 20,000 c.f.s. limit to flows down the Assiniboine River should only be exceeded in the event of inflows greater than 45,000 c.f.s.

9) The 15,000 c.f.s. limit to flows down the Diversion should only be exceeded when,

   a) there is the possibility of exceeding a flow of 20,000 c.f.s. in an ice-free Assiniboine River.

   b) there is the possibility of exceeding a flow of 5,000 c.f.s. in an ice-bound Assiniboine River.

   c) the stage of James Avenue is at such a level that flows down the Assiniboine River must be reduced. This condition may be reached at all inflows as conditions at James Avenue may require that the entire inflow or a very large portion of it be diverted.

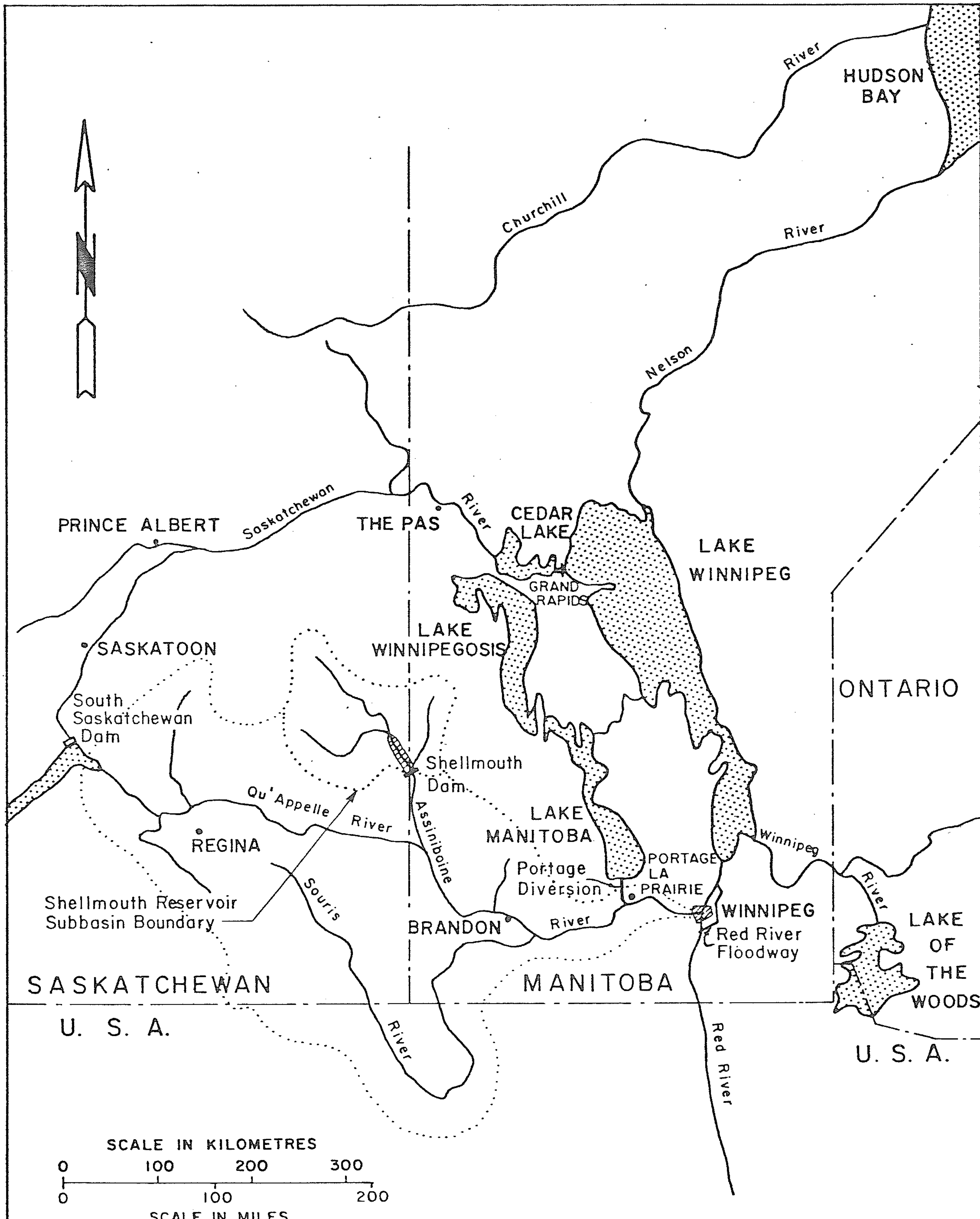


Figure II-1

ASSINIBOINE RIVER DRAINAGE BASIN

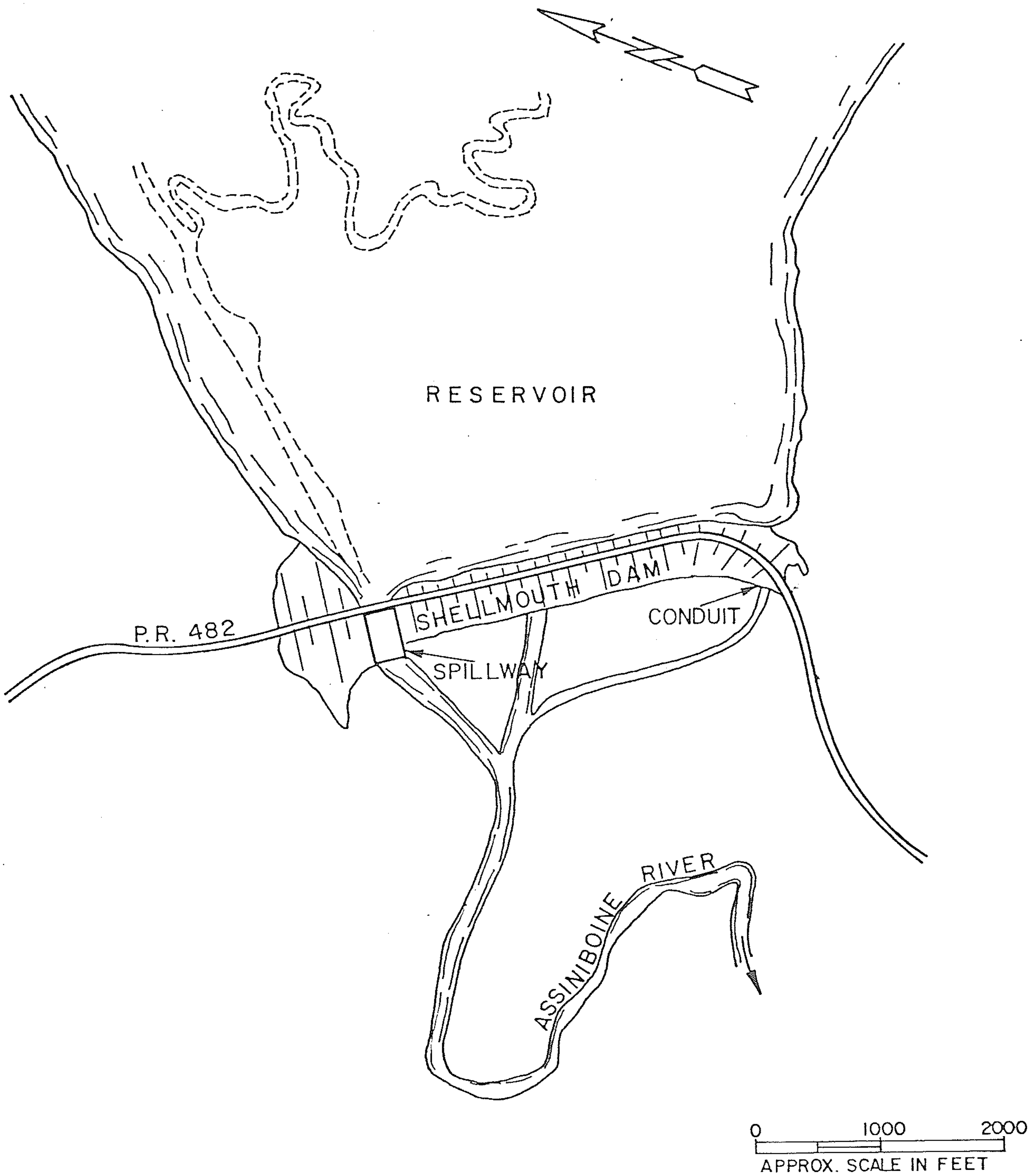


Figure II-2

SHELLMOUTH DAM LOCATION

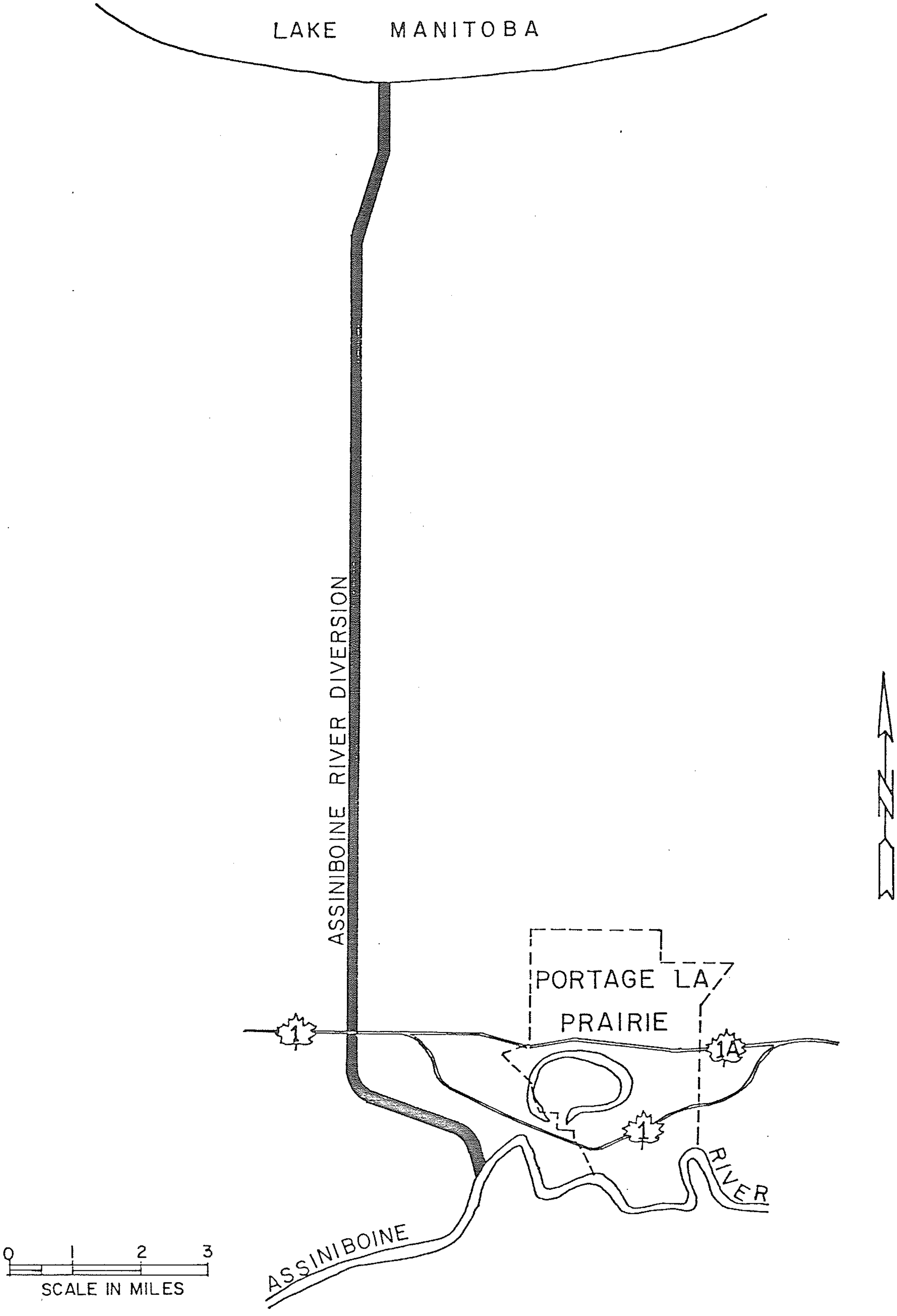


Figure II-3

ASSINIBOINE RIVER DIVERSION LOCATION

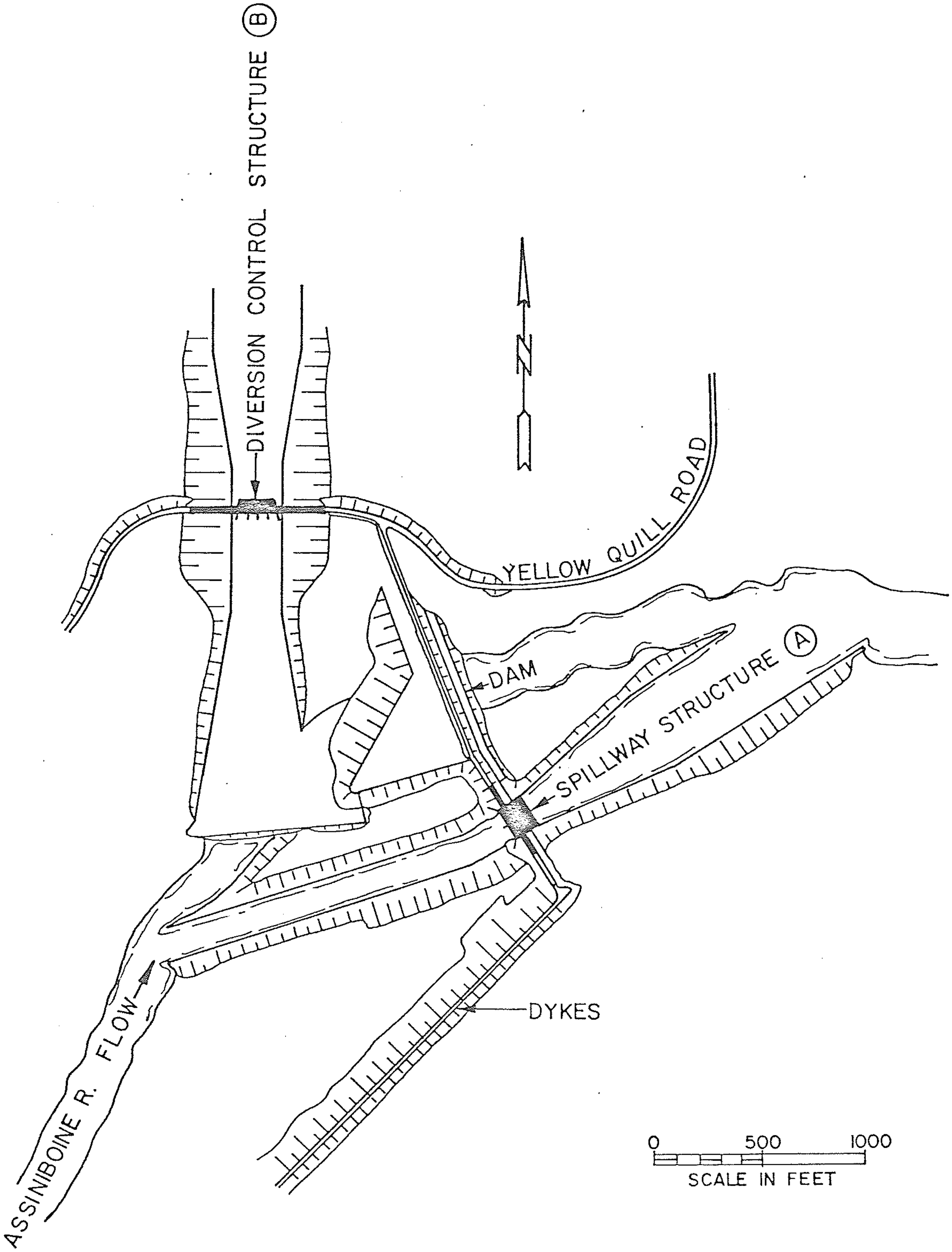


Figure II-4
ASSINIBOINE RIVER DIVERSION
INLET CONTROL STRUCTURE

3.0

THE GENERAL LINEAR PROGRAMMING MODEL FOR A FLOOD CONTROL SYSTEM

3.0 THE GENERAL LINEAR PROGRAMMING MODEL FOR A FLOOD CONTROL SYSTEM

3.1 The Linear Programming Technique

In the development of an optimization model to determine optimal operating schedules for flood control system components it was decided in this thesis to employ a linear programming analysis. Linear programming has decided advantages in that if the problem at hand can be adapted to the linear programming technique an optimal solution can be obtained very quickly at a reasonable cost. Most non-linear optimization techniques on the other hand, such as a pattern or gradient search may arrive at a local optimum solution which could be quite different from the true global or overall optimal solution to the problem at hand. Many times the cost of the non-linear technique may be prohibitive. This problem does not exist with the linear programming technique.

Linear programming is a numerical technique that generates a solution to the optimization problem at hand by means of a iterative procedure. The linear programming technique involved in optimization manipulates all the variables in the analysis simultaneously on each iteration subject to the constraints of the problem in the quest for an optimum solution.

A linear programming problem is one in which a linear function is the criterion to be minimized or maximized. This linear criterion to be minimized or maximized is subject to constraints that are also linear functions. A combination of variables denoted in general by X is said to be linear if the variables can be assembled in the form:

$$C_1 X_1 + C_2 X_2 + \ldots C_n X_n$$

where the C's are constants. For example the function:

$$4X_1 + 3X_2 + 5X_3 + 2$$

is linear in the variable X_1 , X_2 , X_3 , whereas the function:

$$2(X_1) + X_1X_2 + 3\ \exp(X_3)$$

is non-linear in the same variables. The linear programming technique solves equations of the following form:

$$U = C_1X_1 + C_2X_2 + \ldots. + C_nX_n = \text{minimum (or maximum)}$$

Subject to:

$$A_{11}X_1 + A_{12}X_2 + \ldots + A_{1n}X_n \gtreqless b_1$$

$$A_{21}X_1 + A_{22}X_2 + \ldots + A_{2n}X_n \gtreqless b_2$$

$$\vdots$$

$$A_{m1}X_1 + A_{m2}X_2 + \ldots + A_{mn}X_n \gtreqless b_m$$

The above equations may be written in a much more concise mathematical form.

Minimize (or Maximize) $\quad U = \sum_{j=1}^{n} C_jX_j$

Subject to:

$$\sum_{j=1}^{n} A_{ij}X_j \gtreqless b_i \quad ; \text{ for } i = 1, m$$

$$X_j \geq 0 \qquad ; \text{ for } j=1, n$$

The a's, b's and c's in the above equations are constants and the x's are variables whose values are sought. A simple linear programming problem will serve to illustrate the technique.

Let us consider a graphical solution of a simple linear programming problem. The problem may be formulated as follows:

Objective Function: $U = 4X_1 + X_2$

Subject to: $2X_1 + X_2 \geq 2$

$4X_1 - 3X_2 \geq -3$

$2X_1 + 3X_2 \leq 21$

$4X_1 - X_2 \leq 16$

$X_1 \geq 0$

$X_2 \geq 0$

It is desired to maximize the objective function in this problem. This problem is shown graphically on Figure III-1.

It is to be noted that all lines on Figure III-1 are straight and the optimization surface is a plane. It may readily be deduced that the limit equations are satisfied by any solution inside the shaded area. If it proves difficult to determine the direction of feasibility graphically for a limit equation this may be determined quickly by taking any point, usually the origin, and evaluating the function at hand. This immediately tells where the origin is on the feasible or infeasible side of the line.

Let us rewrite the objective function U in the form:

$$X_2 = U - 4X_1$$

The dashed lines on Figure III-1 represent this equation for various values of the objective function U. It is apparent that point D is the optimum solution with objective function U having a value of

3.43. Variable X_1 having the value 4.93 and variable X_2 having the value of 3.71.

Essentially the procedure in linear programming is to start in any one corner of the shaded polygon shown and jump to an adjacent corner having a higher value of the objective function U. This is continued until there is no adjacent corner having a higher value. The general problem has more than two variables and cannot be thought of in geometrical terms. However, the mathematical method is essentially similar. Various computational algorithms have been developed to solve the linear programming problem.

The linear programming solution algorithm employed in this thesis is based upon the mutual primal dual simplex method of Michael L. Polinsky and Ralph E. Gomery. The algorithm in question was supplied through the courtesy of Charles Howard and Associates, Professional Engineers, Winnipeg, Manitoba. It is recognized that different algorithms are available for the solutions of linear programming problems. However, the algorithm used in this thesis proved extremely efficient. Moreso, valuable assistance was available from Charles Howard and Associates regarding the use of the algorithm in particular and the linear programming technique in general.

3.2 The Model Description

The linear programming model is comprised of two components. The first of these is a linear objective function and the second is a linear system of constraints. These two components are as described in the preceding section.

Some general comments regarding the linear programming model developed in this thesis are in order. It is assumed in the formulation of the model that all reservoirs and/or diversions have gated or controllable outflows and that decisions regarding the size and location of individual flood control system components have already been made. It is not intended, in its present form, to size reservoirs and/or diversions in a planning study. In other words, the linear programming model constructed herein is an operative model rather than a planning model. The optimal operating schedules for a flood control system proposed in this thesis are based upon the object of minimizing the total flooded area, with respect to the system as a whole, based on the peak mean seven day discharges at selected damage centres within the system. The use of a seven day time period in the formulation of the model allows adequate starting postulates for a simulation analysis and reduces the computational burden of the linear programming solution.

For the purpose of illustrating the linear programming model developed in this thesis a hypothetical river system is shown on Figure III-2. While this system, in general, is much simpler than an actual flood control system, it serves to illustrate the linear programming model for the optimal operation of a flood control system as developed in this thesis.

3.3 Linear Programming Model Constraints

The constraints, which together with the objective function comprise the linear programming model, may be classified in two types. These are physical constraints and computational constraints. Physical constraints force the linear programming model to follow the physical realities of the flood control system being modelled. These would include upper storage limits for reservoirs in the flood control system, diversion capacity of diversions within the flood control system, and minimum flow requirements within the system. Computational constraints adapt the mathematical linear programming technique to the determining of optimal operating schedules for individual components of the flood control system. An example of this type of constraint is that which is required to determine peak discharges at individual damage centers in a form suitable for the linear programming technique.

3.3.1 Physical Constraints

3.3.1.1 Storage Constraints

Each reservoir in the flood control system is limited to its maximum storage capacity. That is, at the start of any time period in the analysis the quantity of water stored in a given reservoir must be equal to or less than the maximum available flood storage volume of that reservoir. This may be represented mathematically as

$$S_i^t \leq V_i \qquad \text{III-1}$$

where S_i is the volume of water stored in reservoir i at the start of a given time period t, and V is the maximum available flood storage volume at the reservoir in question. It should be noted that the maximum available storage for a given reservoir may be set in the model at any preselected magnitude less than or equal to the absolute physical reservoir capacity in order to address, for example, recreation use constraints on the reservoir in question.

3.3.1.2 Reservoir Mass Balance Constraint

This constraint is based on the principle of continuity and states that during any time period the inflow volume minus the outflow volume for a given reservoir must equal the change in reservoir storage. Evaporation and seepage losses from reservoirs during flood periods are generally an insignificant portion of the total flow and are therefore not included in this model. Because of the seven day time period used in this study all storage terms are in units of c.f.s.-weeks. This constraint may be represented mathematically as

$$S_i^t = S_i^{t-1} + I_i^{t-1} - O_i^{t-1} \qquad \text{III-2}$$

where I_i^{t-1} is the inflow to a given reservoir over a given time period t-1; O_i^{t-1} is the corresponding outflow from the reservoir in question over the same time period and S^t and S^{t-1} are storage volumes for a given reservoir at the beginning of the time period in question and the beginning of the preceding time period. All terms in this constraint are expressed in a consistent set of units, in this case c.f.s.-weeks. Figure III-3 shows the definition of time periods.

3.3.1.3 Reservoir Release Constraint

Reservoir releases are limited by the conduit discharge capacity which is a function of the reservoir storage volume. In general this is a non-linear function. The reservoir release constraint may be expressed mathematically by the equation

$$O_i \leq f(S_i) \qquad \text{III-3}$$

where i denotes Reservoir i and t denotes time period t. $f(S_i)$ is the outflow limiting function for reservoir i.

3.3.1.4 Channel Continuity of Storage Constraint

Inflow must equal outflow for any river channel reach over each week in the model as changes in channel storage are neglected. Channel inflows are comprised of the outflow from the immediately upstream channel or reservoir, local inflow to the reach, expressed as end of reach inflow, and as a negative term, any flow lost from the reach by diversion in the reach in question. This may be expressed mathematically as follows:

$$Q_i^t = I_i^t + LOC_i^t - DIVR_i^t \qquad \text{III-4}$$

With reference to Figure III-2 this would be expressed as

$$Q_i^t = O_i^t + LOC_i^t - DIVR_i^t \qquad \text{III-5}$$

where Q_i^t is the mean seven day discharge at the end of reach i over time period t; O_i^t is the mean seven day outflow from reservoir i over time period t, that is, the mean seven day inflow to reach i over time period t; LOC_i^t is the mean seven day local inflow to reach i over time period t; $DIVR_i^t$ is the mean seven day diversion flow diverted from reach i over time period t.

3.3.1.5 Riparian Constraint

Minimum releases are usually specified for any reservoir in order to meet downstream riparian rights. This may be expressed mathematically as follows:

$$O_i^t \geq C_i \qquad \text{III-6}$$

where O_i^t is the mean seven day outflow from reservoir i over time period t; and C is the minimum mean seven day release allowed for reservoir i.

3.3.1.6 Diversion Capacity Constraint

Any diversion in the flood control system will have an upper limit conceptionally similar to that specified for reservoir storage. In the case of a diversion it is the diversion capacity. This may be expressed mathematically as follows:

$$Divr_i^t \leq D_i \qquad \text{III-7}$$

where $Divr_i^t$ is the mean seven day diversion flow diverted from channel reach i over time period t; D_i is the absolute diversion capacity for the diversion in channel reach i.

3.3.1.7 Upper Limit on Diversion Flow Values

As well as the physical diversion capacity described in the preceding section, any diversion within the flood control system must be constrained so that its flow is less than or equal to the inflow above it in the river system. That is, it is impossible for a diversion to divert more flow away from a damage centre than is available to the diversion. With reference to Figure III-2 this may be expressed mathematically as

$$Divr_i^t \leq O_i^t + LOC_i^t \qquad \text{III-8}$$

or in general

$$Divr_i^t \leq I_i^t + LOC_i^t \qquad \text{III-9}$$

where $Divr_i^t$ is the mean seven day diversion flow diverted from reach i over time period t; I_i^t is the mean seven day inflow to reach i over time period t; LOC_i^t is the mean seven day local inflow to reach i, expressed as end of reach inflow over time period t. All terms are in units of mean seven day c.f.s.

3.3.2 Computational Constraints

3.3.2.1 Peak Discharge Constraint

This constraint is a computational constraint used simply to identify the peak mean seven day discharge as the largest of all mean seven day discharges during the time periods in the analysis at each damage centre. It may be represented mathematically as

$$QP_i \geq Q_i^t \qquad \text{III-10}$$

where Q_i^t is the mean seven day discharge at the end of channel reach i, that is, at damage centre i over the time interval t; QP_i is the peak mean seven day discharge at damage centre i. It should be noted that damage centres are assumed to be located at the end of a given reach.

The peak mean seven day discharge at the respective damage centres are used in the objective function.

3.3.2.2 Non-negativity Constraint

This constraint is fundamental to the linear programming technique and states that all variables in the linear programming analysis must be greater than or equal to zero. No variables may take on negative values.

3.4 Objective Function

The linear programming technique requires a linear relationship of the variables involved in the analysis to be minimized. This relationship is known as the objective function. In this thesis the objective function is the damage cost of flooding at selected damage centres expressed in arbitrary damage units. For simplicity these damage units are taken as weighted magnitudes of flooded areas. For the purposes of this thesis, that is the obtaining of preliminary optimal operating schedules for the flood control system components it is not necessary to express the damage in dollars. The weighted magnitudes of the flooded areas serve equally well provided the weights make the dollar values and the areas roughly proportional.

Thus the objective of the linear programming model constructed in this thesis is to obtain optimal operating schedules for the flood control system components so as to minimize the total flooded area, considering all locations being protected, given the run-off hydrographs at all significant points in the system. The flood damage to be minimized, or objective function, is assumed to be some function of only peak mean weekly discharge. The problem therefore requires finding the minimum of a non-linear objective function subject to a large number of linear and/or non-linear constraints.

3.5 Time Dependency Of Objective Function at Damage Centres

In the application of the linear programming technique to the determination of optimal operating schedules for the components of the Assiniboine River flood control system it must be recognized that a major portion of the flood prone area in the Assiniboine River Basin is agricultural in nature. Agricultural flood damages are decidedly time dependent in that flooding early in a crop year, before the crop is planted, may cause little or no reduction to the crop yield that year and therefore little or no damage. However, flooding later during the year will cause steadily increasing damage as the crop yield is reduced due to a shortened growing season until, at some point, it is too late to plant a crop at all during the year in question and harvest the crop during the same year. At this point the entire value of the crop in question is lost.

It is necessary that this time dependency of agricultural flood damages be adequately reflected in the linear programming model. It has been noted earlier that the basis of optimization in this thesis is to minimize flooded area within the river basin. By this technique all flooded area would be assumed to have the same value regardless of the time of flooding. What is required to reflect the time variability of agricultural damage is that flooded areas in the river basin may take on different values of flood damage, dependent on the time of flooding.

This may be accomplished by including in the objective function several flood peak values for each damage centre each for a different time period.

By means of introducing this family of time dependent peak mean seven day dishcarges denoted as QP_{Li} where i is the damage centre in question with each QP_{Li} defined for a different time dependent family component 1 over a different time period t, $t=t_1$, t_2, it is possible to model the phenomenon that agricultural flood damages are time dependent. Each QP_{Li} will be the peak discharge at damage centre i for the time dependent family component 1 over time period t_1 to t_2.

Each variable QP_{Li} has a different coefficient in the objective function reflecting the relative time variability of agricultural damages. All individual time periods t must be included once in the analysis and in only one time dependent family component.

This concept may be illustrated as follows with reference to equation III-10.

$$QP_i \geq Q_i^t \qquad \text{III-10}$$

For the purpose of this discussion let us assume ten time periods. Therefore t varies from one to ten. Also let us assume that the damage relationship for time periods one to ten is as follows:

Time Period	Damage Relationship
One to three	Damage = 0.25 QP_{1i}
Four to Six	Damage = 0.50 QP_{2i}
Seven to ten	Damage = 0.90 QP_{3i}

There are three time dependent family components in this example. Equation III-10 may be modified to represent this situation as follows:

$$QP_{1i} \geq Q_i^t \quad \text{for} \quad t=1,3 \qquad \text{III-10a}$$

$$QP_{2i} \geq Q_i^t \quad \text{for} \quad t=4,6 \qquad \text{III-10b}$$

$$QP_{3i} \geq Q_i^t \quad \text{for} \quad t=7,10 \qquad \text{III-10c}$$

Each variable QP_{Li}, $L=1,3$ is given a different value in the objective function as follows:

$0.25\ QP_{1i}$

$0.50\ QP_{2i}$

$0.90\ QP_{3i}$

As shown, equation III-10 has been replaced with three separate equations, each modelling one segment of a time dependent family relationship for flood damage.

3.6 Nonlinearity

In the application of the linear programming algorithm to the flood control problem in this study non-linear relations occur in the objective function. These nonlinear relations must be replaced by piecewise linear approximations so that the problem may be solved by a standard linear programming solution procedure employing a separable programming analysis.

The application of the separable programming technique will be illustrated in the case of the damage curves for the damage centers in the model. These non-linear damage curves provide the information needed to derive the optimal release schedules for the system. The form of these functions is important since the total damage is to be minimized in the optimal solution. If the curves are convex in shape, the problem may be solved in a straightforward manner. Concave curves or a combination of concave and convex curves, on the other hand, tend to create difficulties as a linear programming technique may, in this case, arrive at a local optimum rather than a global optimum for the solution. Concave curves must either be approximated in a convex manner, or if this involves an unacceptable loss of accuracy in the analysis, dealt with through another form of optimization rather than linear programming. This thesis deals only with convex functions.

The method of solution, used in this study, involving a modification of linear programming known as separable programming will be illustrated with reference to Figure III-4, which is assumed to represent the peak mean seven day discharge-damage function for a given damage centre.

A convex cost curve for the damage centre is first approximated by piecewise linear approximation, as shown in Figure III-4. This is accomplished by selecting a number of breakpoints, or points at which the slope of the piecewise linear function changes. Let us define M as the number of segments in the piecewise linear function approximating $U_j(Q_j)$ and let

$$U_{1j}, U_{2j}, \ldots, U_{mj}$$

be the ascending values of Q at which the slopes of the piecewise linear segments change value. Next let us subdivide the peak discharge at the damage centre Q, into a set of auxiliary variable such that

$$Q_j = \sum_{m=1}^{M} Q_{mj} \qquad \text{III-11}$$

where M = 1,2, ... M and each Q_{mj} is bounded as follows:

$$Q_{mj} \leq U_{mj} - U_{m-1j} \qquad \text{III-12}$$

The nonlinear cost function $U_j(Q_j)$ can now be defined in terms of its piecewise linear approximations:

$$U_j(Q_j) = \sum_{m=1}^{M} K_{mj} Q_{mj} \qquad \text{III-13}$$

where K_{mj} is the partial difference of the objective function with respect to Q_{mj} and is defined as:

$$K_{mj} = \Delta C / \Delta Q_{mj} \qquad \text{III-14}$$

When the nonlinear terms are replaced by the piecewise linear terms, the objective function becomes:

$$\text{Min}\left(\sum_{j=1}^{N} \sum_{m=1}^{M} K_{mj} Q_{mj}\right) \qquad \text{III-15}$$

where M is the number of components for a given cost function approximation and N is the number of damage centres in the analysis.

The problem has now been transformed into an ordinary linear programming problem. Since the variables K_{mj} are increasing in character, in a cost minimization problem the linear programming algorithm will select the cost variables in their correct sequential order, and no additional constraints are required. That is, the linear programming algorithm will naturally exhaust the lower valued K_{mj} variables first, which is computationally correct.

3.7 Size of the Linear Programming Problem

The computational burden of solving a linear programming application is directly reflected in the cost of doing so on an electronic computer. In order for any model constructed to be operationally applicable it is extremely important that this computational cost be minimized. It should be noted that computational costs involved in the solution of linear programming applications rise as a positively increasing exponential function of the number of variables in the analysis. It may be readily appreciated that is is imperative to minimize the number of variables in the analysis while at the same time constructing an adequate model of the flood control system under analysis. Two techniques were applied in this thesis to minimize the number of variables in the analysis.

3.7.1 Elimination of Variable Q_i^t

The variable Q_i^t has been defined previously in this thesis as the mean seven day flow at damage centre i over time period t. The variables Q_i^t do not appear directly in the linear programming model formulated in this thesis. Rather, they are calculated as the summation of all system inflows, positive and negative, at the damage centre in question. Equations III-4 and III-10 are repeated at this point for reference.

$$Q_i^t = I_i^t + LOC_i^t - Divr_i^t \qquad \text{III-4}$$

$$QP_i \geq Q_i^t \qquad \text{III-10}$$

With reference to equation III-5 and III-10 the following equation can be arrived

$$QP_i \geq I_i^t + LOC_i^t - Divr_i^t \qquad \text{III-16}$$

Variable QP_i is the peak mean seven day discharge at damage centre i, which is located at the end of channel reach i, over time period t. This variable is as defined earlier in this thesis. I_i^t is the mean seven day inflow to channel reach i over time period t. LOC_i^t is the mean seven day local inflow to channel reach i over time period t, and $Divr_i^t$ is the mean seven day diversion flow diverted from channel reach i over time period t.

It is to be noted that no new variables have been introduced in the formulation of III-16, rather the variable Q_i^t has been eliminated. With reference to equation III-16 it may be seen that the peak mean seven day discharge at any damage centre in question, which is noted as QP_i is defined as being greater than or equal to the sum of all inflow arriving at a damage centre in question for a given time period. The given time period varies over the entire range of time periods analysed in the model. It must be noted that both positive and negative flows to the damage centre in question are considered in the formulation of equation III-16.

3.7.2 Elimination of Fixed Valued Variables

Certain variables in the analysis are fixed in value by their very nature and thus cannot be allowed to assume different values at the optimal solution. Examples of variables of this type are system inflows or initial reservoir storage levels. In the interest of computational efficiency a transformation is carried out with respect to these noted fixed valued variables. For any constraints containing fixed valued variables the variables in question are first multiplied by their corresponding coefficient in the constraint equation and then subtracted from the right hand side of the constraint in question. In this manner the number of variables that the linear programming algorithm must address is significantly reduced.

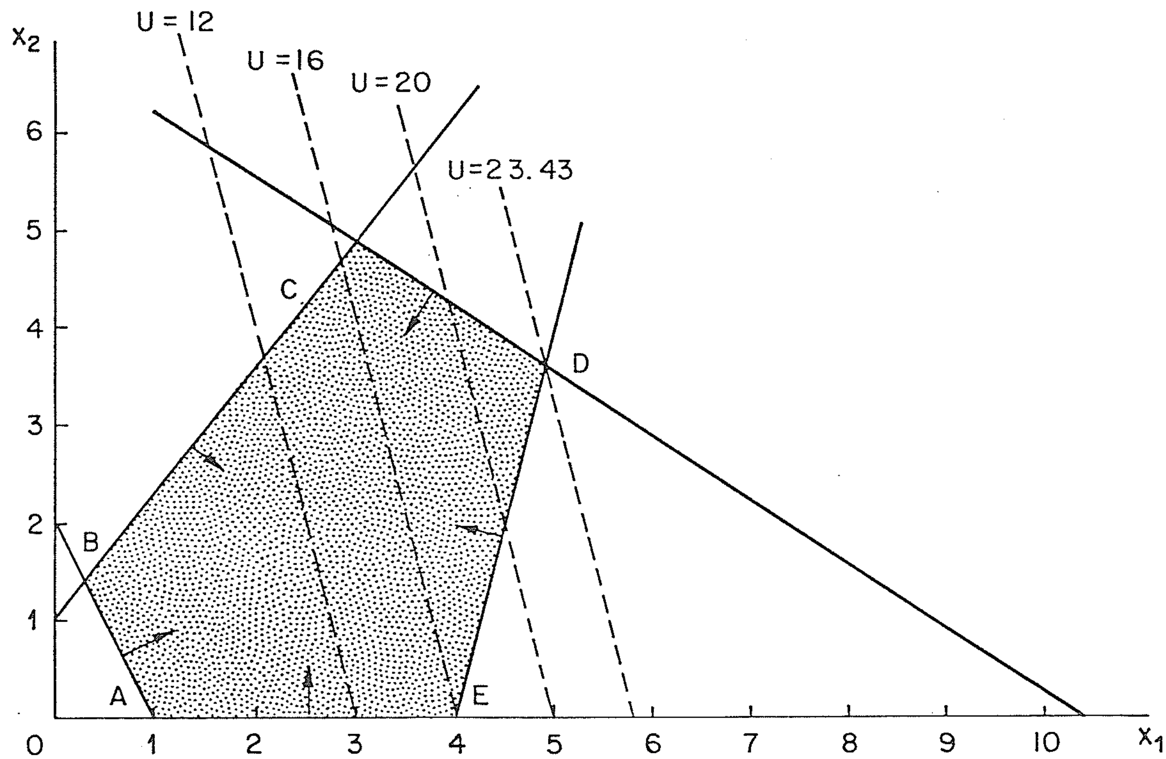


Figure III-1

SAMPLE LINEAR PROGRAMMING PROBLEM

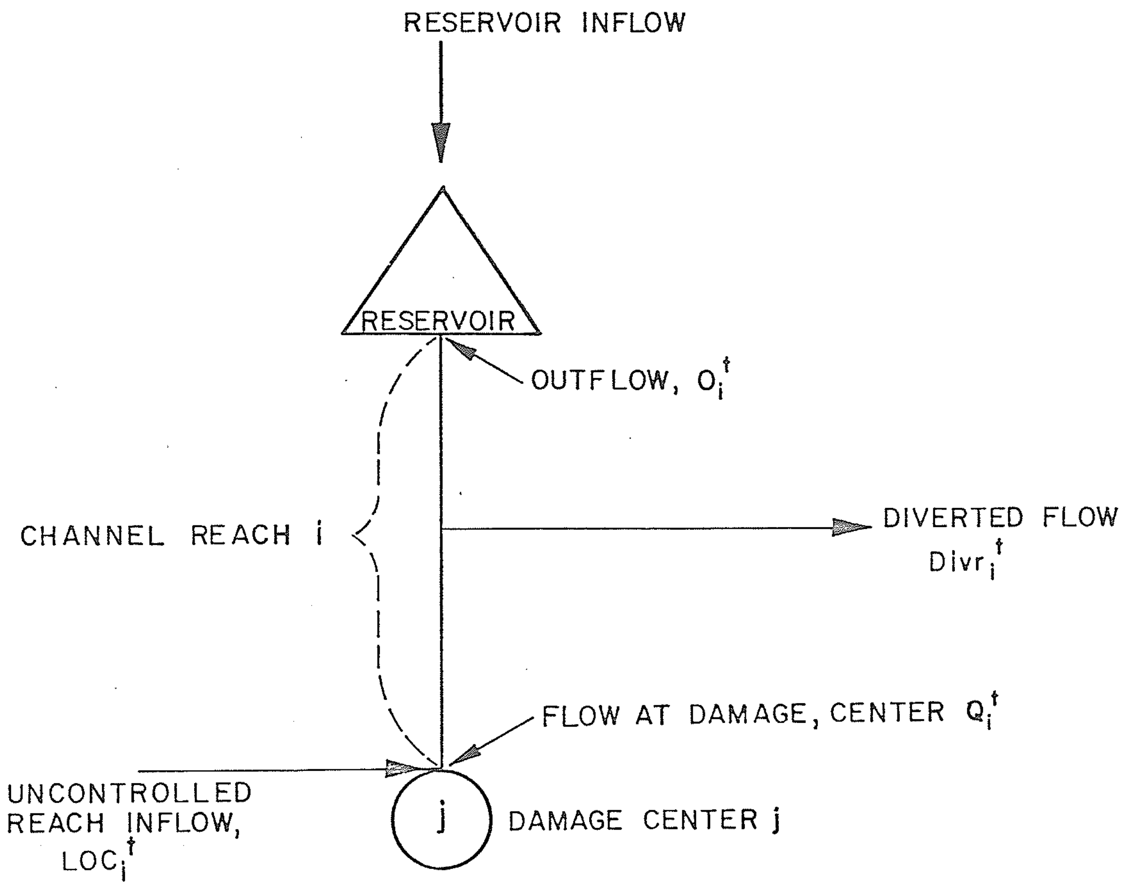
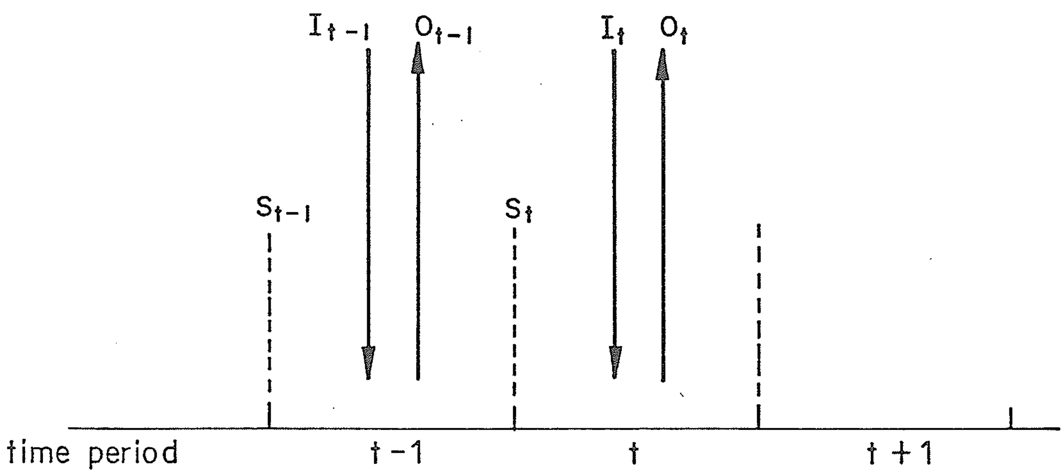


Figure III – 2

HYPOTHETICAL RIVER SYSTEM



$$S_t = S_{t-1} + I_{t-1} - O_{t-1}$$

Figure III - 3

DEFINITION OF TIME PERIODS USED IN ANALYSIS

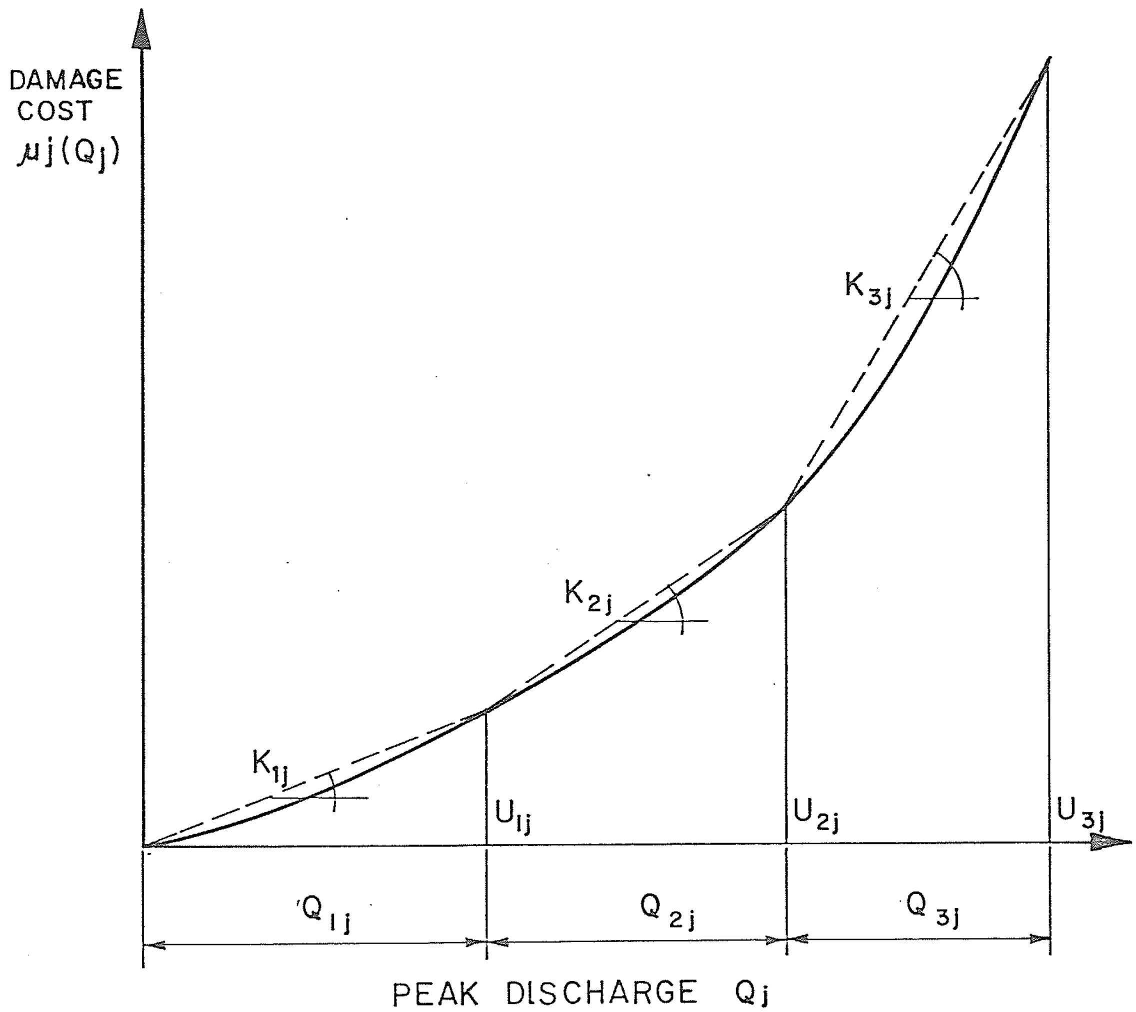


Figure III-4

SEPARABLE PROGRAMMING EXAMPLE FIGURE

4.0

THE LINEAR PROGRAMMING MODEL APPLIED TO THE ASSINIBOINE RIVER SYSTEM

4.0 THE LINEAR PROGRAMMING MODEL APPLIED TO THE ASSINIBOINE RIVER SYSTEM

4.1 The Assiniboine River Model

The Assiniboine River basin in Manitoba between Shellmouth Reservoir and Winnipeg is the river basin or physical system modelled in this thesis. It is broken down into six river reaches on the basis of the location of Water Survey of Canada streamflow gauging stations on the Assiniboine River. These river reaches are from Shellmouth Reservoir to Russell, Russell to Miniota, Miniota to Brandon, Brandon to Portage la Prairie, Portage la Priarie to Headingley and Headingley to Winnipeg. The system thus described is shown on Figure IV-1, and the locations of the above noted Water Survey of Canada streamflow gauging stations are shown on Figure IV-2.

There are seven points of inflow in this model. These are: the inflow to Shellmouth Reservoir, inflow from Shellmouth Reservoir to Russell, inflow from Russell to Miniota, inflow from Miniota to Brandon, inflow from Brandon to Portage la Prairie, inflow from Portage la Prairie to Headingley, and the inflow from Headingley to Winnipeg. The inflow from Headingley to Winnipeg includes flow on the Red River in Manitoba not diverted down the Red River Floodway.

The model constructed in this thesis was tested using 1974 streamflow data over the time period April 15 to August 11. The year 1974 was selected because it was a high flow year and hydrometric flow data was readily available. The inflows to Shellmouth Reservoir were calculated by the Water Resources Division, Department of Mines, Resources and Environmental Management, Government of Manitoba. The remaining inflow values were calculated on a mean seven day basis as the difference in mean seven day flow values between successive Water Survey of Canada streamflow gauging stations. The exception to the above noted calculation technique involves the inflow at Winnipeg, which includes flow from Assiniboine River and the Red River minus whatever flow was diverted through the Red River Floodway.

4.2 Study Operational Rules

For the purposes of this thesis the operational guidelines for the two major flood control works on the Assiniboine River, that is Shellmouth Reservoir and the Assiniboine River Diversion, have been simplified somewhat from those outlined in Chapter II. Shellmouth Reservoir is regulated so that the spillway will not be used. In other words there is no use of live storage above the spillway in flood control operations. This assumption is in accordance with actual operating criteria for the Shellmouth Reservoir in that reservoir live storage is generally not relied on for flood control purposes by the Water Resources Division. As well, a mean seven day release from the reservoir of 100 c.f.s. has been assumed for riparian purposes. That is, during no week during the analysis will the discharge from the Shellmouth Reservoir be allowed to fall below 100 c.f.s.

The operation of the Assiniboine River Diversion has been constrained to follow the Assiniboine River Diversion operation guideline outlined in Chapter II. The pattern of operation assumed for the purpose of this thesis is as follows:

	Total Flow at Diversion Point
First 10000 c.f.s. down Assiniboine River	10000 c.f.s.
Next 15000 c.f.s. down Assiniboine River Diversion	25000 c.f.s.
Next 10000 c.f.s. down Assiniboine River	35000 c.f.s.
Next 10000 c.f.s. down Assiniboine River Diversion	45000 c.f.s.
Remainder down the Assiniboine River	45000 + c.f.s.

The flood stage at Winnipeg is taken into account at all times with regard to the operation of the Assiniboine River Diversion by means of placing a high damage value on flood stages greater than bank capacity in Winnipeg. It is to be noted that Winnipeg flows include flow of the Red River not diverted by the Winnipeg Floodway. The high value of possible damage at the Winnipeg damage centre may at any time overrule the assumed general pattern of operation of the Assiniboine River Diversion. This in accord with the present actual operating practices with respect to the Assiniboine River Diversion in which flood protection at Winnipeg assumes paramount importance.

4.3 Flood Damage Functions

As noted previously the linear programming algorithm requires a linear relationship of the variables in the problem to be minimized. This is known as the objective function. In this thesis the objective function is comprised of damage functions at each damage centre in the analysis. These damage functions are described earlier in Chapter 3.0 in section 3.4, Objective Function.

There are seven damage centres in the analysis carried out in this thesis. These damage centres are located at Water Survey of Canada streamflow gauging stations. The locations are as follows:

Location	Water Survey of Canada Station Number
Assiniboine River near Russell	05ME001
Assiniboine River near Miniota	05ME006
Assiniboine River near Brandon	05MH001
Assiniboine River near Portage la Prairie	05MJ003
Assiniboine River near Headingley	05MJ001
Assiniboine River Diversion near Portage la Prairie	05LL019
Red River at Winnipeg	05OJ001

Each damage centre is assumed to be representative of the reach of river from the damage centre in question upstream to the next damage centre. The location of the damage centre at Water Survey of Canada streamflow gauging stations provided stage-discharge relationships at each damage centre. The only exception to this is at Winnipeg where the Water Survey of Canada does not calculate a stage-discharge relationship.

Flooded area or damage versus discharge relationships were obtained from the Water Resources Division, the Department of Mines, Resources and Environmental Management, Government of Manitoba, for the first four damage centres, Russell, Miniota, Brandon and Portage la Prairie. These relationships are based on air photo analysis from previous flood years. They are shown on Figures IV-3, IV-4, IV-5 and IV-6. From inspection of the above noted figures it may readily be seen that all of these functions are convex linear approximations to distinctly non-linear functions. This non-linearity is to be expected in functions of this type.

All of the functions have an initial segment of zero slope which infers zero damage. This represents the channel capacity for the damage centre in question and is in actual fact the range of flow values that may occur in the river reach between the proceeding damage centre and the centre in question before any flood damage occurs in the reach. It should be noted that this range may be quite different from the range at the actual site of the Water Survey of Canada gauging station. This phenomenon results from the fact that Water Survey of Canada streamflow gauging stations are generally located at constrictions in the river with high channel capacities so as to catch all flow in the river in easily metered channels.

The flooded area versus discharge relationships are converted to damage relationships by multiplying each curve segment slope by an agricultural damage factor as discussed in Chapter III to yield damage, in agricultural damage units, versus discharge relationships. The agricultural damage factors used were as follows:

Date	Week of Analysis	Agricultural Damage Factor
April 15 - May 26	1 - 6	0.333
May 27 - June 23	7 - 10	0.5
June 24 - onwards	11 - 17	1.0

The selection of these weights is rather arbitrary since the purpose of the analysis is to test the model capability rather than to devise practical operating rules.

These weights imply that up to May 26 there is a linear agricultural damage relationship of 0.333 agricultural damage units per acre of land flooded. For the period of May 26 to June 23 there is a linear agricultural damage relationship of 0.5 agricultural units per acre of land flooded. For the period of June 24 onward there is a linear agricultural damage relationship of 1.0 agricultural damage units per acre of land flooded.

It is to be noted that in the application of the linear programming model to the Assiniboine River basin all flooded area was assumed to have the same unit value per acre. Agricultural damage factors were then applied against these unit values. This assumption may be easily relaxed to permit any differention in land values deemed necessary in a given analysis.

The final three discharge-damage relationships, namely, at Assiniboine River Diversion, at Headinley and in Winnipeg were not based on flooded area versus discharge relationships. Rather, they are what is termed in this thesis as surrogate damage functions in which preselected flood control component operating schedule characteristics are forced on the linear programming analysis by selected formulation of the above noted relationships. Operating rules for the Assiniboine River Diversion have been established as a matter of policy. To achieve compliance with these rules surrogate damage functions have been introduced. These relationships are shown on Figure IV-7, IV-8 and IV-9.

The pre-selected component operating characteristics forced on the linear programming analysis by these damage relationships is the previously discussed operation pattern of the Assiniboine River Diversion. The operation pattern of the Diversion desired in the analysis is controlled by the stage discharge relationships for the Assiniboine River Diversion, the Assiniboine River at Headingley and the combined Assiniboine River and non-diverted Red River flow at Winnipeg.

The last damage relationship, for the Assiniboine River at Winnipeg, is not formulated to control the operation characteristics of the Assiniboine River Diversion directly but rather to reflect the channel capacity of the Assiniboine-Red River complex in Winnipeg and the very high potential damage should flooding occur in the City. As noted previously the damage discharge relationship at Winnipeg may at any time overrule the preselected operation pattern of the Assiniboine River Diversion so as to relieve flood damage at Winnipeg. This is in accord to the present operating practices with respect to the Assiniboine River Diversion and is to be expected when one considers the extremely high potential damage of flooding in Winnipeg.

All flood damage relationships, with the exception of Winnipeg, reflect the time dependency of agricultural damages as noted previously in this thesis. In the case of Winnipeg the damage weights are assumed to be unity for all three time periods. That is, it is assumed that flood damage in Winnipeg is not time dependent and would be equally severe regardless of the time of year in which flooding would occur.

As noted previously in Chapter 3.0 the damage functions which comprise the objective functions for the linear program optimization technique are non-linear. This situation is addressed by the previously defined technique of separable programming. As well the previously defined technique allowing time variability in the objective function through a time dependent family of damage functions is employed in the application of the model to the Assiniboine River basin.

4.4 Specific Linear Programming Model for the Assiniboine River System

4.4.1 Physical Constraints

4.4.1.1 Storage Constraints

The maximum storage available at Shellmouth Reservoir at the spillway elevation is 388,000 acre feet or approximately 27572 c.f.s. - weeks. With reference to equation (III-1) the storage variables for Shellmouth Reservoir in the linear programming model must be upper bounded at a value of 27572 that is

$$S^{t} \leq 27572 \qquad \text{IV-1}$$

where S^t is the volume of water stored in Shellmouth Reservoir at the start of time period t and is in units of c.f.s. - weeks.

4.4.1.2 Reservoir Mass Balance Equation

With reference to equation (III-2) the reservoir mass balance equation for Shellmouth Reservoir may be stated as follows:

$$S^{t} = S^{t-1} + I^{t-1} - O^{t-1} \qquad \text{IV-2}$$

where S^t and S^{t-1} are the Shellmouth Reservoir storage volumes, in units of c.f.s. - weeks, at the beginning of time intervals t and t-1. I^{t-1} and O^{t-1} are the mean seven day inflow and outflow from Shellmouth Reservoir over time period t-1. The storage units of c.f.s. - weeks are required in order to maintain dimensional homogenity in the problem in which all flow values are mean seven day values.

4.4.1.3 Reservoir Release Constraint

For the purpose of this study releases from Shellmouth Reservoir are only allowed via the reservoir conduit. That is, no flow over the spillway is allowed since the problem is constrained so that the water level on the reservoir may not exceed the spillway crest elevation.

An elevation-discharge relationship for the conduit and spillway flow is shown on Figure IV-10. The conduit rating curve on this figure is a maximum flow curve and based on a Prairie Farm Rehabilitation Authority memorandum of August 25, 1966.

An elevation storage relationship for Shellmouth Reservoir is shown on Figure IV-11.

Figures IV-10 and IV-11 may be combined to yield on outflow-storage relationship for conduit flow only or conduit and spillway combined. An outflow-storage relationship for conduit flow only is shown on Figure IV-12.

For the purposes of this thesis the conduit flow curve may be approximated as shown on Figure IV-12. All reservoir releases must be less than or equal to this limiting function defined by the reservoir storage for the time period in question.

With reference to equation (III-3) this may be represented as

$$O^t \leq 0.066\, S^t + 1930 \qquad \text{IV-3}$$

where O^t is the mean seven day outflow from Shellmouth Reservoir over time period t; S^t is the storage volume in Shellmouth Reservoir at the beginning of time period t.

4.4.1.4 Riparian Constraint

With reference to equation (III-6) the riparian constraint for

Shellmouth Reservoir for the purposes of this study may be stated as:

$$O^t \geq 100 \qquad \text{IV-4}$$

where O^t is the mean seven day outflow from Shellmouth Reservoir over time period t. This outflow is constrained to be at least 100 c.f.s. for all time periods.

4.4.1.5 Diversion Capacity Constraint

With reference to equation (II-8) the upper limit for flow down the Assiniboine Diversion may be stated as:

$$DIVR^t \leq 25000 \qquad \text{IV-5}$$

where $DIVR^t$ is the mean seven day Assiniboine River Diversion flwo over time period t and is constrained to be less than 25000 c.f.s. for all time periods in the analysis.

4.4.1.6 Upper Limit on Diversion Flow Values

With reference to equation (II-10) the Assiniboine River Diversion flow must be constrained so that at all times it is less than or equal to the flow available to be diverted down the Diversion. This may be represented as:

$$DIVR^t \leq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t \qquad \text{III-13}$$

where all terms are as defined earlier.

4.4.2 Computational Constraints

4.4.2.1 Peak Discharge Constraint

The channel flow constraints are defined for each damage centre in the format shown in equation (II-6). With reference to Figure IV-13 they are defined as follows:

Damage Centre A - Russell

$$QPA \geq O^t + LOCA^t \qquad \text{III-4}$$

Damage Centre B - Miniota

$$QPB \geq O^t + LOCA^t + LOCB^t \qquad \text{III-5}$$

Damage Centre C - Brandon

$$QPC \geq O^t + LOCA^t + LOCB^t + LOCC^t \qquad \text{III-6}$$

Damage Centre D - Portage la Prairie

$$QPD \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t - DIVR^t \qquad \text{III-7}$$

Damage Centre E - Headingley

$$QPE \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t + LOCE^t - DIVR^t \qquad \text{III-8}$$

Damage Centre F - Winnipeg

$$QPF \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t + LOCE^t + LOCF^t - DIVR^t \qquad \text{III-9}$$

Damage Centre G - Assiniboine River Diversion

$$QPG \geq DIVR^t \qquad \text{III-10}$$

where:

O^t is the mean seven day outflow from Shellmouth Reservoir over time period t

$LOCA^t$ is the mean seven day inflow to reach A, Shellmouth Reservoir to Russell, over time period t

$LOCB^t$ is the mean seven day inflow to reach B, Russell to Miniota, over time period t

$LOCC^t$ is the mean seven day inflow to reach C, Miniota to Brandon, over time period t

$LOCD^t$ is the mean seven day inflow to reach D, Brandon to Portage la Prairie over time period t

$LOCE^t$ is the mean seven day inflow to reach E, Portage la Prairie to Headingley, over time period t

$LOCF^t$ is the mean seven day inflow to reach F, Headingley to Winnipeg, over time period t

QPA is the peak mean seven day flow at damage centre A, Russell

QPB is the peak mean seven day flow at damage centre B, Miniota

QPC is the peak mean seven day flow at damage centre C, Brandon

QPD is the peak mean seven day flow at damage centre D, Portage la Prairie

QPE is the peak mean seven day flow at damage centre E, Headingley

QPF is the peak mean seven day flow at damage centre F, Winnipeg

QPG is the peak mean seven day flow at damage centre G, Assiniboine River Diversion

DIVR is the mean seven day Assiniboine River Diversion flow

4.5 Summary of Problem Contraints

A summary of all constraints involved in the linear programming model of the Assiniboine River flood control system is provided herein. This summary includes the previously discussed techniques of time dependency and separable programming employed to address the time dependence and non-linearity situations inherent in the problem under analysis.

Storage Constraint

$$S^t \leq 27572 \qquad \text{for } t = 1,17$$

Reservoir Mass Balance Constraint

$$S^t = S^{t-1} + I^{t-1} - O^{t-1} \qquad \text{for } t = 2,17$$

Reservoir Release Constraint

$$O^t \leq 0.066\ S^t + 1930 \qquad \text{for } t = 1,17$$

Peak Flow Constraint at Damage Centre A - Russell

$$PA1L + PA2L + PA3L \geq O^t + LOCA^t \qquad \text{for } t = 1,6$$

$$PA1M + PA2M + PA3M \geq O^t + LOCA^t \qquad \text{for } t = 7,10$$

$$PA1H + PA2H + PA3H \geq O^t + LOCA^t \qquad \text{for } t = 11,17$$

Peak Flow Constraint at Damage Centre B - Miniota

$$PB1L + PB2L + PB3L \geq O^t + LOCA^t + LOCB^t \qquad \text{for } t = 1,6$$

$$PB1M + PB2M + PB3M \geq O^t + LOCA^t + LOCB^t \qquad \text{for } t = 7,10$$

$$PB1H + PB2H + PB3H \geq O^t + LOCA^t + LOCB^t \qquad \text{for } t = 11,17$$

Peak Flow Constraint at Damage Centre C - Brandon

$$PC1L + PC2L \geq O^t + LOCA^t + LOCB^t + LOCC^t \qquad \text{for } t = 1,6$$

$$PC1M + PC2M \geq O^t + LOCA^t + LOCB^t + LOCC^t \qquad \text{for } t = 7,10$$

$$PC1H + PC2H \geq O^t + LOCA^t + LOCB^t + LOCC^t \qquad \text{for } t = 11,17$$

<u>Peak Flow Constraint at Damage Centre D - Portage la Prairie</u>

$$PD1L + PD2L \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t - DIVR^t \qquad \text{for } t = 1,6$$

$$PD1M + PD2M \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t - DIVR^t \qquad \text{for } t = 7,10$$

$$PD1H + PD2H \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t - DIVR^t \qquad \text{for } t = 11,17$$

<u>Peak Flow Constraint at Damage Centre E - Headingley</u>

$$PE1L + PE2L + PE3L \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t + LOCE^t - DIVR^t \qquad \text{for } t = 1,6$$

$$PE1M + PE2M + PE3M \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t + LOCE^t - DIVR^t \qquad \text{for } t = 7,10$$

$$PE1H + PE2H + PE3H \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t + LOCE^t - DIVR^t \qquad \text{for } t = 11,17$$

<u>Peak Flow Constraint at Damage Centre F - Winnipeg</u>

$$PF1 + PF2 + PF3 \geq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t + LOCE^t + LOCF^t - DIVR^t \qquad \text{for } t = 1,17$$

Peak Flow Constraint at Damage Centre G - Assiniboine River Diversion

$PV1L + PV2L \geq DIVR^t$ for t = 1,6

$PV1M + PV2M \geq DIVR^t$ for t = 7,10

$PV1H + PV2H \geq DIVR^t$ for t = 11,17

Riparian Constraint

$O^t \geq 100$ for t = 1,77

Diversion Capacity Constraint

$DIVR^t \leq 25000$ for to = 1,17

Upper limit on Diversion Flow Constraint

$DIVR^t \leq O^t + LOCA^t + LOCB^t + LOCC^t + LOCD^t$ for to = 1,17

where:

S^t is the storage volume, in c.f.s. - weeks, in Shellmouth Reservoir at the beginning of time period t

I^t is the mean seven day inflow to Shellmouth Reservoir over time period t

O^t is the mean seven day outflow from Shellmouth Reservoir over time period t

PA1L is the peak mean seven day flow at damage centre A, the Assiniboine River near Russell. It is section 1 of the linear approximation to the non-linear damage function and is selected over time period L which varies from t=1 to t=6

PA2L is the peak mean seven day flow at damage centre A, the Assiniboine River near Russell. It is section 2 of the linear approximation to the non-linear damage function and is selected over time period L which varies from t=1 to t=6. Other peak variables are identified in a similar manner. The first character of the variable name, P, indicates a peak mean seven day flow; the second character, A,B,C,D,E,F or V indicates a damage centre as follows:

A - Russell

B - Miniota

C - Brandon

D - Portage la Prairie

E - Headingley

F - Winnipeg

V - Assiniboine River Diversion

The next character is numeric and represents the section of the linear approximation to the non-linear damage function the variable represents.

The last character represents the family of time dependent variables to which the variable in question belongs. This is defined as follows:

L - April 15, to May 26

M - May 27 to June 23

H - June 24 onwards

O^t is the mean seven day outflow from Shellmouth Reservoir over time period t

$LOCA^t$ is the mean seven day local inflow to reach A, over time period t and is applied to the model at Russell

$LOCB^t$ is the mean seven day local inflow to reach B, over time period t and is applied to the model at Miniota

$LOCC^t$ is the mean seven day local inflow to reach C, over time period t and is applied to the model at Brandon

$LOCD^t$ is the mean seven day local inflow to reach D, over time period t and is applied to the model at Portage la Prairie

$LOCE^t$ is the mean seven day local inflow to reach E, over time period t and is applied to the model at Headingley

$LOCF^t$ is the mean seven day local inflow to reach F, over time period t and is applied to the model at Winnipeg

$DIVR^t$ is the mean seven day flow down the Assiniboine River Diversion over time period t

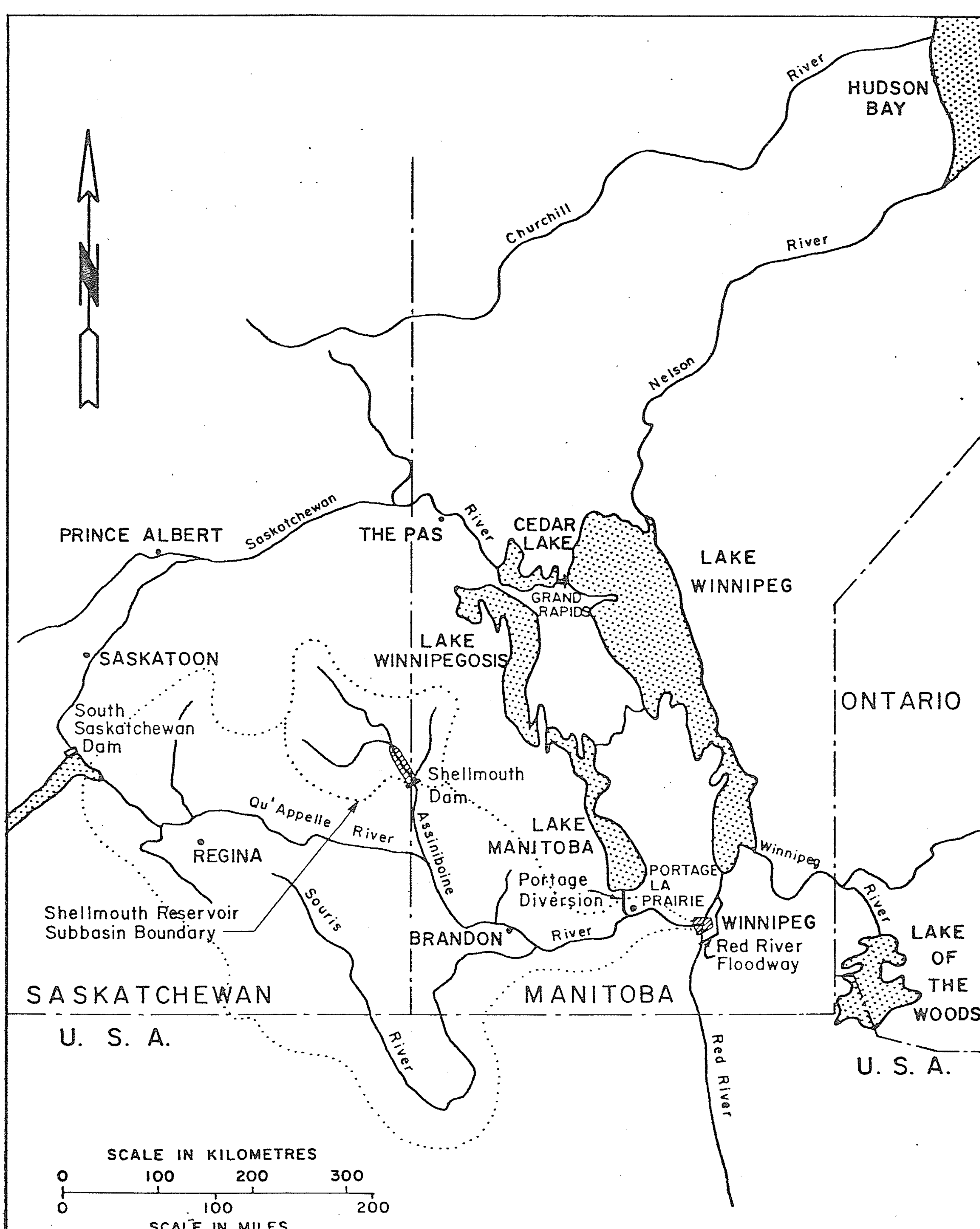


Figure IV – 1

ASSINIBOINE RIVER DRAINAGE BASIN

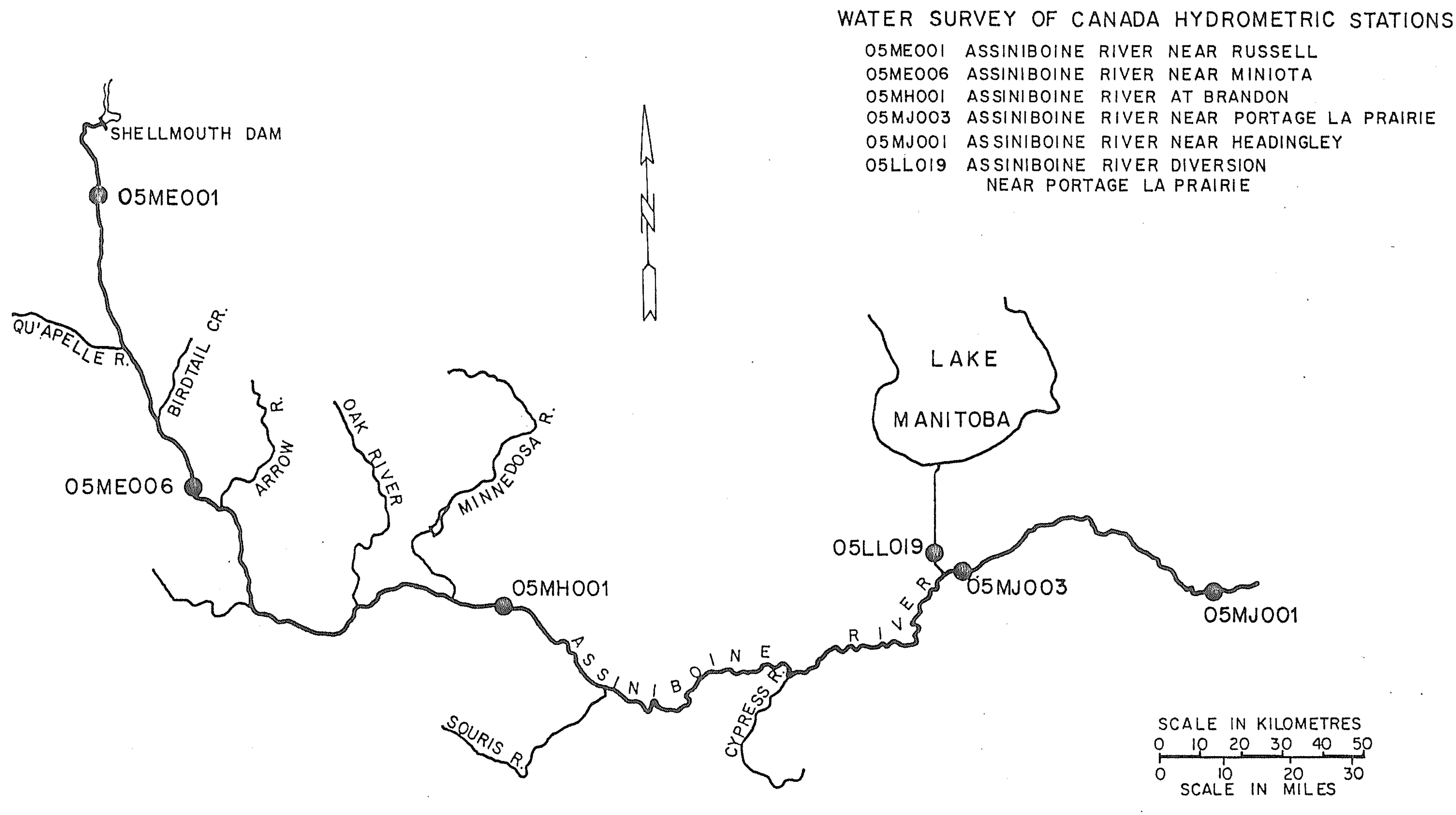


Figure IV – 2

WATER SURVEY OF CANADA

STREAMFLOW GAUGING LOCATIONS IN THE STUDY AREA

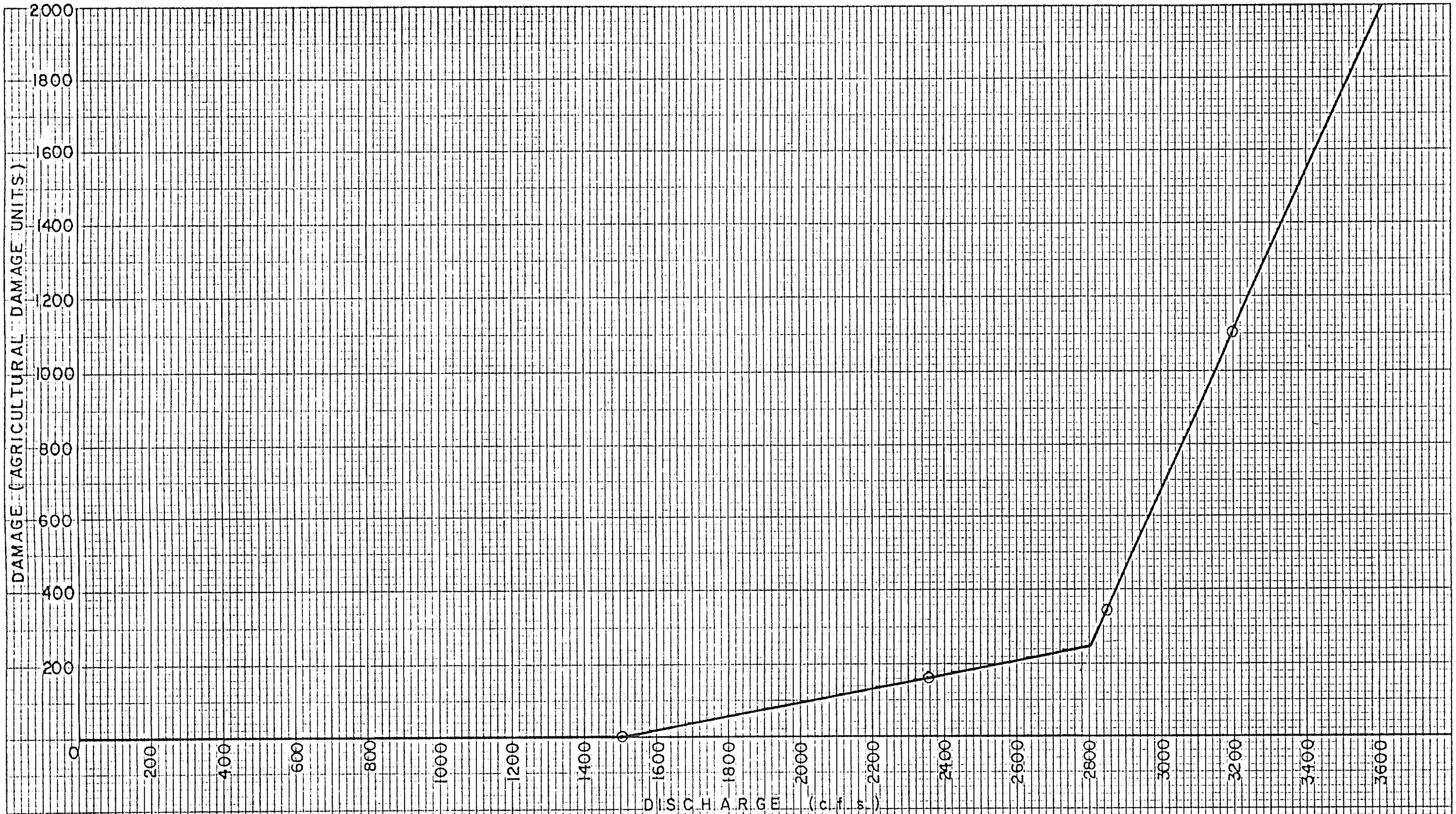


Figure IV – 3

DISCHARGE DAMAGE RELATIONSHIP

ASSINBOINE RIVER AT RUSSELL

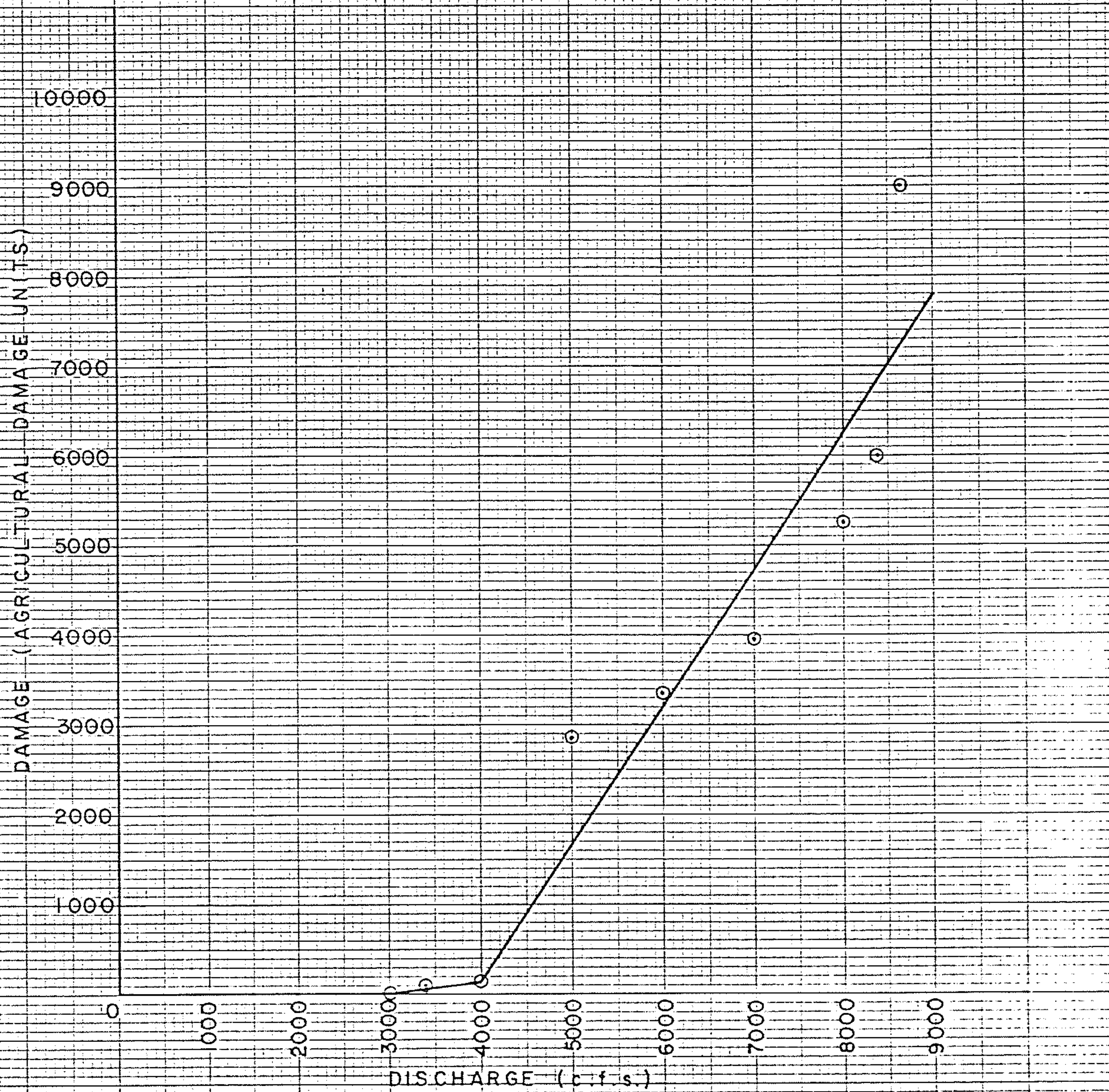


Figure IV – 4

DISCHARGE DAMAGE RELATIONSHIP

ASSINIBOINE RIVER AT MINIOTA

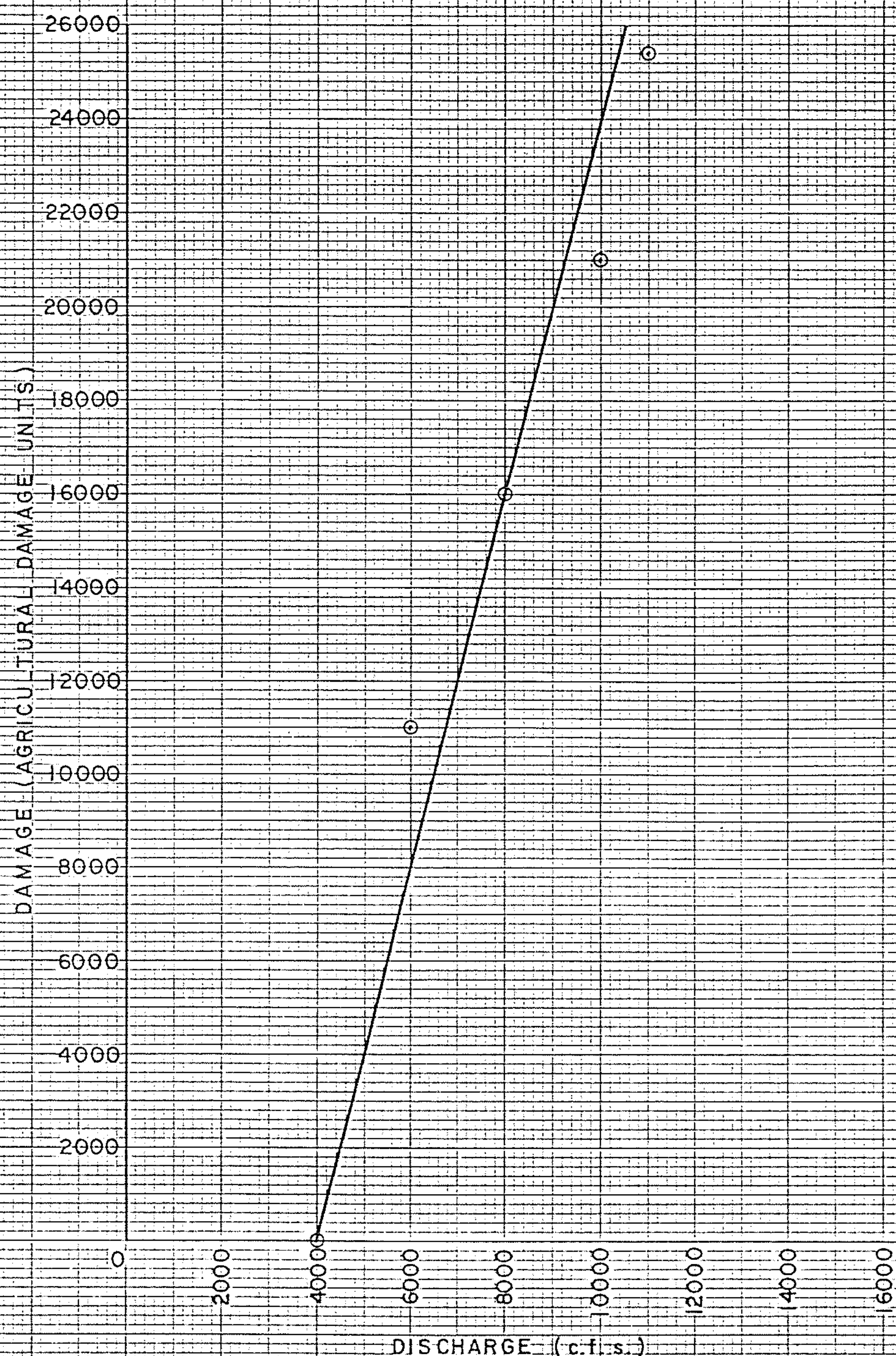


Figure IV – 5

DISCHARGE DAMAGE RELATIONSHIP

ASSINIBOINE RIVER AT BRANDON

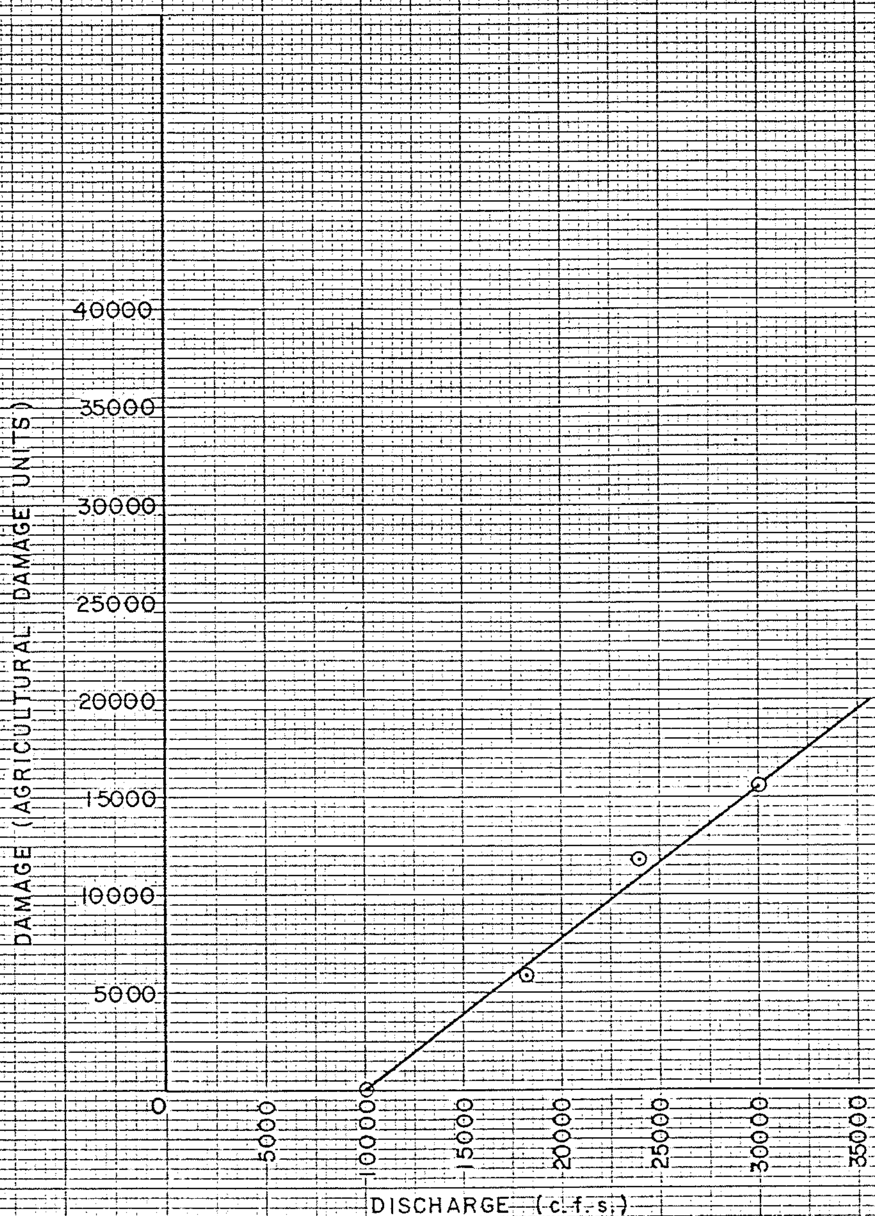


Figure IV-6

DISCHARGE DAMAGE RELATIONSHIP

ASSINIBOINE RIVER AT PORTAGE LA PRAIRIE

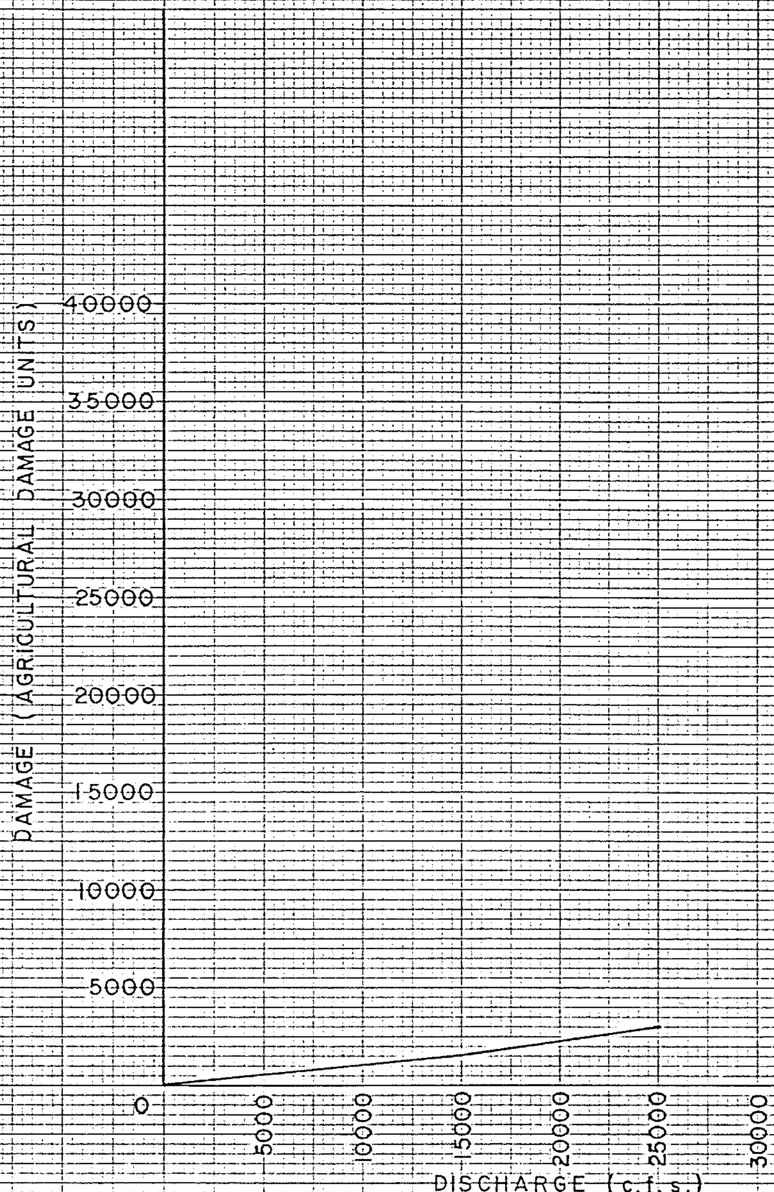


Figure IV-7

DISCHARGE DAMAGE RELATIONSHIP

ASSINIBOINE RIVER DIVERSION

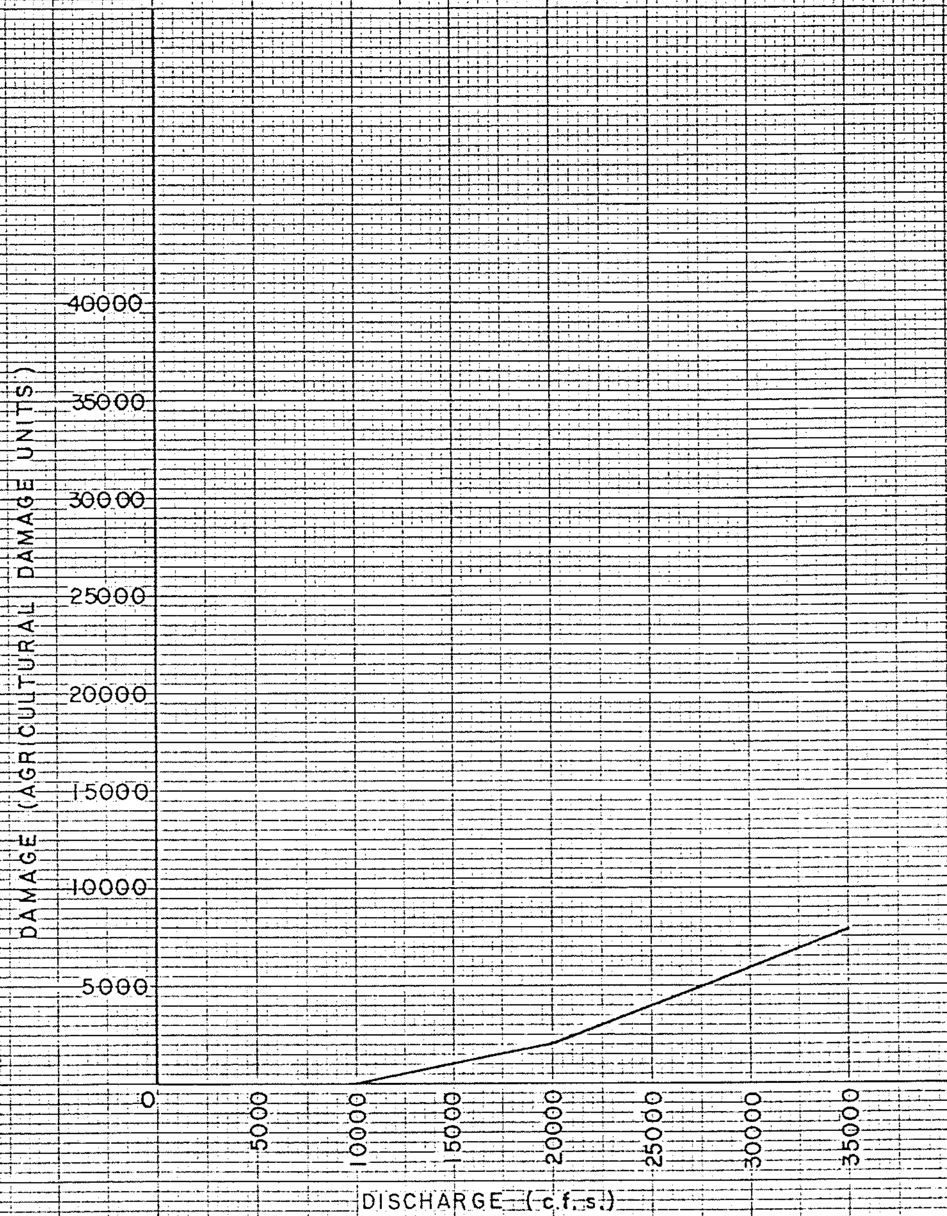


Figure IV-8

DISCHARGE DAMAGE RELATIONSHIP

ASSINIBOINE RIVER AT HEADINGLEY

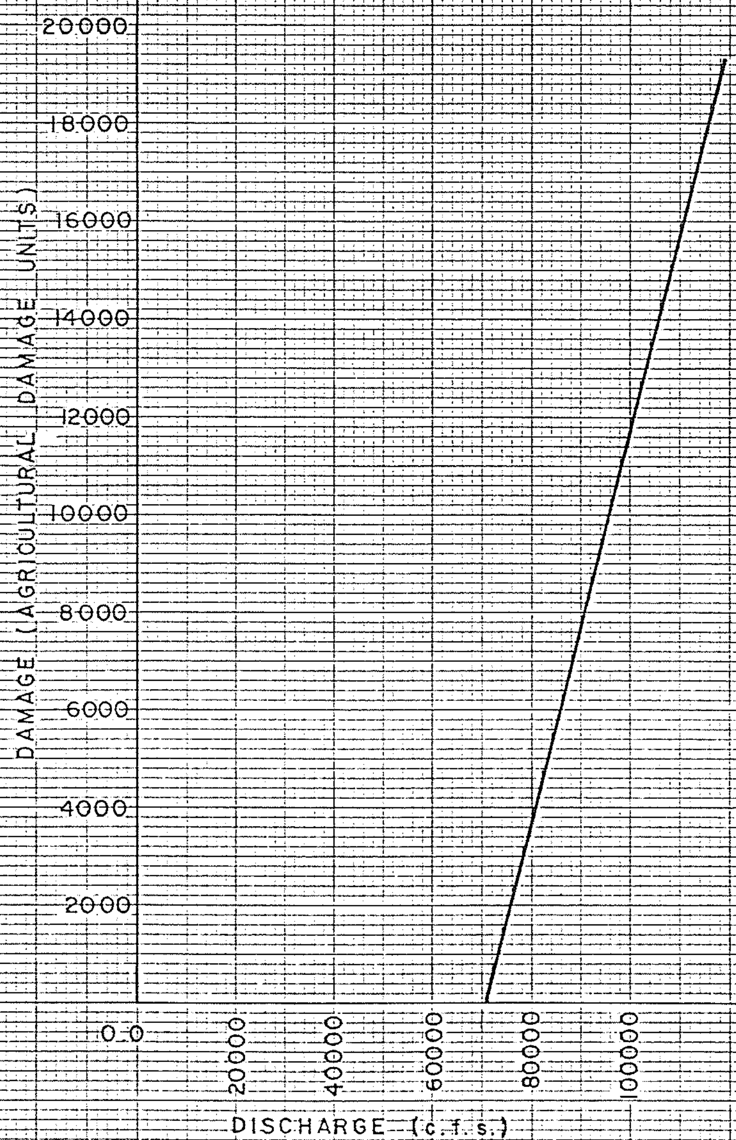


Figure IV-9

DISCHARGE DAMAGE RELATIONSHIP

ASSINIBOINE RIVER AT WINNIPEG

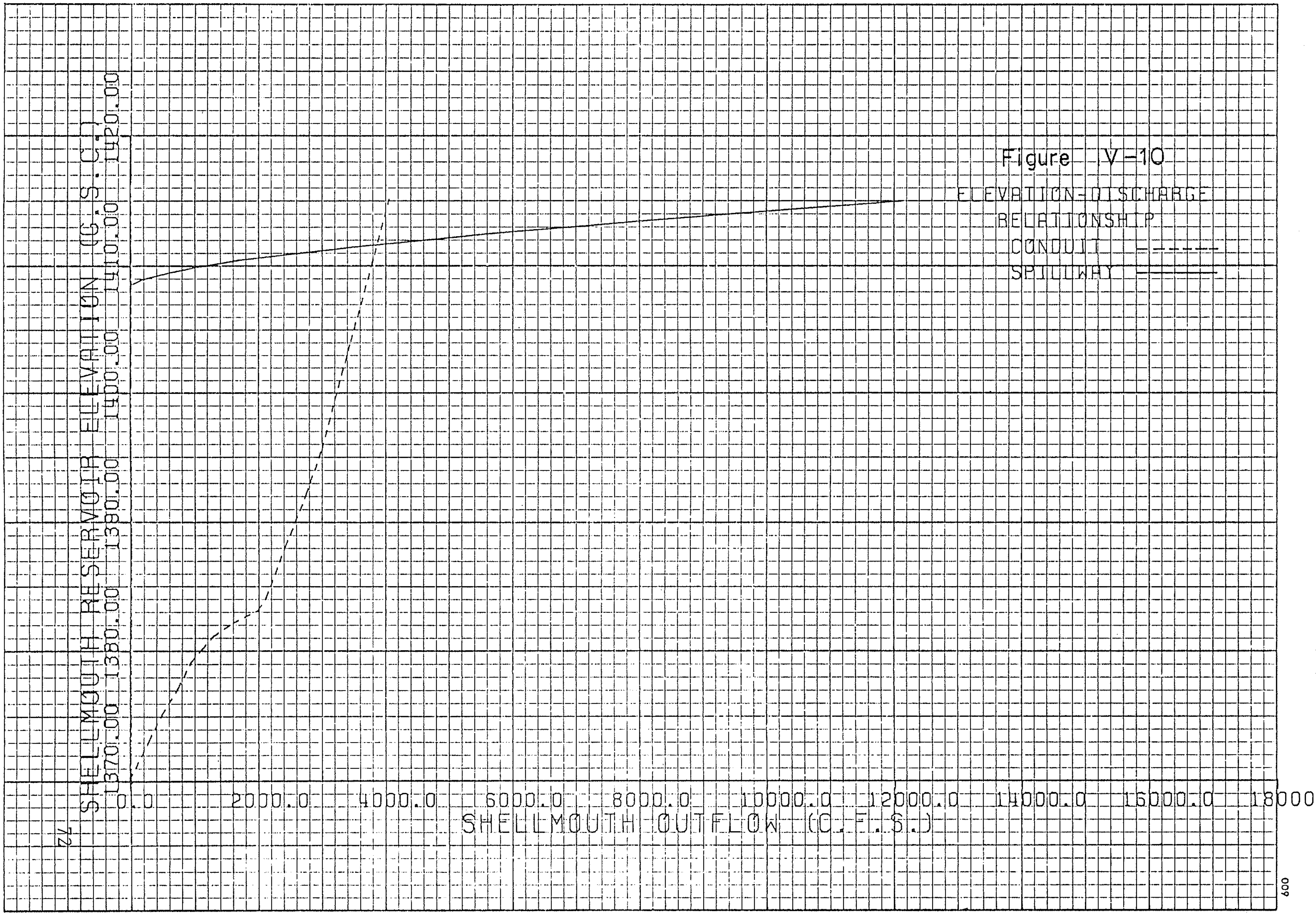
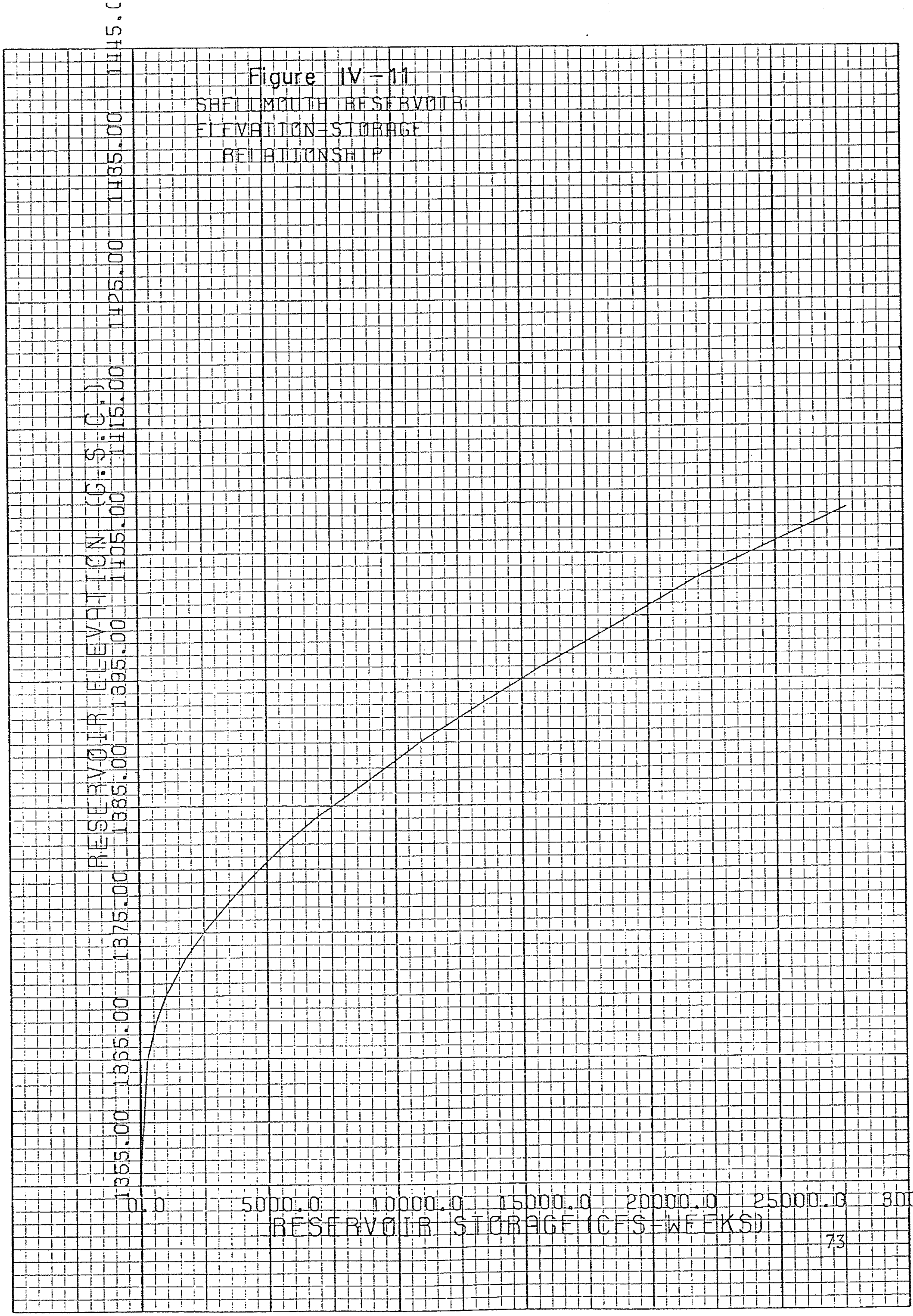


Figure V-10
ELEVATION-DISCHARGE
RELATIONSHIP
CONDUIT
SPILLWAY
SHELLMOUTH RESERVOIR ELEVATION (G.S.C.)
1370.00
1380.00
1380.00
1400.00
1410.00
1420.00
0.0
2000.0
4000.0
6000.0
8000.0
10000.0
12000.0
14000.0
16000.0
18000
SHELLMOUTH OUTFLOW (C.F.S.)

009

Figure IV-11
SHELLMOUTH RESERVOIR
ELEVATION-STORAGE
RELATIONSHIP



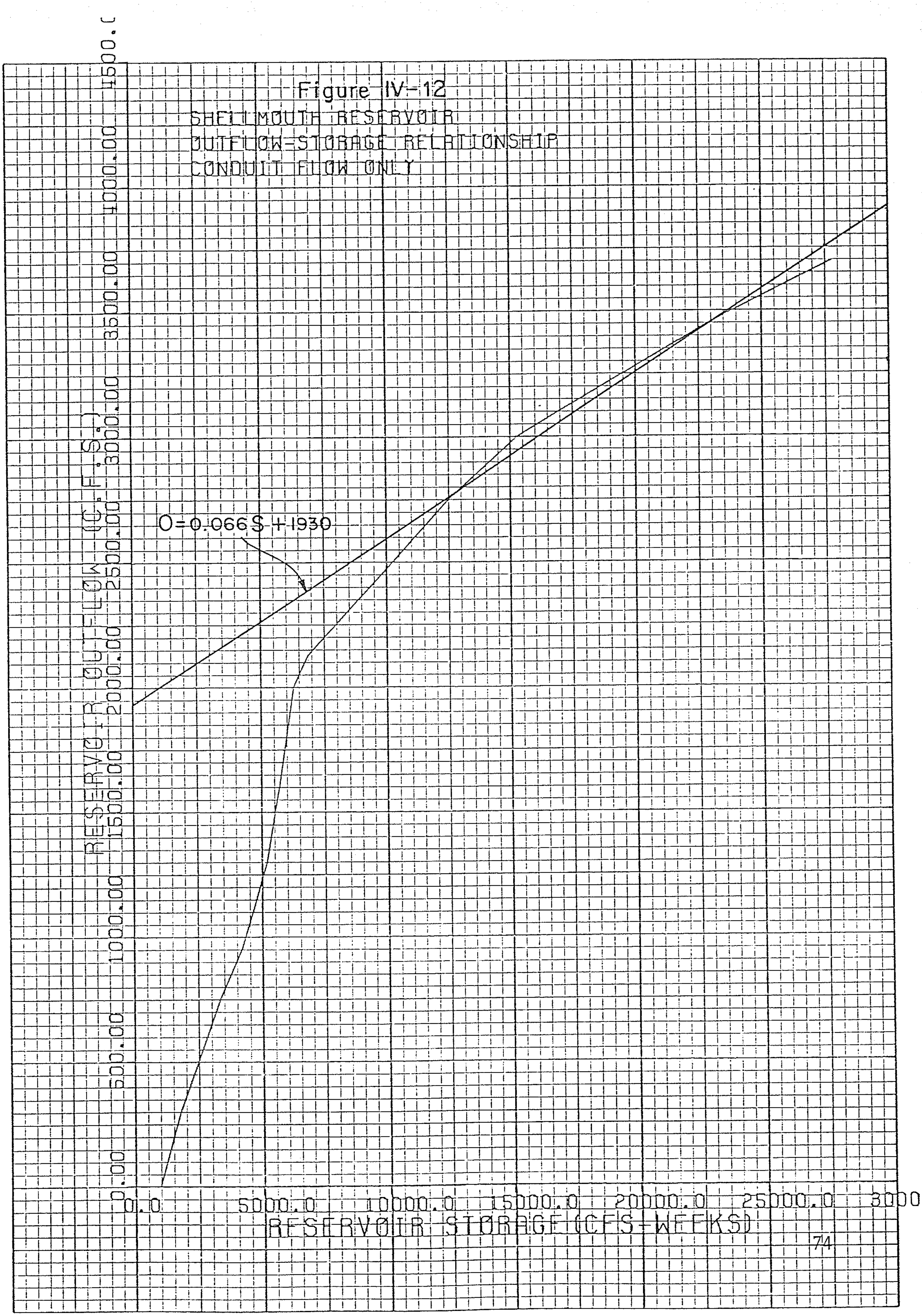


Figure IV-12
SHELLMOUTH RESERVOIR
OUTFLOW-STORAGE RELATIONSHIP
CONDUIT FLOW ONLY
O=0.066S+1930
RESERVOIR OUT-FLOW (C.F.S.)
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.0
0.0
5000.0
10000.0
15000.0
20000.0
25000.0
3000
RESERVOIR STORAGE (CFS-WEEKS)

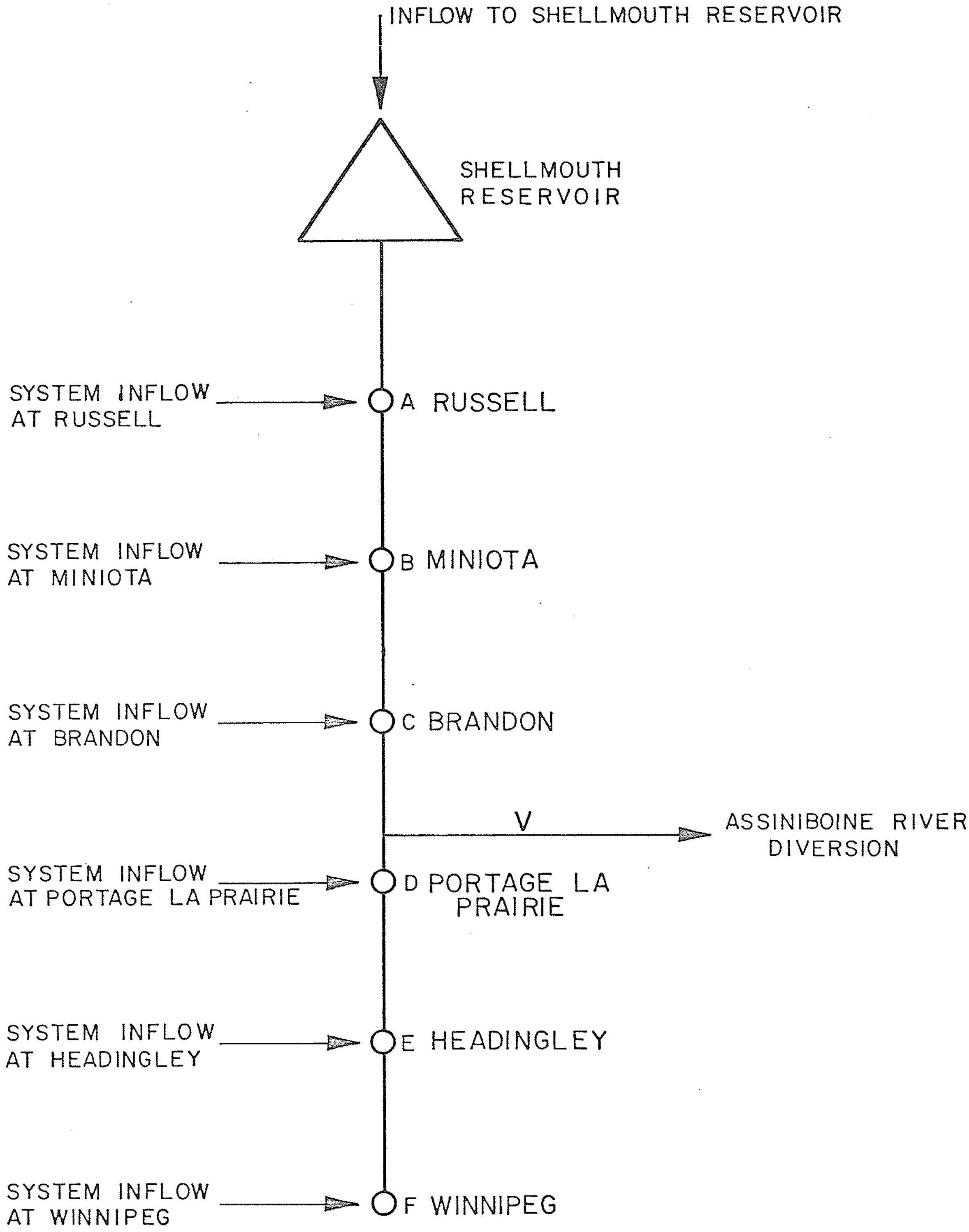


Figure IV – 13

SCHEMATIC REPRESENTATION OF ASSINIBOINE RIVER BASIN

5.0

COMPUTATIONAL TECHNIQUES

5.0 COMPUTATIONAL TECHNIQUES

5.1 The Computer Model

The computer model constructed in this thesis consists of three separate programs which are run sequentially but individually in the analysis. That is, each program is run and the output from the program in question is inspected and accepted before the next program is run. The three programs are:

1. the Matrix Generator
2. the Linear Programming Sollution Algorithm
3. the Report Writer

These individual programs will not be discussed separately.

5.2 Matrix Generator

The purpose of the matrix generator program is to transpose the problem under analysis from an algebraic representation of constraints and an objective function to the input format required by the linear programming solution algorithm.

Each individual problem under analysis could be keypunched separately in the correct input format for the linear programming solution algorithm. However, one must realize the volume of input that is required. In the case of this study approximately 250 computer cards are required for every single problem analyzed. It should be noted that this means that for every single minor change made to a problem under analysis, a new deck of approximately 250 cards would be required. A minor change would involve such things as a different reservoir storage starting level or changes in any one of the inflows to the system. These changes would occur frequently on an operational basis.

It must also be noted that in the development of the working linear programming model there were literally hundreds of problem formulations attempted before the final linear programming model was determined. Without a matrix generator to generate this input for the linear programming solution algorithm, it may readily be seen that the volume of work required to develop the working linear programming model would be high enough to have been infeasible.

The matrix generator written for this thesis is a general matrix generator and is not limited to the problem analyzed in the thesis. The matrix generator will handle any linear programming problem as long as the problem is expressed in a simple algebraic notation. As well, the matrix generator has the flexibility of designating any variables so desired as constants. This type of variable would include local inflows or initial reservoir storage conditions. With the matrix generator developed in this thesis it is a simple matter to investigate different linear programming models or the effect of different inflow hydrographs on optimal operation of a given flood control system that has already been modelled.

As noted previously in this thesis, in the interest of computational efficiency, it is desirable to limit the number of variables actually in the analysis to as small a number as possible. The matrix generator developed in this thesis employs a transformation with regard to the previously noted fixed-valued variables. For any constraint containing constants, these constants are first multiplied by their corresponding coefficient in the constraint and then subtracted from the right-hand side of the constraint in question. In this manner the number of variables that the linear programming algorithm must address is reduced.

As noted previously the number of variables in the problem has a direct effect on computational efficiency and will be reflected in the cost of the computer resources required to solve the problem. It should be noted that if the number of variables exceeds an upper bound determined by the storage capability of the computer installation used for the analysis the particular linear programming solution algorithm employed in this thesis is inapplicable. A computer source code listing of the matrix generator developed in this thesis is provided in Appendix A. As well, Appendix A contains documentation as to the format of input required by the matrix generator program and sample output from the computer program.

5.3 The Linear Programming Solution Algorithm

The linear programming solution algorithm employed in this thesis is based upon the mutual primal dual simplex method of Michael L. Bolinski and Ralph E Gomery. The algorithm in question was supplied through the courtesy of Charles D.D. Howard and Associates, Consulting Civil Engineers, Winnipeg, Manitoba.

The algorithm proved to be quite efficient in the solution of the linear programming problems involved in this thesis. Several different algorithms were tried out in the analysis and computational difficulties were encountered with them. On the other hand the mutual primal dual simplex method proved to be computationally practicable and quite efficient.

5.4 The Report Writer

An important point in an optimization model is that the model output must be presented in a readily understandable concise format. It is not necessary that this output is meaningful from a linear programming point of view. Rather, it is important that the output related to the physical system being modelled especially since the object of the optimization model is to assist in the formulation of subsequent simulation analysis.

The report writer shows firstly all system inflow values. Under operational conditions these would be forecast values for all damage centres. Secondly, the natural streamflows are presented at all damage centres. Thirdly, optimal operating schedules for Shellmouth Reservoir and the Assiniboine River Diversion resulting from the optimization analysis are presented in a table together with streamflow conditions arising from the optimal operation of the flood control system. All terms are in units of mean c.f.s. - weeks.

The output from the report writer is shown in Appendix B. Also shown is a listing of the computer source code and user information to describe input to the report writer program.

6.0

RESULTS

6.0 RESULTS

6.1 The Optimization Model

The linear programming optimization model constructed in this thesis is not intended to provide actual operational decisions with respect to the operation of the Assiniboine River flood control system. Rather, it is intended to provide reasonable starting postulates for a more detailed simulation analysis of the flood control system in question. It is important nevertheless that the optimization model produce starting postulates which are near optimal with respect to the relative timing of the individual operations. The values of the reservoir and diversion releases should also be fairly close to optimal values. In the case of the Assiniboine River flood control system it is important that periods of high and low Shellmouth Reservoir release be accurately timed. The timing of the high and low values of the flood control system operating components is more important to the postulating of input to a simulation analysis than the actual values of the individual flood control system components obtained from the optimization analysis.

The results from the optimization model, that is operating schedules for the flood control system, may be input to a more detailed simulation model to fine tune the operating schedules. This will allow the determination of acceptably accurate estimates of the operating schedules with a minimum of simulation model computer runs. This in turn minimizes the cost of determining the operating schedules and, possibly from a flood control viewpoint, more important the time required for the analysis.

The linear programming optimization model constructed in this thesis was evaluated by applying the model spring 1974 conditions on the Assiniboine River in Manitoba. This application was described earlier in this thesis.

As noted previously there are six damage centers located along the Assiniboine River; Russell, Miniota, Portage la Prairie, Headingly and Winnipeg. For each of the above noted damage centers natural flow values and resultant optimal flow values from the optimization model constructed in the thesis are shown on Figures VI-1 to VI-6 inclusive.

The optimal operating schedules resulting from the linear programming optimization model for both Shellmouth Reservoir and the Assiniboine River Diversion of the Assiniboine River flood control system are shown on Figures VI-7 and VI-8 respectively.

The computer printout from the report writer constructed in this thesis is shown on Figures VI-9 to VI-11 inclusive.

Inspection of the above noted figures will give a complete graphic and numeric summary of the results of the linear programming optimization model constructed in this thesis for a given hydrologic event. In this case the hydrologic event is the spring 1974 streamflow conditions on the Assiniboine River as noted earlier.

6.2 Discussion of Results

As noted previously in this thesis the objective function with respect to agricultural damage is decidedly time dependent. The time dependency of the objective function is as follows:

Date	Week of Analysis	Agricultural Damage Factor
April 15 - May 26	1 - 6	0.333
May 27 - June 23	7 - 10	0.5
June 24 onwards	11 - 17	1.0

With reference to the above table it may be seen that least damage is caused in time periods 1 to 6. More severe damage is caused in time periods 7 to 10, and the most severe damage is caused in time periods 11 to 17.

With reference to Figure VI-11, it may be seen that for each damage centre in the analysis the peak mean seven day discharge is greatest during time period 1 to 6, less in time periods 7 to 10 and least in time periods 11 to 17. As noted previously, flood damage in terms of agricultural damage units has been assumed to be a simple function of peak mean seven day discharge. Thus, for each damage centre in the analysis, flood damage is greatest in time periods 1 to 6, less in time periods 7 to 10 and least in time periods 11 to 17. This result is as expected because of the previously noted time dependency of agricultural damages in the objective function.

With reference to Figure VI-11 it may be seen that the first week in the analysis involves a spilling of Shellmouth Reservoir. This is realistic when one considers that the second week of the analysis is the peak mean seven day inflow to Shellmouth Reservoir. With respect to the formulation of input for a subsequent simulation analysis it should be noted that the model indicates that a postulated generating schedule for Shellmouth Reservoir that spills early in the spring period is in order. The balance of time periods 1 to 6 indicate that the first time frame in the analysis, that is time periods 1 to 6, generally be one of Shellmouth Reservoir spilling. This is in accord with the time dependency of agricultural damage functions used in the model developed in this thesis.

With reference to Figure VI-11, it may be noted that the mean seven day Assiniboine River Diversion flow rate for time period 2 is 16,100 c.f.s. This is greater than the previously noted primary limit for flow down the Assiniboine River Diversion of 15,000 c.f.s. It is anticipated that investigations through the use of subsequent simulation analysis would ascertain whether or not the Assiniboine River Diversion discharge could be held to 15,000 c.f.s. without undue flood damage downstream on the Assiniboine River.

In overview Figure VI-11, the output from the report writer constructed in this thesis, provides the necessary timing relationships between the operation of individual flood control system components of the Assiniboine River system and the relative magnitude of the same operating schedules to formulate reasonable starting postulates for a subsequent simulation analysis. With reference to Figure VI-11 it may be seen that the operation of Shellmouth Reservoir has been determined by the optimization model to be one of generally early spilling of the reservoir followed by a period of moderate releases and finally by a period of minimal release as determined by riparian flow constraints.

The operation of the Assiniboine River Diversion may be seen to be one of initially high diverted flow values followed by a period of steadily decreasing diversion flow values and finally by a period of non use of the diversion.

The above noted timing of the operation of the individual flood control components together with approximate magnitudes of the operating schedules for the same flood control system components is what is required to formulate initial postulates for a subsequent simulation analysis. This is the objective of the optimization model constructed in this thesis.

6.3 Model Run Cost

The three components of the model constructed in this thesis, that is, the matrix generator, the linear programming solution algorithm and the report writer are run on a CDC Cyber, 170 computer located in Winnipeg at Cybershare Ltd.

Run costs were as follows:

Matrix generator	\$1.04
Linear programming solution algorithm	1.15
Report writer	.36
Total run cost	2.55

From the above it may be seen that the total cost for the analysis of one set of forecast inflows for the system as a whole is \$2.55. It is argued that at this price rate it is quite feasible to evaluate the effect on system component operating schedules of different inflow values to the system. In this manner it is thus possible to deal with the stochastic aspect of system inflow values in a manner which is acceptable from an operational if not theoretically elequant point of view.

6.4 Summary Conclusions

In summary it is concluded that the linear programming optimization model constructed in this thesis successfully provides feasible operating schedule postulates for a subsequent simulation analysis. The model constructed in this thesis has been successfully applied to a rather simple flood control network on the Assiniboine River in Manitoba. It is recognized that the application of the model in this specific instance may well be a form of overkill in that the system is in fact simple enough that acceptable starting postulates for a subsequent simulation analysis may be determined without the optimization model. However, it is argued that this would not be the case in a more complicated system. Moreover, it is the simplicity of the Assiniboine River flood control system that allows one to properly assess the applicability of the model.

The model can be used at a reasonable cost. This factor augers well for the feasibility of using this model on an operational basis for more complex flood control systems.

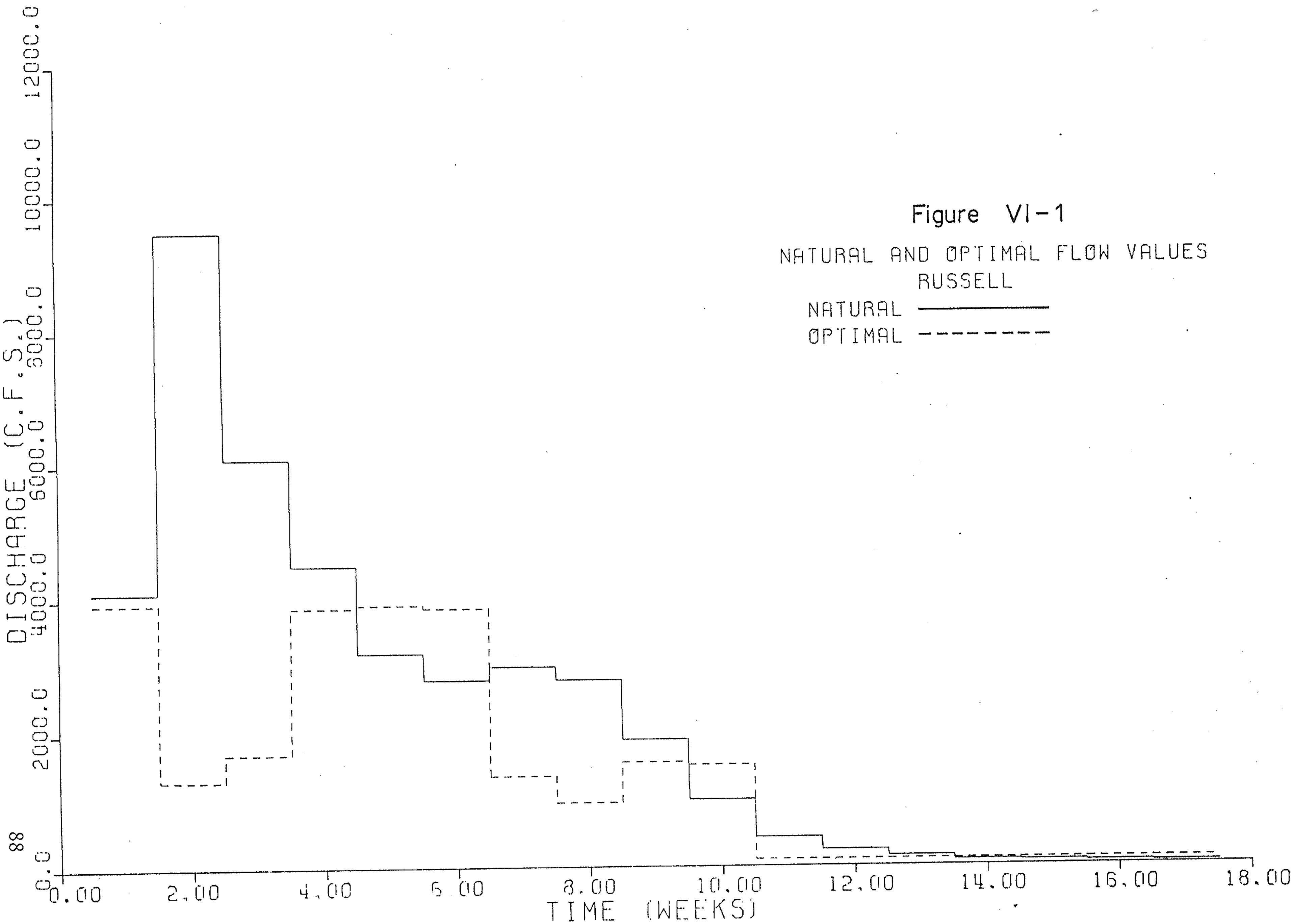


Figure VI-1
NATURAL AND ØPTIMAL FLOW VALUES
RUSSELL
NATURAL
ØPTIMAL
DISCHARGE (C.F.S.)
0.0
2000.0
4000.0
6000.0
8000.0
10000.0
12000.0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
TIME (WEEKS)

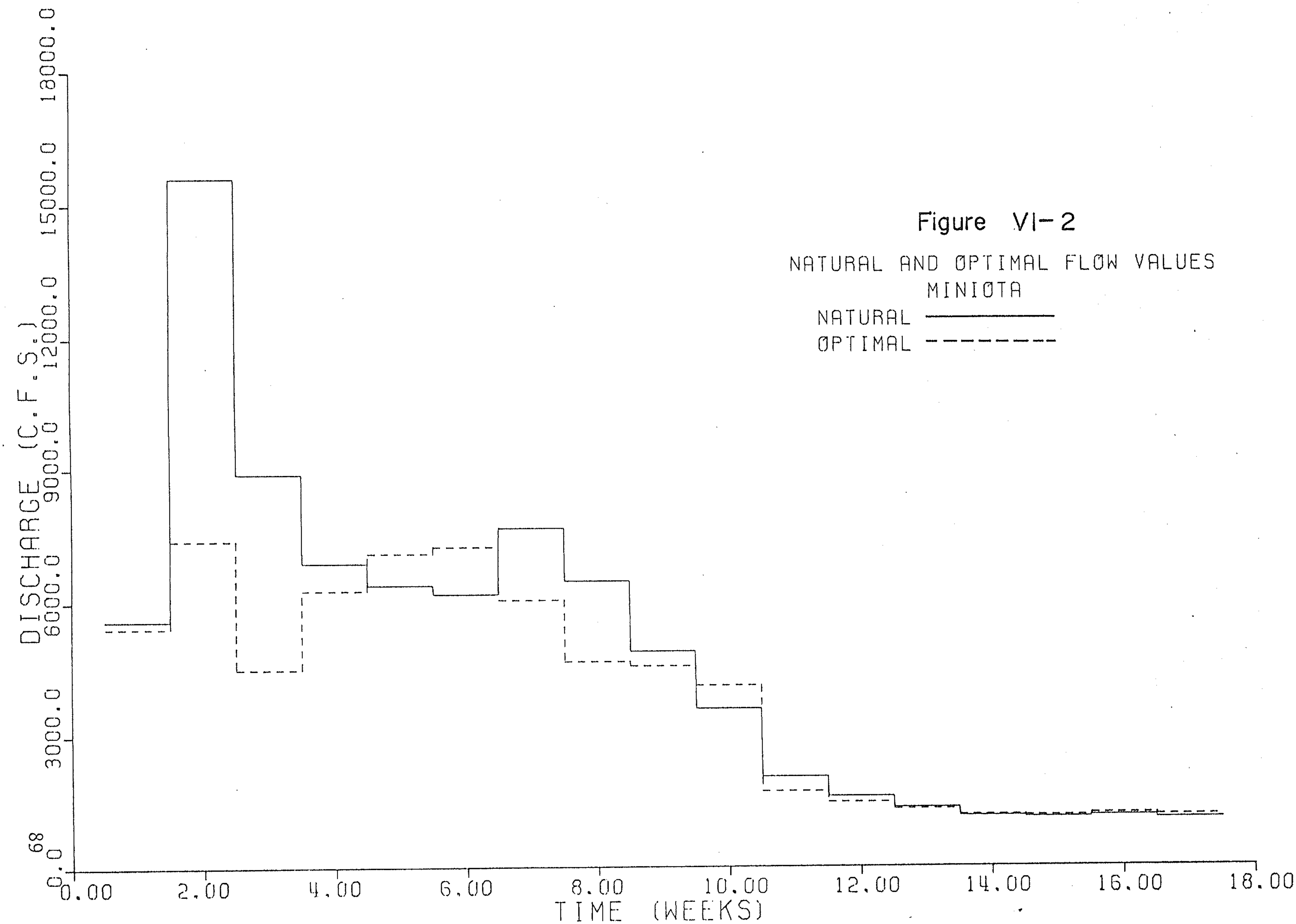


Figure VI-2
NATURAL AND ØPTIMAL FLØW VALUES
MINIØTA
NATURAL
ØPTIMAL
DISCHARGE (C.F.S.)
0.0
3000.0
6000.0
9000.0
12000.0
15000.0
18000.0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
TIME (WEEKS)

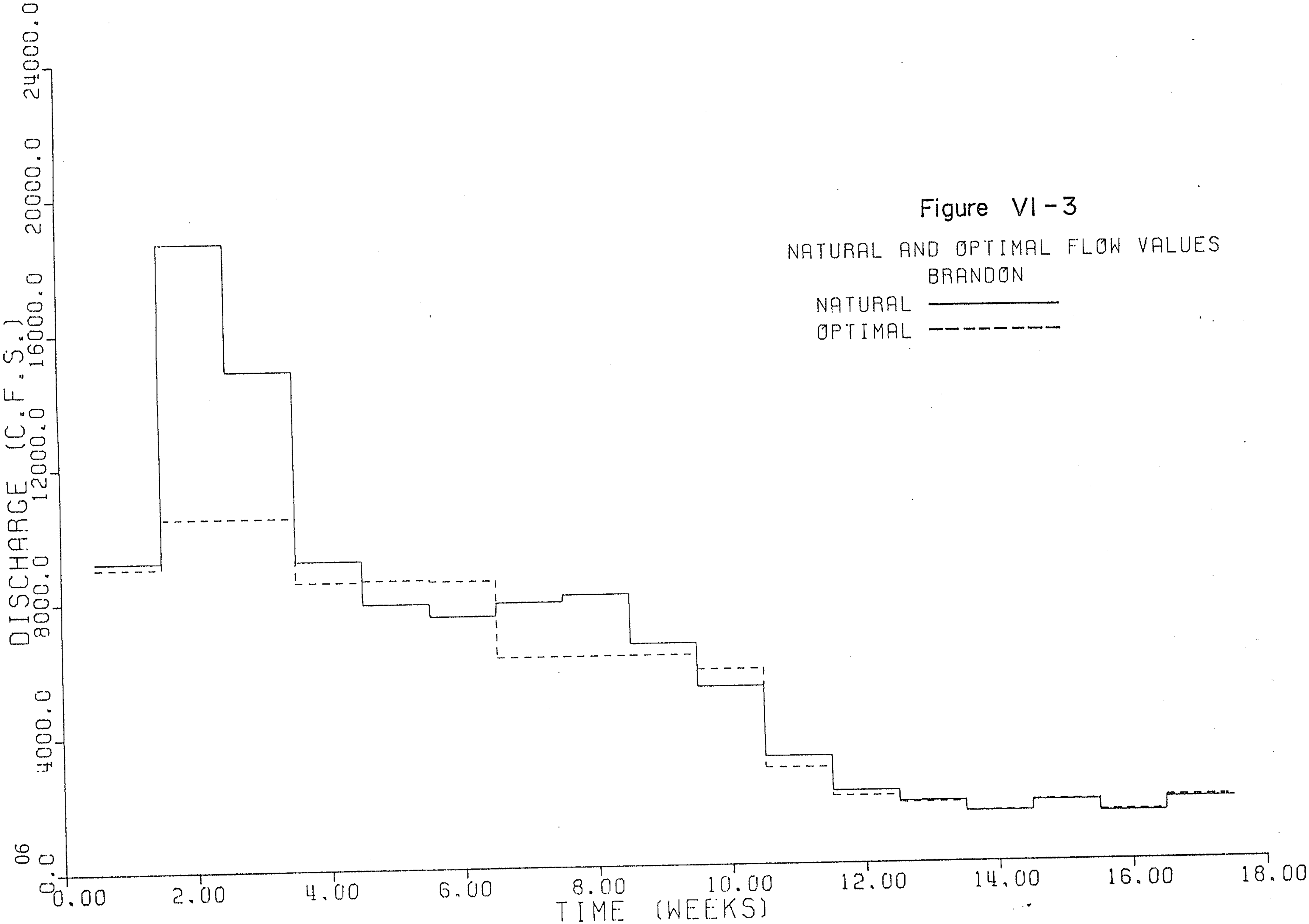

NATURAL AND ØPTIMAL FLØW VALUES
BRANDØN
NATURAL
ØPTIMAL
DISCHARGE (C.F.S.)
0.0
4000.0
8000.0
12000.0
16000.0
20000.0
24000.0
TIME (WEEKS)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

Figure VI-3

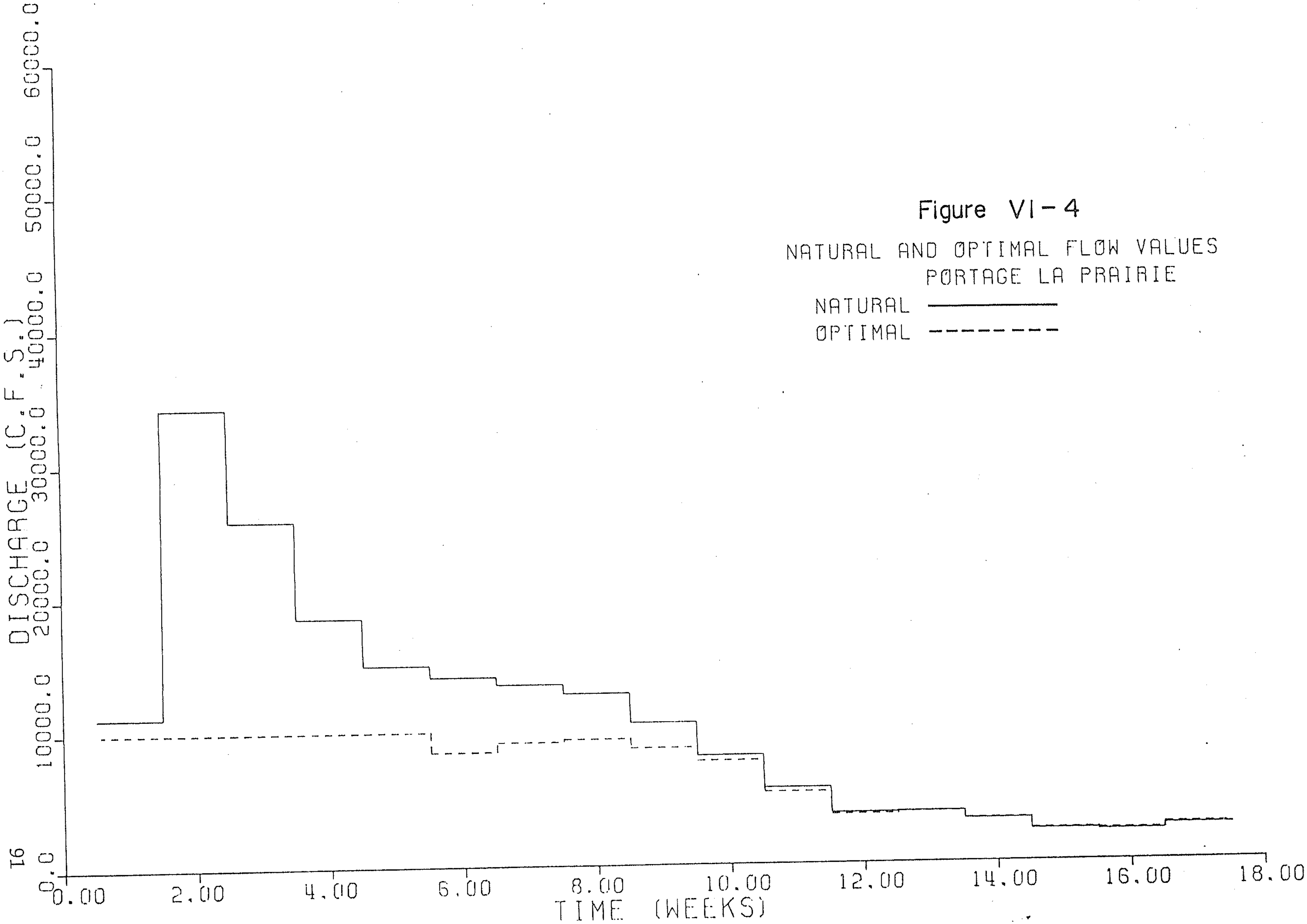

NATURAL AND ØPTIMAL FLØW VALUES
PØRTAGE LA PRAIRIE
NATURAL
ØPTIMAL
DISCHARGE (C.F.S.)
0.0
10000.0
20000.0
30000.0
40000.0
50000.0
60000.0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
TIME (WEEKS)

Figure VI-4

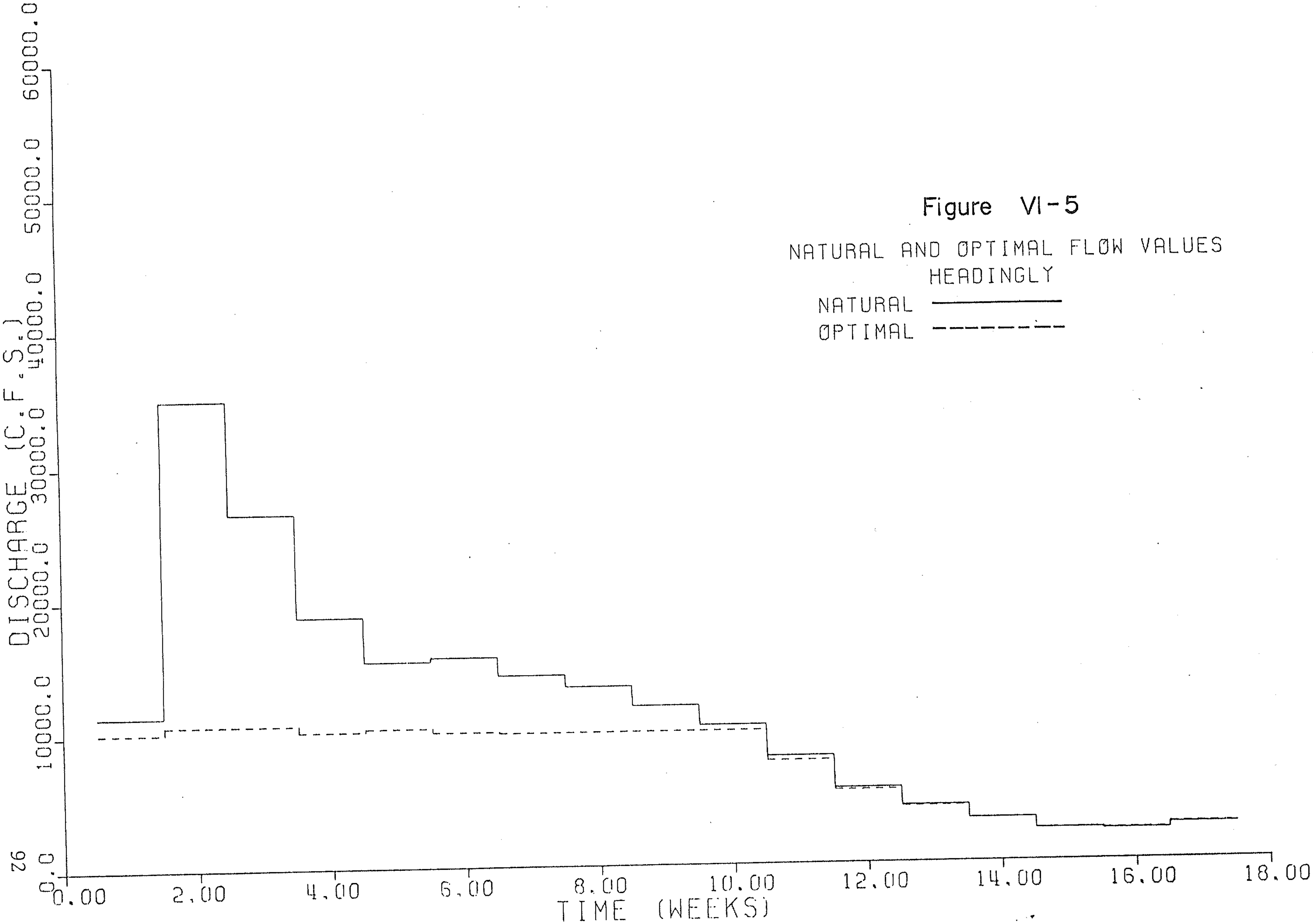

NATURAL AND OPTIMAL FLØW VALUES
HEADINGLY
NATURAL
ØPTIMAL
DISCHARGE (C.F.S.)
0.0
10000.0
20000.0
30000.0
40000.0
50000.0
60000.0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
TIME (WEEKS)

Figure VI-5

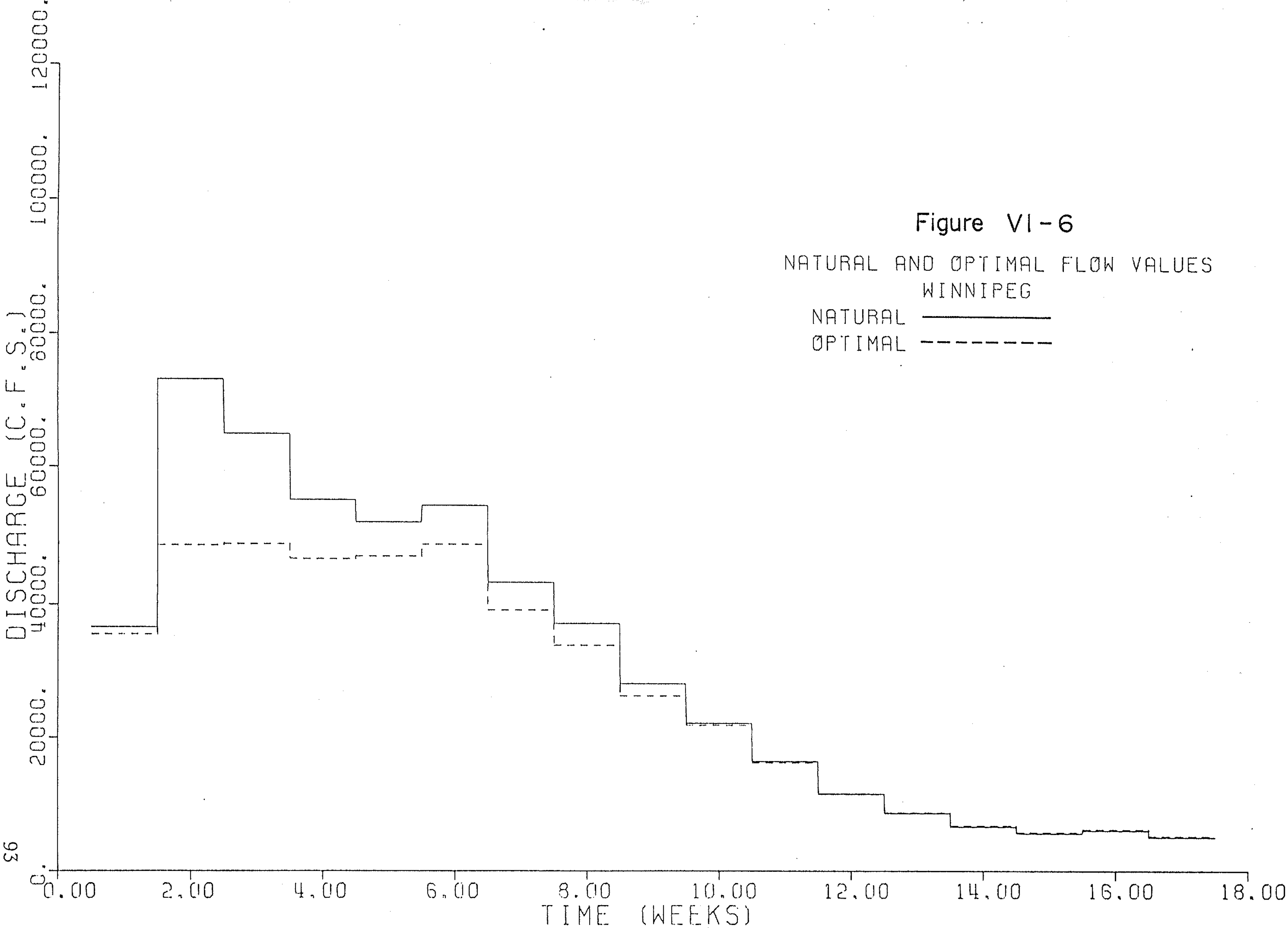

NATURAL AND ØPTIMAL FLØW VALUES
WINNIPEG
NATURAL
ØPTIMAL
DISCHARGE (C.F.S.)
0.
20000.
40000.
60000.
80000.
100000.
120000.
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
TIME (WEEKS)

Figure VI-6

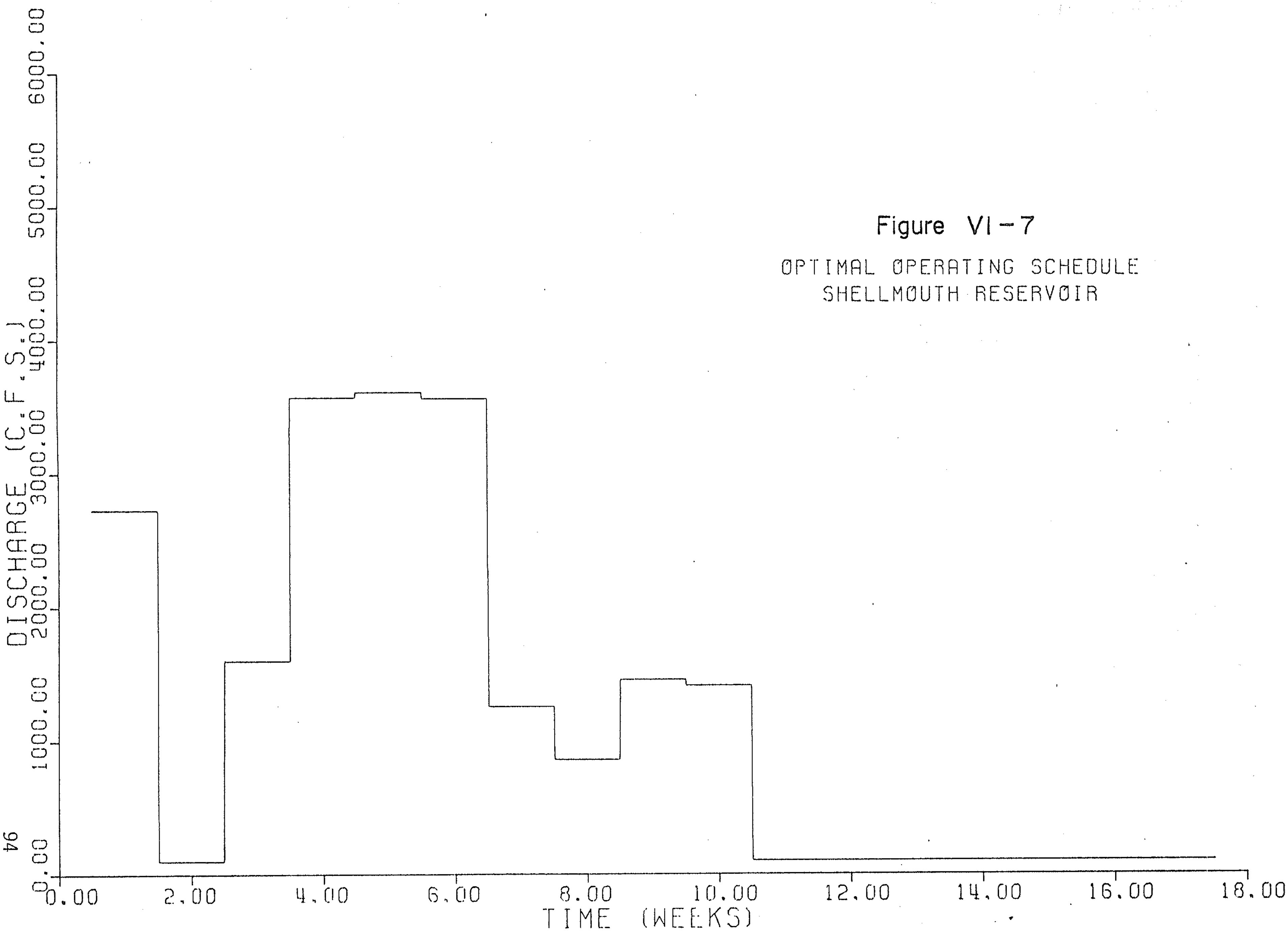


Figure VI – 7

OPTIMAL OPERATING SCHEDULE
SHELLMOUTH RESERVOIR

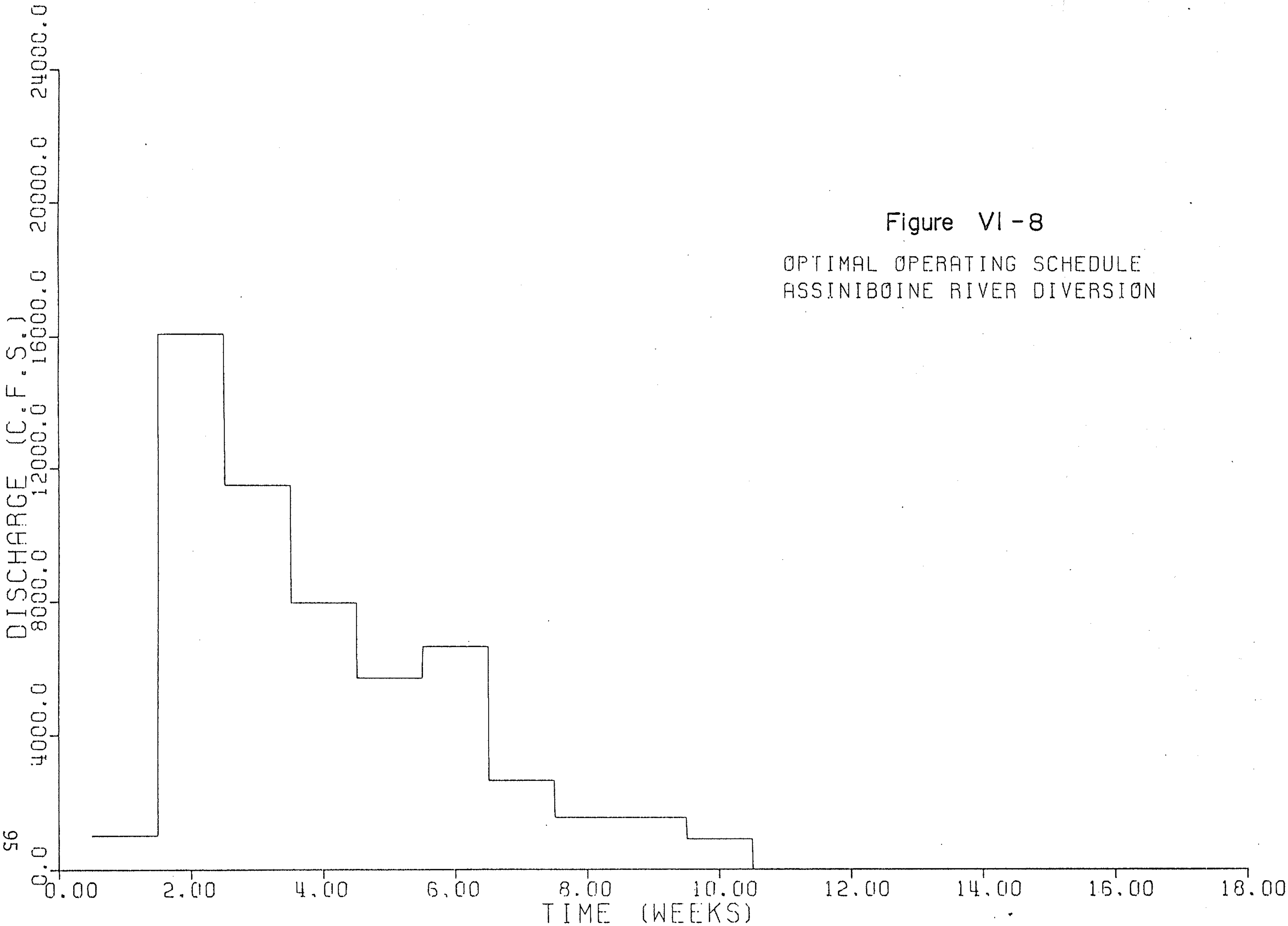


Figure VI - 8

OPTIMAL OPERATING SCHEDULE
ASSINIBOINE RIVER DIVERSION

ASSINIBOINE RIVER LINEAR PROGRAMMING FLOOD CONTROL OPTIMIZATION STUDY
FIRST DATE OF ANALYSIS...APRIL 15,1974

SYSTEM INFLOWS

TIME PERIOD	SHELLMOUTH INFLOW	SHELLMOUTH TO RUSSELL	RUSSELL TO MINIOTA	MINIOTA TO BRANDON	BRANDON TO PORTAGE LA PRAIRIE	PORTAGE LA PRAIRIE TO HEADINGLY	HEADINGLY TO WINNIPEG
1	2900.	1200.	1500.	3600.	2000.	200.	25200.
2	8300.	1200.	6100.	3100.	15600.	700.	38200.
3	6000.	100.	2800.	6000.	11000.	700.	38400.
4	4200.	300.	2400.	2300.	9400.	200.	36700.
5	2900.	300.	3200.	1500.	7100.	400.	36900.
6	2500.	300.	3400.	1300.	5600.	1600.	39000.
7	2900.	100.	4700.	200.	5600.	800.	29200.
8	2700.	100.	3700.	1600.	4700.	600.	23900.
9	1800.	100.	3000.	1700.	4000.	1300.	16300.
10	900.	100.	2600.	1700.	2800.	2300.	11900.
11	433.	0.	1619.	1151.	2455.	2368.	8536.
12	241.	0.	1363.	547.	1593.	1842.	6130.
13	143.	0.	1204.	469.	1966.	410.	4556.
14	77.	0.	1071.	343.	1695.	0.	3496.
15	64.	0.	1054.	663.	557.	0.	3330.
16	50.	0.	1100.	284.	813.	0.	3969.
17	35.	0.	1055.	731.	799.	0.	2487.

Figure VI-9
Output From Report Writer

ASSINIBOINE RIVER LINEAR PROGRAMMING FLOOD CONTROL OPTIMIZATION STUDY
FIRST DATE OF ANALYSIS...APRIL 15,1974

NATURAL(UNREGULATED) SYSTEM FLOW VALUES

TIME PERIOD	RUSSELL	MINIOTA	BRANDON	PORTAGE LA PRAIRIE	HEADINGLY	WINNIPEG
1	4100.	5600.	9200.	11200.	11400.	36600.
2	9500.	15600.	19700.	34300.	35000.	73200.
3	6100.	8900.	14300.	25900.	26600.	65000.
4	4500.	6900.	9200.	18600.	18800.	55500.
5	3200.	6400.	7900.	15000.	15400.	52300.
6	2900.	6200.	7500.	14100.	15700.	54700.
7	3000.	7700.	7900.	13500.	14300.	43500.
8	2800.	6500.	8100.	12800.	13400.	37300.
9	1900.	4900.	5600.	10600.	11900.	28200.
10	1000.	3500.	5300.	8100.	10400.	22300.
11	433.	2052.	3203.	5558.	8026.	16562.
12	241.	1604.	2151.	3744.	5585.	11666.
13	143.	1347.	1816.	3782.	4192.	8748.
14	77.	1148.	1491.	3186.	3186.	6682.
15	64.	1119.	1781.	2338.	2338.	5668.
16	50.	1150.	1434.	2247.	2247.	6116.
17	35.	1092.	1823.	2622.	2622.	5109.

Figure VI-10
Output from Report Writer

ASSINIBOINE RIVER LINEAR PROGRAMMING FLOOD CONTROL OPTIMIZATION STUDY
FIRST DATE OF ANALYSIS...APRIL 15,1974

TIME PERIOD	SHELLMOUTH RESERVOIR INFLOW	OUTFLOW	STORAGE	SYSTEM HYDROGRAPHS RUSSELL	MINIOTA	BRANDON	PORTAGE DIVERSION	PORTAGE LA PRAIRIE	HEADINGLY	WINNIPEG
1	2900.	2731.	12143.	3931.	5431.	9031.	1031.	10000.	10200.	35400.
2	8300.	100.	12312.	1300.	7400.	10500.	16100.	10000.	10700.	48900.
3	6000.	1600.	20512.	1700.	4500.	10500.	11500.	10000.	10700.	49100.
4	4200.	3574.	24912.	3874.	6274.	8574.	7974.	10000.	10200.	46900.
5	2900.	3615.	25537.	3915.	7115.	8615.	5715.	10000.	10400.	47300.
6	2500.	3568.	24832.	3868.	7268.	8568.	6658.	9500.	10100.	49100.
7	2900.	1261.	23754.	1361.	6061.	6261.	2661.	9200.	10000.	39200.
8	2700.	861.	25333.	961.	4661.	6261.	1561.	9400.	10000.	33900.
9	1830.	1461.	27233.	1561.	4561.	6261.	1561.	8700.	10000.	26300.
10	900.	1417.	27572.	1517.	4117.	5817.	917.	7700.	10000.	21900.
11	433.	100.	27055.	100.	1713.	2870.	0.	5325.	7693.	16229.
12	241.	100.	27398.	100.	1463.	2010.	0.	3603.	5445.	11525.
13	143.	100.	27529.	100.	1304.	1773.	0.	3739.	4149.	8705.
14	77.	100.	27572.	100.	1171.	1514.	0.	3209.	3209.	6705.
15	64.	100.	27549.	100.	1154.	1817.	0.	2374.	2374.	5704.
16	50.	100.	27513.	100.	1200.	1484.	0.	2297.	2297.	6166.
17	36.	100.	27463.	100.	1156.	1887.	0.	2696.	2685.	5173.

Figure VI-11
Output from Report Writer

APPENDIX A

MATRIX GENERATOR

APPENDIX A - MATRIX GENERATOR

A-1 Introduction

The matrix generator program transfers the problem under analysis from an algebraic representation of constraints and an objective function to the input format required by the linear programming solution algorithm. The matrix generator allows the flexibility of designating any variables as constants. In this manner different variables in a given analysis may easily be held to constant values in the analysis.

A-2 Program Logic

The matrix generator transforms time related families of constraints to the input format required by the linear programming solution algorithm. A time related family constraint is a constraint which has the same form with respect to the variables involved and the same coefficients over a finite number of time periods. Only the variables change in that a new variable is defined for each time period. This is illustrated as follows:

Constraint Family Name - LESS

time periods defined over - 1 to 5

Constraint Name	Constraint
LESS 1	$Q1 \leq 5000$
LESS 2	$Q2 \leq 5000$
LESS 3	$Q3 \leq 5000$
LESS 4	$Q4 \leq 5000$
LESS 5	$Q5 \leq 5000$

In this example it may be seen that the same form of the constraint is maintained over the five time periods involved but a new variable is introduced for each time period.

The matrix generator reduces constraints of the family related type to the input matrix format required by the linear programming solution algorithm.

An internal function of the matrix generator program is to transfer each constraint name and each variable in the analysis to a unique integer value in the interests of programming efficiency. A cross reference table is built for both constraint names and variables in the analysis.

In the interest of computational efficiency the matrix generator employs a transformation with regard to the previously noted constants. For any constraint containing constants, these variables are first multiplied by their corresponding coefficient and then subtracted from the right hand side of the constraint in question. In this manner the number of variables that the linear programming solution algorithm must address is reduced. The number of variables in the problem under analysis has a direct effect on computational efficiency. A listing of the program is provided on Figures A-1 to A-7 inclusive.

A-3 Capacity and Limitations

The following limitations are imposed:

1. A maximum of two hundred unique variables in the problem under analysis.
2. A maximum of sixty unique variables in any one constraint.

Problems involving either a greater number of equations or a greater number of variables in any given constraint than noted above will require minor program modifications.

A-4 Input

Sample Input is shown on Figures A-8 to A-14 inclusive. An input deck consists of the following:

1. System Initial Condition Cards

These cards define initial system conditions in the analysis, one constant per card.

Columns	Description	Example
2-5	Variable Family Name	S
7-10	Variable Time Period	1
11-20	Variable Constant Value	12143

2. Constant Value Cards

These cards define constants in the analysis, one constant per card.

Columns	Description	Example
2-5	Variable Family Name	I
7-10	Variable Time Period	1
11-20	Variable Constant Value	2900

3. Run Title Card

This card contains the alpha-numeric description of the problem under analysis.

Columns	Description	Example
1-80	Run Title	Assiniboine River L/P Flood Control Optimization Study.

4. Objective Function and Constraints

The objective function and the constraints are input to the matrix generator in the same format. The objective function is input first, prior to the problem constraints.

All constraints are identified by a constraint type as follows:

Type		Description
N	-	Objective Function
E	-	Equality Contraint: =
L	-	Less than constraint; <
LE	-	Less than or equal to constraint; ≤
GE	-	Greater than or equal to constraint; ≥
G	-	Greater than constraint; >

4.1 Constraint Name Card

Columns	Description	Example
2-5	Constraint family name	OBJT
9-10	Constraint type	N
11-20	Right Hand Side Value of constraint	Blank

4.2 Row Definition Card

Columns	Description	Example
1-10	Starting time value for row names	1
11-20	Number of time periods constraint is to be generated for	1

4.3 Variable Counter Card

Columns	Description	Example
1-10	Number of variables in constraint	54

4.4 Variable Family Name Cards

Eight variable family names may be input per card.

Columns	Description	Example
2-5	Variable family name	PA1L
7-10	Variable family name	PA2L
37-40	Variable family name	PA2H

4.5 Coefficient Card

Eight coefficients may be input per card to correspond to the variable family names on the preceding Variable Family Name Card.

Columns	Description	Example
1-10	Coefficient value	0.0
11-20	Coefficient value	0.06
71-80	Coefficient value	0.18

4.6 Variable Lower Time Qualifier Card

This card defines the lower time qualifier for each variable input on the preceding Variable Family Name Card.

Columns	Description	Example
1-10	Variable lower time qualifier	1
21-30	Variable lower time qualifier	1
71-80	Variable lower time qualifier	1

4.7 Variable Upper Time Qualifier Card

This card defines the upper time qualifier for each variable input on the preceding Variable Family Name Card.

Columns	Description	Example
1-10	Variable upper time qualifier	1
21-30	Variable upper time qualifier	1
71-80	Variable upper time qualifier	1

4.8 Fixed Value Card

This card defines whether or not the variables input on the preceding Variable Family Name Card are constants. Two types of constants are allowed as follows:

F - Fixed value variable or constant for all time periods.

F1 - Fixed value variable or constant for only the first time period.

Columns	Description	Example
1-10	Constant indicator	
11-20	Constant indicator	
71-80	Constant indicator	

4.9 Variable Upper Bound Card

This card is used to input an upper bound on all variables introduced on the preceding Variable Family Name Card.

Columns	Description	Example
1-10	Upper bound value	1500
11-20	Upper bound value	1300
71-80	Upper bound value	1300

Card types 4.1 to 4.9 are repeated as necessary to introduce and define all the variables for a given family of constraints.

Output

The resultant output from the Matrix generator program is shown on Figures A-16 to A-24b inclusive.

The printed output is in two parts. The first part is a listing of each constraint family in the analysis. Each constraint family is identified by a one to four character alphameric name. To this name an integer is added to denote which time period the constraint applies to. For example with reference to Figure A-17:

MXAL 1-6

This corresponds to the following constraints:

MXAL1

MXAL2

MXAL3

MXAL4

MXAL5

MXAL6

Each variable in the constraint is identified by a one to four character alphameric name and an integer denoted time period. With reference to Figure A-17 it may be seen that a range is given for the time period. For example:

PA1L

1 - 1

Corresponds to: PA1L1

while:

0

1 - 6

Corresponds to: 01

02

03

04

05

06

For each constraint defined by the time period indicator the variables in the constraint are defined according to their family name and their time period qualifier. With reference to Figure A-17 for constraint MXAL 1-6 the following constraints are implied:

MXAL1: -1.0 PA1L -1.0 PA21 -1.0 PA3L + 01 + LOCA1 $\leq$ 0.0

MXAL2: -1.0 PA1L -1.0 PA2L -1.0 PA3L + 02 + LOCA2 $\leq$ 0.0

MXAL3: -1.0 PA11 -1.0 PA2L -1.0 PA3L + 03 + LOCA3 $\leq$ 0.0

MXAL4: -1.0 PA1L -1.0 PA2L -1.0 PA3L + 04 + LOCA4 $\leq$ 0.0

MXAL5: -1.0 PA1L -1.0 PA2L -1.0 PA3L + 05 + LOCA5 $\leq$ 0.0

MXAL6: -1.0 PA1L -1.0 PA2L -1.0 PA3L + 06 + LOCA6 $\leq$ 0.0

As shown above each variable in the constraint is multiplied by its corresponding coefficient as shown in the row labelled "coefficient".

As noted earlier any variable in the analysis may be held constant. Any variables held constant are shown in the next row labelled "Fixed Value". A "F" indicates that the variable in question is fixed over the entire range of the constraint in question while a "F1" indicates that the variable in question is only held constant for the first time period in the analysis.

All variables are upper bounded in this analysis. The upper bound specified for each variable is shown in the next row of the output labelled "Upper Bounds".

As noted earlier all variable names and all row names are converted to integer values to facilitate the computer programming required. A cross-reference of variable names and integer representation and row names and integer representation is shown on Figures A-25 to A-31 inclusive.

The output from the matrix generator in the format required for the linear programming solution algorithm is shown on Figures A-32 to A-35 inclusive.

```
      PROGRAM MATGEN(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,
     *REF1,TAPE1=REF1,REF2,TAPE2=REF2,TAPE20,TAPE21,TAPE22,TAPE23,
     *TAPE24,TAPE88,TAPE25,MATRIX,TAPE8=MATRIX,FIXVAL,TAPE9=FIXVAL)
C
C     MATRIX GENERATOR PROGRAM
C
C     THIS PROGRAM TRANSPOSES AN ALGEBRAIC SYSTEM OF CONSTRAINTS AND
C     AN OBJECTIVE FUNCTION INTO THE INPUT FORMAT REQUIRED BY THE
C     LINEAR PROGRAMMING SOLUTION ALGORITHM. IT IS A GENERAL USE MATRIX
C     GENERATOR AND IS APPLICABLE TO ANY PROBLEM EXPRESSED IN THE
C     CORRECT INPUT FORMAT
C
      INTEGER OBJT
      INTEGER T,COUNTR
      INTEGER ROWCNT,ROW,VARIBL,FILE1,FILE2,FILE3,VAR,VARCNT
      INTEGER HILMT,CNFAM,PERIOD
      INTEGER EE
      INTEGER TEST,EEND
      INTEGER TYPE,TYPO,E,L,EQUAL,LESS,N,G,GRTR
      DIMENSION FIXED(60),UPBNDS(60),IROW(60),IVAR(8),COEFF(8),
     *BOUNDS(8),B(8),INVAR(60),HILMT(60),LOWLMT(60),COEF(60),TITLE(8)
      DIMENSION VAR(200),PERIOD(200),VALUE(200),TEST(200,3)
      DATA INDATA/8/
      DATA IN,IOUT/5,6/
      DATA E/4H    E/,L/4H    L/,LESS/4H  LE/,EQUAL/4H  EQ/,N/4H    N/,
     1G/4H    G/,GRTR/4H  GE/
      DATA E/4H    E/,EEND/4HEEND/,IOUT1/1/,IOUT2/2/
      DATA OBJT/4HOBJT/
      DATA F/10H         F/
      DATA F1/10H        F1/
C
C     INITIALIZE CROSS-REFERENCE ARRAY
C
      DO 3500 I=1,200
      TEST(I,1)=EEND
      VAR(I)=EEND
 3500 CONTINUE
C
          NVAR=0
          NROW=0
      NCN=-1
      ROW=0
      VARIBL=0
      ICNTR=0
      ICOUNT=0
      IRHSCT=0
      IRWCNT=1
      IN=1
      NTIMES=0
C
          WRITE(IOUT1,242)
          WRITE(IOUT1,240)
          WRITE(IOUT2,243)
          WRITE(IOUT2,241)
      WRITE(24,299)
C
C
```

Figure A-1
Matrix Generator Program Listing

```
C     INPUT FIXED VALUE VARIABLES
C
 3022 READ(9,102) VAR(IN),PERIOD(IN),VALUE(IN)
      IF(EOF(9)) 3020,3021
 3021 IN=IN+1
      GO TO 3022
 3020 CONTINUE
C
C     INPUT RUN TITLE CARD
C
      READ(INDATA,109) TITLE
C
C     INPUT CONSTRAINT EQUATIONS.NOTE THAT THE OBJECTIVE FUNCTION
C     IS TREATED AS THE FIRST CONSTRAINT EQUATION FOR INPUT PURPOSES.
C
C
  410 READ(INDATA,104) CNFAM,TYPE,RHS
      IF(EOF(INDATA)) 4999,4101
 4101 CONTINUE
      NTIMES=NTIMES+1
      IF(NTIMES.EQ.2) WRITE(IOUT,278)
          READ(INDATA,106) ISTART,T
          READ(INDATA,106) NV
C
C     INPUT DATA FEASIBILITY TEST
C
      IF(NV.GT.60) GO TO 901
C
          IST=1
          IEND=8
C
          DO 361 J=1,200
          IF(J.NE.1) IST=IST+8
          IF(J.NE.1) IEND=IEND+8
          IF(IEND.GT.NV) IEND=NV
          READ(INDATA,105)(INVAR(I),I=IST,IEND)
          READ(INDATA,107)(COEF(I),I=IST,IEND)
          READ(INDATA,106)(LOWLMT(I),I=IST,IEND)
          READ(INDATA,106)(HILMT(I),I=IST,IEND)
      READ(INDATA,109) (FIXED(I),I=IST,IEND)
      READ(INDATA,107)(UPBNDS(I),I=IST,IEND)
          IF(IEND.EQ.NV) GO TO 381
  361     CONTINUE
  381     CONTINUE
C
C     OUTPUT SUMMARY OF CONSTRAINT FORMS
C
      IF(CNFAM.EQ.OBJT) WRITE(IOUT,279)
          NCN=NCN+1
          IF(NCN.GT.3) WRITE(IOUT,278)
          IF(NCN.GT.3) NCN=1
          WRITE(IOUT,260) CNFAM,ISTART,T
          WRITE(IOUT,269)
          IF(TYPE.EQ.N) TYPO=EQUAL
          IF(TYPE.EQ.L) TYPO=LESS
          IF(TYPE.EQ.E) TYPO=EQUAL
          IF(TYPE.EQ.G) TYPO=GRTR
```

Figure A-2
Matrix Generator Program Listing

```
            IST=1
            IEND=8
      C
            DO 360 J=1,200
            IF(J.NE.1) IST=IST+8
            IF(J.NE.1) IEND=IEND+8
            IF(IEND.GT.NV) IEND=NV
            WRITE(IOUT,262)(INVAR(I),I=IST,IEND)
            WRITE(IOUT,295)(LOWLMT(I),HILMT(I),I=IST,IEND)
            WRITE(IOUT,264)(COEF(I),I=IST,IEND)
          WRITE(IOUT,270)(FIXED(I),I=IST,IEND)
          WRITE(IOUT,271)(UPBNDS(I),I=IST,IEND)
            IF(TYPE.EQ.N.AND.IEND.EQ.NV) WRITE(IOUT,263) TYPO
            IF(TYPE.NE.N.AND.IEND.EQ.NV) WRITE(IOUT,265) TYPO,RHS
            IF(IEND.EQ.NV) GO TO 380
        360 CONTINUE
        380 CONTINUE
      C
            ICNT=1
      C
      C     PROGRAM GOES THRU THIS DO-LOOP ONCE FOR EVERY ROW IN THE MATRIX.
      C
            DO 320 I=ISTART,T
          ROW=ROW+1
          RHSS=RHS
      C
      C     SET ROW TYPE
      C
          IF(TYPE.EQ.L) IROW(IRWCNT)=-1
          IF(TYPE.EQ.G) IROW(IRWCNT)=1
          IF(TYPE.EQ.E) IROW(IRWCNT)=0
          IF(TYPE.NE.N) IRWCNT=IRWCNT+1
          IF(IRWCNT.LE.20) GO TO 3010
          IRWCNT=1
          WRITE(22,296)(IROW(II),II=1,20)
       3010 CONTINUE
            ICNT=ICNT+1
      C
      C     PROGRAM GOES THRU THIS DO-LOOP ONCE FOR EVERY VARIABLE IN
      C     EACH ROW OF THE MATRIX.
      C
            DO 321 J=1,NV
            IF(ICNT.EQ.1) COUNTR=LOWLMT(J)
            IF(ICNT.NE.1) COUNTR=LOWLMT(J)+ICNT-1
            IF(COUNTR.GT.HILMT(J)) COUNTR=HILMT(J)
      C
      C     OUTPUT CROSS REFERENCE OF ROW NAMES
      C
            IF(J.EQ.1) NROW=NROW+1
            IF(NROW.GT.50) WRITE(IOUT1,242)
            IF(NROW.GT.50) WRITE(IOUT1,240)
            IF(NROW.GT.50) NROW=1
            IF(J.EQ.1) WRITE(IOUT1,281) CNFAM,     I,ROW
      C
      C     CHECK FOR A FIXED VALUE VARIABLE
      C
            IF(FIXED(J).EQ.F) CALL FIXVAL(INVAR(J),COUNTR,RHSCHG,VAR,PERIOD,
```

Figure A-3
Matrix Generator Program Listing

```
     *VALUE,ICHCK,COEF(J))
      IF(FIXED(J).NE.F) GO TO 3100
      IF(ICHCK.EQ.1) WRITE(6,253) INVAR(J),COUNTR
      IF(ICHCK.EQ.1) STOP
      RHSS=RHSS-RHSCHG
      GO TO 321
 3100 CONTINUE
      IF(FIXED(J).EQ.F1.AND.COUNTR.EQ.LOWLMT(J)) CALL FIXVAL(INVAR(J),
     *COUNTR,RHSCHG,VAR,PERIOD,VALUE,ICHCK,COEF(J))
      IF(FIXED(J).NE.F1.OR.COUNTR.NE.LOWLMT(J)) GO TO 3101
      IF(ICHCK.EQ.1) WRITE(6,253) INVAR(J),COUNTR
      IF(ICHCK.EQ.1) STOP
      RHSS=RHSS-RHSCHG
      GO TO 321
 3101 CONTINUE
C
C     TEST TO SEE IF VARIABLE HAS ALREADY BEEN DEFINED
C
          VARCNT=0
 3001     VARCNT=VARCNT+1
      IF(VARCNT.GT.200) GO TO 902
          IF(TEST(VARCNT,1).EQ.EEND) GO TO 4000
          IF(TEST(VARCNT,1).EQ.INVAR(J)) GO TO 3000
          GO TO 3001
 3000     IF(TEST(VARCNT,2).EQ.COUNTR) GO TO 3007
          GO TO 3001
 4000     TEST(VARCNT,1)=INVAR(J)
          TEST(VARCNT,2)=COUNTR
      VARIBL=VARIBL+1
          TEST(VARCNT,3)=VARIBL
C
C     OUTPUT CROSS REFERENCE LISTING OF VARIABLES
C
      ICNT2=ICNT2+1
      BOUNDS(ICNT2)=UPBNDS(J)
      IF(ICNT2.LT.8) GO TO 3008
      WRITE(21,213)(BOUNDS(II),II=1,8)
      ICNT2=0
 3008 NVAR=NVAR+1
          IF(NVAR.GT.50) WRITE(IOUT2,243)
          IF(NVAR.GT.50) WRITE(IOUT2,241)
          IF(NVAR.GT.50) NVAR=1
          WRITE(IOUT2,281) INVAR(J),COUNTR,VARIBL
      WRITE(25,282) INVAR(J),COUNTR,VARIBL
 3007 CONTINUE
      ICOUNT=ICOUNT+1
      IF(ICOUNT.GT.8) GO TO 3006
      IVAR(ICOUNT)=TEST(VARCNT,3)
      COEFF(ICOUNT)=COEF(J)
      GO TO 321
C
C     OUTPUT MATRIX
C
 3006 WRITE(24,212)(IVAR(II),COEFF(II),II=1,8)
      ICOUNT=1
      IVAR(ICOUNT)=TEST(VARCNT,3)
      COEFF(ICOUNT)=COEF(J)
```


Figure A-4
Matrix Generator Program Listing

```
      GO TO 321
C
  321     CONTINUE
C
C     OUTPUT MATRIX
C
      IF(ICOUNT.EQ.8) WRITE(24,212)(IVAR(II),COEFF(II),II=1,8)
      IF(ICOUNT.EQ.8) WRITE(24,290)
      IF(ICOUNT.NE.8) WRITE(24,212)(IVAR(II),COEFF(II),II=1,ICOUNT)
      ICOUNT=0
C
C
      IF(TYPE.EQ.N) GO TO 320
      IRHSCT=IRHSCT+1
      IF(IRHSCT.GT.8) GO TO 3011
      B(IRHSCT)=RHSS
      GO TO 320
 3011 WRITE(23,297)(B(II),II=1,8)
      IRHSCT=1
      B(IRHSCT)=RHSS
  320     CONTINUE
C
          GO TO 410
C
C     OUTPUT PROBLEM FO L/P
C
 4999 WRITE(20,290)
      WRITE(20,291)
      WRITE(20,292) TITLE
      WRITE(20,290)
      WRITE(20,290)
      VARIBL=VARIBL+1
      WRITE(20,294) ROW,VARIBL
C
C     OUTPUT VARIABLE BOUNDS,R.H.S.VALUES,ROW TYPES
C
      IF(ICNT2.EQ.0) GO TO 3009
      IF(ICNT2.LT.8) WRITE(21,213)(BOUNDS(II),II=1,ICNT2)
 3009 CONTINUE
      IRW=IRWCNT-1
      IF(IRWCNT.LE.20) WRITE(22,296)(IROW(II),II=1,IRW)
      IF(IRHSCT.EQ.8) WRITE(23,297)(B(II),II=1,8)
      IF(IRHSCT.NE.8) WRITE(23,297)(B(II),II=1,IRHSCT)
      GO TO 999
C
C     TERMINATION CONDITIONS
C
  901     WRITE(IOUT,251) NV
          GO TO 999
  902     WRITE(IOUT,252)
          GO TO 999
C
  999 STOP
C
C     FORMAT STATEMENTS
C
  100 FORMAT(2X,A8)
```

Figure A-5
Matrix Generator Program Listing

```
101 FORMAT(A4,I4,F12.0)
102 FORMAT(1X,A4,1X,I4,F10.0)
104 FORMAT(1X,A4,1X,A4,F10.0)
105 FORMAT( 8(1X,A4))
106 FORMAT( 8I10)
107 FORMAT (8F10.0)
109 FORMAT(8A10)
212 FORMAT(8(I3,F7.3))
213 FORMAT(8F10.1)
240 FORMAT(*-*,10X,*ROW NAME*,2X,*ROW NO.*/)
241 FORMAT(*-*,10X,*VARIABLE*,4X,*NUMBER*/)
242 FORMAT(*1*,*CROSS REFERENCE OF ROW NAMES AND L/P INPUT MATRIX ROW
   *NUMBERS*)
243 FORMAT(*1*,*CROSS REFERENCE OF VARIABLE NAMES AND L/P INPUT MATRIX
   * COLUMN NUMBERS*)
250 FORMAT(*1*,*VALUE OF T=*,I10,2X,*GREATER THAN 60.EXECUTION TERMINA
   *TED*)
251 FORMAT(*1*,*VALUE OF NV=*,I10,2X,*GREATER THAN  20.EXECUTION TERMI
   *NATED.*)
252 FORMAT(*1*,*NUMBER OF INDEPENDENT VARIABLES IN ANALYSIS EXCEEDS 20
   *0. EXECUTION TERMINATED.*)
253 FORMAT(*1*,*ERROR...FIXED VARIABLE *,A4,I4,1X,*NOT FOUND*)
255 FORMAT(*1*,*VARIABLE*,1X,A4,I4,1X,*NOT FOUND*)
256 FORMAT(*1*,*VARIABLE*,1X,A4,1X,I4,1X,*NOT FOUND.EXECUTION TERMINAT
   *ED.ATTEMPTING TO ESTABLISH UPPER BOUND*)
260 FORMAT(*-*,*CONSTRAINT NAME...*,A4,I4,1X,*-*,I4)
261 FORMAT(* *,*GENERAL CONSTRAINT FORM*)
262 FORMAT(*1*,*VARIABLE   *,10X,8(4X,A4,4X))
263 FORMAT(* *,110X,*.*,A4,2X,*.*)
264 FORMAT(* *,*COEFFICIENT*,10X,F10.3,7(2X,F10.3))
265 FORMAT(* *,110X,*.*,A4,2X,*.*,1X,F10.1)
269 FORMAT(* *,*----------------------*)
270 FORMAT(* *,*FIXED VALUE*,10X,A10,7(2X,A10))
271 FORMAT(* *,*UPPER BNDS*,11X,F10.0,7(2X,F10.0))
278 FORMAT(*1*,*SUMMARY OF CONSTRAINT FORMS*)
279 FORMAT(*1*,*OBJECTIVE FUNCTION(TREATED AS FIRST CONSTRAINT BY MATR
   *IX GENERATOR*)
281 FORMAT(* *,10X,A4,I4,I10)
282 FORMAT(1X,A4,I5,I5)
290 FORMAT(*
   *                              *)
291 FORMAT(*    1*)
292 FORMAT(8A10)
294 FORMAT(2I4)
295 FORMAT(* *,*TIME PERIOD*,10X,4X,I2,*-*,I2,1X,7(6X,I2,*-*,I2,1X))
296 FORMAT(20I4)
297 FORMAT(8F10.1)
298 FORMAT(*    1*)
    END
```


SYMBOLIC REFERENCE MAP (R=3)

Figure A-6
Matrix Generator Program Listing

```
      SUBROUTINE FIXVAL (INVAR,ICNTR,RHSCHG,VAR,PERIOD,VALUE,ICHCK,
     *COEF)
C
C     THIS SUBROUTINE FINDS THE INPUT VALUE THAT A VARIABLE IS TO BE
C     SET TO AND MODIFIES THE ROW R.H.S. VALUE BY THE NEGATIVE OF THE
C     FIXED VARIABLE VALUE TIMES THE VARIABLE COEFFICIENT.
C
      INTEGER VAR,PERIOD,EEND
      DIMENSION VAR(200),PERIOD(200),VALUE(200)
      DATA EEND/4HEEND/
C
      ICHCK=0
      ICNT=0
 3001 ICNT=ICNT+1
      IF(INVAR.EQ.VAR(ICNT)) GO TO 3000
      IF(VAR(ICNT).EQ.EEND) GO TO 999
      GO TO 3001
 3000 IF(ICNTR.EQ.PERIOD(ICNT)) GO TO 3002
      GO TO 3001
 3002 RHSCHG=VALUE(ICNT)*COEF
      RETURN
  999 ICHCK=1
      WRITE(88,200) VAR
  200 FORMAT(10(1X,A4))
      WRITE(88,201) INVAR,ICNTR
  201 FORMAT(* *,A4,I4)
      RETURN
      END
```

```
SYMBOLIC REFERENCE MAP (R=3)

ENTRY POINTS     DEF LINE     REFERENCES
  3  FIXVAL          1           21       27

VARIABLES      SN   TYPE              RELOCATION
   0  COEF          REAL                   F.P.      REFS        20    DEFINED       1
  34  EEND          INTEGER                          REFS         8        16    DEFINED       10
   0  ICHCK         INTEGER                F.P.      DEFINED      1        12        22
  53  ICNT          INTEGER                          REFS        14        15        16        18        20
                                                     DEFINED     13        14
   0  ICNTR         INTEGER                F.P.      REFS        18        25    DEFINED        1
   0  INVAR         INTEGER                F.P.      REFS        15        25    DEFINED        1
   0  PERIOD        INTEGER      ARRAY     F.P.      REFS         8         9        18    DEFINED        1
   0  RHSCHG        REAL                   F.P.      DEFINED      1        20
   0  VALUE         REAL         ARRAY     F.P.      REFS         9        20    DEFINED        1
   0  VAR           INTEGER      ARRAY     F.P.      REFS         8         9        15        16        23
                                                     DEFINED      1

FILE NAMES        MODE
   TAPE88         FMT                      WRITES       23        25
```

Figure A-7
Matrix Generator Program Listing

S	1	12143.
I	1	2900.
I	2	8300.
I	3	6000.
I	4	4200.
I	5	2900.
I	6	2500.
I	7	2900.
I	8	2700.
I	9	1800.
I	10	900.
I	11	433.
I	12	241.
I	13	143.
I	14	77.
I	15	64.
I	16	50.
I	17	36.
LOCA	01	1200.
LOCA	02	1200.
LOCA	03	100.
LOCA	04	300.
LOCA	05	300.
LOCA	06	300.
LOCA	07	100.
LOCA	08	100.
LOCA	09	100.
LOCA	10	100.
LOCA	11	0.
LOCA	12	0.
LOCA	13	0.
LOCA	14	0.
LOCA	15	0.
LOCA	16	0.
LOCA	17	0.
LOCB	01	1500.
LOCB	02	6100.
LOCB	03	2800.
LOCB	04	2400.
LOCB	05	3200.
LOCB	06	3400.
LOCB	07	4700.
LOCB	08	3700.
LOCB	09	3000.
LOCB	10	2600.
LOCB	11	1619.
LOCB	12	1363.
LOCB	13	1204.
LOCB	14	1071.
LOCB	15	1054.
LOCB	16	1100.
LOCB	17	1056.
LOCC	01	3600.
LOCC	02	3100.
LOCC	03	6000.
LOCC	04	2300.
LOCC	05	1500.
LOCC	06	1300.
LOCC	07	200.
LOCC	08	1600.
LOCC	09	1700.

Figure A-8
Input to Matrix Generator

LOCC	10	1700.
LOCC	11	1151.
LOCC	12	547.
LOCC	13	469.
LOCC	14	343.
LOCC	15	663.
LOCC	16	284.
LOCC	17	731.
LOCD	01	2000.
LOCD	02	15600.
LOCD	03	11000.
LOCD	04	9400.
LOCD	05	7100.
LOCD	06	6600.
LOCD	07	5600.
LOCD	08	4700.
LOCD	09	4000.
LOCD	10	2800.
LOCD	11	2455.
LOCD	12	1593.
LOCD	13	1966.
LOCD	14	1695.
LOCD	15	557.
LOCD	16	813.
LOCD	17	799.
LOCE	01	200.
LOCE	02	700.
LOCE	03	700.
LOCE	04	200.
LOCE	05	400.
LOCE	06	1600.
LOCE	07	800.
LOCE	08	600.
LOCE	09	1300.
LOCE	10	2300.
LOCE	11	2368.
LOCE	12	1842.
LOCE	13	410.
LOCE	14	0.
LOCE	15	0.
LOCE	16	0.
LOCE	17	0.
LOCF	01	25290.
LOCF	02	38200.
LOCF	03	38400.
LOCF	04	36700.
LOCF	05	36900.
LOCF	06	39000.
LOCF	07	29200.
LOCF	08	23900.
LOCF	09	16300.
LOCF	10	11900.
LOCF	11	8536.
LOCF	12	6080.
LOCF	13	4556.
LOCF	14	3496.
LOCF	15	3330.
LOCF	16	3869.
LOCF	17	2487.

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Figure A-9
Input to Matrix Generator

```
       1           1
      54
PA1L PA2L PA3L PA1M PA2M PA3M PA1H PA2H
      0.0        0.06        0.73        0.0        0.09        1.09        0.0        0.18
        1           1           1          1           1           1          1           1
        1           1           1          1           1           1          1           1

    1500.       1300.     100000.      1500.       1300.     100000.      1500.       1300.
PA3H PH1L PH2L PH3L PH1M PH2M PH3M PH1H
     2.18         0.0        0.05       0.62         0.0        0.06       0.93         0.0
        1           1           1          1           1           1          1           1
        1           1           1          1           1           1          1           1

  100000.       3000.       1000.    100000.       3000.       1000.    100000.       3000.
PH2H PH3H PC1L PC2L PC1M PC2M PC1H PC2H
     0.15        1.85         0.0       1.33         0.0         2.0        0.0         4.0
        1           1           1          1           1           1          1           1
        1           1           1          1           1           1          1           1

    1000.     100000.       4000.    100000.       4000.     100000.      4000.     100000.
PD1L PD2L PD1M PD2M PD1H PD2H PE1L PE2L
      0.0        0.26         0.0        0.4         0.0        0.79        0.0        0.07
        1           1           1          1           1           1          1           1
        1           1           1          1           1           1          1           1

   10000.     100000.      10000.    100000.      10000.     100000.     10000.      10000.
PE3L PE1M PE2M PE3M PE1H PE2H PE3H PF1A
      0.1         0.0         0.1       0.15         0.0         0.2        0.3         0.0
        1           1           1          1           1           1          1           1
        1           1           1          1           1           1          1           1

  100000.      10000.      10000.    100000.      10000.      10000.    100000.      70700.
PF2L PF3L PF1M PF2M PF3M PF1H PF2H PF3H
      0.4         0.4         0.0        0.4         0.4         0.0        0.4         0.4
        1           1           1          1           1           1          1           1
        1           1           1          1           1           1          1           1

   90000.     100000.      70700.     90000.     100000.      70700.     90000.     100000.
PV1L PV2L PV1M PV2M PV1H PV2H
     0.03        0.10        0.05       0.15         0.1         0.3
        1           1           1          1           1           1
        1           1           1          1           1           1

   15000.      10000.      15000.     10000.      15000.      10000.
MXAL    L         0.0
        1           6
        5
PA1L PA2L PA3L     0 LOCA
     -1.0        -1.0        -1.0        1.0         1.0
        1           1           1          1           1
        1           1           1          6           6
                                                       F
    1500.       1300.     100000.    100000.     100000.
MXAM    L         0.0
        7          10
        5
PA1M PA2M PA3M     0 LOCA
     -1.0        -1.0        -1.0        1.0         1.0
        1           1           1          7           7
        1           1           1         10          10
                                                       F
    1500.       1300.     100000.    100000.     100000.
```

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Figure A-10
Input to Matrix Generator

10553

```
MXAH     L         0.0
        11          17
         5
PA1H PA2H PA3H     0 LOCA
      -1.0       -1.0       -1.0        1.0        1.0
         1          1          1         11         11
         1          1          1         17         17
                                                     F
     1500.      1300.    100000.    100000.    100000.
MXBL     L         0.0
         1           6
         6
PB1L PB2L PB3L     0 LOCA LOCB
      -1.0       -1.0       -1.0        1.0        1.0        1.0
         1          1          1          1          1          1
         1          1          1          6          6          6
                                                     F          F
     3000.      1000.    100000.    100000.    100000.    100000.
MXBM     L         0.0
         7          10
         6
PB1M PB2M PB3M     0 LOCA LOCB
      -1.0       -1.0       -1.0        1.0        1.0        1.0
         1          1          1          7          7          7
         1          1          1         10         10         10
                                                     F          F
     3000.      1000.    100000.    100000.    100000.    100000.
MXBH     L         0.0
        11          17
         6
PB1H PB2H PB3H     0 LOCA LOCB
      -1.0       -1.0       -1.0        1.0        1.0        1.0
         1          1          1         11         11         11
         1          1          1         17         17         17
                                                     F          F
     3000.      1000.    100000.    100000.    100000.    100000.
MXCL     L         0.0
         1           6
         6
PC1L PC2L     0 LOCA LOCB LOCC
      -1.0       -1.0        1.0        1.0        1.0        1.0
         1          1          1          1          1          1
         1          1          6          6          6          6
                                          F          F          F
     4000.    100000.    100000.    100000.    100000.    100000.
MXCM     L         0.0
         7          10
         6
PC1M PC2M     0 LOCA LOCB LOCC
      -1.0       -1.0        1.0        1.0        1.0        1.0
         1          1          7          7          7          7
         1          1         10         10         10         10
                                          F          F          F
     4000.    100000.    100000.    100000.    100000.    100000.
MXCH     L         0.0
        11          17
         6
PC1H PC2H     0 LOCA LOCB LOCC
      -1.0       -1.0        1.0        1.0        1.0        1.0
         1          1         11         11         11         11
         1          1         17         17         17         17
                                          F          F          F
```

Figure A-11
Input to Matrix Generator

```
   4000.    100000.    100000.    100000.    100000.    100000.
MXDL     L        0.0
         1          6
         A
PD1L PD2L     0 LOCA LOCB LOCC LOCD DIVB
     -1.0       -1.0       1.0        1.0        1.0        1.0        1.0       -1.0
        1          1         1          1          1          1          1          1
        1          1         6          6          6          6          6          6
                                        F          F          F          F
  10000.    100000.    100000.    100000.    100000.    100000.    100000.     25000.
MXDM     L        0.0
         7         10
         8
PD1M PD2M     0 LOCA LOCF LOCC LOCD DIVR
     -1.0       -1.0       1.0        1.0        1.0        1.0        1.0       -1.0
        1          1         7          7          7          7          7          7
        1          1        10         10         10         10         10         10
                                        F          F          F          F
  10000.    100000.    100000.    100000.    100000.    100000.    100000.     25000.
MXDH     L        0.0
        11         17
         A
PD1H PD2H     0 LOCA LOCH LOCC LOCD DIVR
     -1.0       -1.0       1.0        1.0        1.0        1.0        1.0       -1.0
        1          1        11         11         11         11         11         11
                                        F          F          F          F
  10000.    100000.    100000.    100000.    100000.    100000.    100000.     25000.
MXEL     L        0.0
         1          6
        10
PE1L PE2L PE3L     0 LOCA LOCB LOCC LOCD
     -1.0       -1.0      -1.0        1.0        1.0        1.0        1.0        1.0
        1          1         1          1          1          1          1          1
        1          1         1          6          6          6          6          6
                                                   F          F          F          F
  10000.     10000.    100000.    100000.    100000.    100000.    100000.    100000.
LOCE DIVR
      1.0       -1.0
        1          1
        6          6
        F
 100000.     25000.
MXEM     L        0.0
         7         10
        10
PE1M PE2M PE3M     0 LOCA LOCB LOCC LOCC
     -1.0       -1.0      -1.0        1.0        1.0        1.0        1.0        1.0
        1          1         1          7          7          7          7          7
        1          1         1         10         10         10         10         10
                                                   F          F          F          F
  10000.     10000.    100000.    100000.    100000.    100000.    100000.    100000.
LOCF DIVR
      1.0       -1.0
        7          7
       10         10
        F
 100000.     25000.
MXEH     L        0.0
        11         17
        10
PE1H PE2H PE3H     0 LOCA LOCB LOCC LOCC
     -1.0       -1.0      -1.0        1.0        1.0        1.0        1.0        1.0
```

Figure A-12
Input to Matrix Generator

```
      1        1        1       11       11       11       11       11
      1        1        1       17       17       17       17       17
                                          F        F        F        F
  10000.   10000.  100000.  100000.  100000.  100000.  100000.  100000.
LOCE DIVH
    1.0     -1.0
     11       11
     17       17
      F
 100000.   25000.
MXFL    L     0.0
      1        6
     11
PF1L PF2L PF3L    0 LOCA LOCB LOCC LOCD
   -1.0     -1.0     -1.0      1.0      1.0      1.0      1.0      1.0
      1        1        1        1        1        1        1        1
      1        1        1        6        6        6        6        6
                                          F        F        F        F
  70700.   90000.  100000.  100000.  100000.  100000.  100000.  100000.
LOCF LOCF DIVH
    1.0      1.0     -1.0
      1        1        1
      6        6        6
      F        F
 100000.  100000.   25000.
MXFM    L     0.0
      7       10
     11
PF1M PF2M PF3M    0 LOCA LOCH LOCC LOCD
   -1.0     -1.0     -1.0      1.0      1.0      1.0      1.0      1.0
      1        1        1        7        7        7        7        7
      1        1        1       10       10       10       10       10
                                          F        F        F        F
  70700.   90000.  100000.  100000.  100000.  100000.   00000.     0
LOCE LOCF DIVH
    1.0      1.0     -1.0
      7        7        7
     10       10       10
      F        F
 100000.  100000.   25000.
MXFH    L     0.0
     11       17
     11
PF1H PF2H PF3H    0 LOCA LOCH LOCC LOCD
   -1.0     -1.0     -1.0      1.0      1.0      1.0      1.0      1.0
      1        1        1       11       11       11       11       11
      1        1        1       17       17       17       17       17
                                          F        F        F        F
  70700.   90000.  100000.  100000.  100000.  100000.  100000.  100000.
LOCF LOCF DIVR
    1.0      1.0     -1.0
     11       11       11
     17       17       17
      F        F
 100000.  100000.   25000.
MOVL    L     0.0
      1        6
      3
PV1L PV2L DIVH
   -1.0     -1.0      1.0
      1        1        1
      1        1        6
```


Figure A-13
Input to Matrix Generator

```
   15000.     10000.     25000.
MOVM     L      0.0
         7      10
         3
PV1M PV2M DIVR
     -1.0       -1.0       1.0
        1          1         7
        1          1        10

   15000.     10000.     25000.
MOVH     L      0.0
        11      17
         3
PV1H PV2H DIVR
     -1.0       -1.0       1.0
        1          1        11
        1          1        17

   15000.     10000.     25000.
WATE     L     1930.
         1      17
         2
   O     S
      1.0     -0.066
        1          1
       17         17
                  F1
  100000.    27572.
PIPA     G     100.
         1      17
         1
   O
      1.0
        1
       17

  100000.
STOR     E      0.0
         2      17
         4
   S     S    I    O
     -1.0        1.0       1.0      -1.0
        2          1         1         1
       17         16        15        16
                  F1         F
   27572.     27572.    100000.    100000.
DIVR     G      0.0
         1      17
         6
DIVR     O LOCA LOCB LOCC LOCD
     -1.0        1.0       1.0       1.0       1.0       1.0
        1          1         1         1         1         1
       17         17        17        17        17        17
                             F         F         F         F
  100000.    100000.    100000.    100000.    100000.    100000.    100000.    100000.
```

Figure A-14
Input to Matrix Generator

OBJECTIVE FUNCTION(TREATED AS FIRST CONSTRAINT BY MATRIX GENERATOR

CONSTRAINT NAME...OBJT 1 - 1

VARIABLE	PA1L	PA2L	PA3L	PA1M	PA2M	PA3M	PA1H	PA2H
TIME PERIOD	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1
COEFFICIENT	0.000	.050	.730	0.000	.090	1.090	0.000	.180
FIXED VALUE								
UPPER BNDS	1500.	1300.	100000.	1500.	1300.	100000.	1500.	1300.

VARIABLE	PA3H	PB1L	PB2L	PB3L	PB1M	PB2M	PB3M	PB1H
TIME PERIOD	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1
COEFFICIENT	2.180	0.000	.050	.620	0.000	.080	.930	0.000
FIXED VALUE								
UPPER BNDS	100000.	3000.	1000.	100000.	3000.	1000.	100000.	3000.

VARIABLE	PB2H	PB3H	PC1L	PC2L	PC1M	PC2M	PC1H	PC2H
TIME PERIOD	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1
COEFFICIENT	.150	1.850	0.000	1.330	0.000	2.000	0.000	4.000
FIXED VALUE								
UPPER BNDS	1000.	100000.	4000.	100000.	4000.	100000.	4000.	100000.

VARIABLE	PD1L	PD2L	PD1M	PD2M	PD1H	PD2H	PE1L	PE2L
TIME PERIOD	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1
COEFFICIENT	0.000	.250	0.000	.400	0.000	.790	0.000	.070
FIXED VALUE								
UPPER BNDS	10000.	100000.	10000.	100000.	10000.	100000.	10000.	10000.

VARIABLE	PE3L	PE1M	PE2M	PE3M	PE1H	PE2H	PE3H	PF1A
TIME PERIOD	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1
COEFFICIENT	.100	0.000	.100	.150	0.000	.200	.300	0.000
FIXED VALUE								
UPPER BNDS	100000.	10000.	10000.	100000.	10000.	10000.	100000.	70700.

VARIABLE	PF2L	PF3L	PF1M	PF2M	PF3M	PF1H	PF2H	PF3H
TIME PERIOD	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1
COEFFICIENT	.400	.400	0.000	.400	.400	0.000	.400	.400
FIXED VALUE								
UPPER BNDS	90000.	100000.	70700.	90000.	100000.	70700.	90000.	100000.

VARIABLE	PV1L	PV2L	PV1M	PV2M	PV1H	PV2H
TIME PERIOD	1- 1	1- 1	1- 1	1- 1	1- 1	1- 1
COEFFICIENT	.030	.100	.050	.150	.100	.300
FIXED VALUE						
UPPER BNDS	15000.	10000.	15000.	10000.	15000.	10000.

Figure A-16
Constraint Family Output

SUMMARY OF CONSTRAINT FORMS

CONSTRAINT NAME...MXAL 1 - 6

VARIABLE	PA1L	PA2L	PA3L	0	LOCA	
TIME PERIOD	1- 1	1- 1	1- 1	1- 6	1- 6	
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	
FIXED VALUE					F	
UPPER BNDS	1500.	1300.	100000.	100000.	100000.	
						. LE . 0.0

CONSTRAINT NAME...MXAM 7 - 10

VARIABLE	PA1M	PA2M	PA3M	0	LOCA	
TIME PERIOD	1- 1	1- 1	1- 1	7-10	7-10	
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	
FIXED VALUE					F	
UPPER BNDS	1500.	1300.	100000.	100000.	100000.	
						. LE . 0.0

CONSTRAINT NAME...MXAH 11 - 17

VARIABLE	PA1H	PA2H	PA3H	0	LOCA	
TIME PERIOD	1- 1	1- 1	1- 1	11-17	11-17	
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	
FIXED VALUE					F	
UPPER BNDS	1500.	1300.	100000.	100000.	100000.	
						. LE . 0.0

Figure A-17
Constraint Family Output

SUMMARY OF CONSTRAINT FORMS

CONSTRAINT NAME...XBL 1 - 6

VARIABLE	PB1L	PB2L	PB3L	0	LOCA	LOCB		
TIME PERIOD	1- 1	1- 1	1- 1	1- 6	1- 6	1- 6		
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	1.000		
FIXED VALUE					F	F		
UPPER BNDS	3000.	1000.	100000.	100000.	100000.	100000.		
							. LE .	0.0

CONSTRAINT NAME...MXBM 7 - 10

VARIABLE	PB1M	PB2M	PB3M	0	LOCA	LOCB		
TIME PERIOD	1- 1	1- 1	1- 1	7-10	7-10	7-10		
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	1.000		
FIXED VALUE					F	F		
UPPER BNDS	3000.	1000.	100000.	100000.	100000.	100000.		
							. LE .	0.0

CONSTRAINT NAME...MXBH 11 - 17

VARIABLE	PB1H	PB2H	PB3H	0	LOCA	LOCB		
TIME PERIOD	1- 1	1- 1	1- 1	11-17	11-17	11-17		
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	1.000		
FIXED VALUE					F	F		
UPPER BNDS	3000.	1000.	100000.	100000.	100000.	100000.		
							. LE .	0.0

Figure A-18
Constraint Family Output

```
SUMMARY OF CONSTRAINT FORMS

CONSTRAINT NAME...MXDL   1 -  6
----------------------

VARIABLE              PD1L      PD2L       O        LOCA      LOCB      LOCC      LOCD      DIVR
TIME PERIOD            1- 1      1- 1      1- 6      1- 6      1- 6      1- 6      1- 6      1- 6
COEFFICIENT          -1.000    -1.000     1.000     1.000     1.000     1.000     1.000    -1.000
FIXED VALUE                                              F         F         F         F
UPPER BNDS            10000.   100000.   100000.   100000.   100000.   100000.   100000.    25000.
                                                                                           .  LE  .        0.0

CONSTRAINT NAME...MXDM   7 -  10
----------------------

VARIABLE              PD1M      PD2M       O        LOCA      LOCB      LOCC      LOCD      DIVR
TIME PERIOD            1- 1      1- 1      7-10      7-10      7-10      7-10      7-10      7-10
COEFFICIENT          -1.000    -1.000     1.000     1.000     1.000     1.000     1.000    -1.000
FIXED VALUE                                              F         F         F         F
UPPER BNDS            10000.   100000.   100000.   100000.   100000.   100000.   100000.    25000.
                                                                                           .  LE  .        0.0

CONSTRAINT NAME...MXDH  11 -  17
----------------------

VARIABLE              PD1H      PD2H       O        LOCA      LOCB      LOCC      LOCD      DIVR
TIME PERIOD            1- 1      1- 1     11-17     11-17     11-17     11-17     11-17     11-17
COEFFICIENT          -1.000    -1.000     1.000     1.000     1.000     1.000     1.000    -1.000
FIXED VALUE                                              F         F         F         F
UPPER BNDS            10000.   100000.   100000.   100000.   100000.   100000.   100000.    25000.
                                                                                           .  LE  .        0.0
```

Figure A-19
Constraint Family Output

1119

SUMMARY OF CONSTRAINT FORMS

CONSTRAINT NAME...MXCL 1 - 6

VARIABLE	PC1L	PC2L	O	LOCA	LOCB	LOCC		
TIME PERIOD	1- 1	1- 1	1- 6	1- 6	1- 6	1- 6		
COEFFICIENT	-1.000	-1.000	1.000	1.000	1.000	1.000		
FIXED VALUE				F	F	F		
UPPER BNDS	4000.	100000.	100000.	100000.	100000.	100000.		
							. LE .	0.0

CONSTRAINT NAME...MXCM 7 - 10

VARIABLE	PC1M	PC2M	O	LOCA	LOCB	LOCC		
TIME PERIOD	1- 1	1- 1	7-10	7-10	7-10	7-10		
COEFFICIENT	-1.000	-1.000	1.000	1.000	1.000	1.000		
FIXED VALUE				F	F	F		
UPPER BNDS	4000.	100000.	100000.	100000.	100000.	100000.		
							. LE .	0.0

CONSTRAINT NAME...MXCH 11 - 17

VARIABLE	PC1H	PC2H	O	LOCA	LOCB	LOCC		
TIME PERIOD	1- 1	1- 1	11-17	11-17	11-17	11-17		
COEFFICIENT	-1.000	-1.000	1.000	1.000	1.000	1.000		
FIXED VALUE				F	F	F		
UPPER BNDS	4000.	100000.	100000.	100000.	100000.	100000.		
							. LE .	0.0

Figure A-20
Constraint Family Output

SUMMARY OF CONSTRAINT FORMS

CONSTRAINT NAME...MXEL 1 - 6

VARIABLE	PE1L	PE2L	PE3L	O	LOCA	LOCB	LOCC	LOCD
TIME PERIOD	1- 1	1- 1	1- 1	1- 6	1- 6	1- 6	1- 6	1- 6
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	1.000	1.000	1.000
FIXED VALUE					F	F	F	F
UPPER BNDS	10000.	10000.	100000.	100000.	100000.	100000.	100000.	100000.

VARIABLE	LOCE	DIVR
TIME PERIOD	1- 6	1- 6
COEFFICIENT	1.000	-1.000
FIXED VALUE	F	
UPPER BNDS	100000.	25000.

. LE . 0.0

CONSTRAINT NAME...MXEM 7 - 10

VARIABLE	PE1M	PE2M	PE3M	O	LOCA	LOCB	LOCC	LOCD
TIME PERIOD	1- 1	1- 1	1- 1	7-10	7-10	7-10	7-10	7-10
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	1.000	1.000	1.000
FIXED VALUE					F	F	F	F
UPPER BNDS	10000.	10000.	100000.	100000.	100000.	100000.	100000.	100000.

VARIABLE	LOCE	DIVR
TIME PERIOD	7-10	7-10
COEFFICIENT	1.000	-1.000
FIXED VALUE	F	
UPPER BNDS	100000.	25000.

. LE . 0.0

CONSTRAINT NAME...MXEH 11 - 17

VARIABLE	PE1H	PE2H	PE3H	O	LOCA	LOCB	LOCC	LOCD
TIME PERIOD	1- 1	1- 1	1- 1	11-17	11-17	11-17	11-17	11-17
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	1.000	1.000	1.000
FIXED VALUE					F	F	F	F
UPPER BNDS	10000.	10000.	100000.	100000.	100000.	100000.	100000.	100000.

VARIABLE	LOCE	DIVR
TIME PERIOD	11-17	11-17
COEFFICIENT	1.000	-1.000
FIXED VALUE	F	
UPPER BNDS	100000.	25000.

. LE . 0.0

Figure A-21
Constraint Family Output

SUMMARY OF CONSTRAINT FORMS

CONSTRAINT NAME...MXFL 1 - 6

VARIABLE	PF1L	PF2L	PF3L	O	LOCA	LOCB	LOCC	LOCD
TIME PERIOD	1- 1	1- 1	1- 1	1- 6	1- 6	1- 6	1- 6	1- 6
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	1.000	1.000	1.000
FIXED VALUE					F	F	F	F
UPPER BNDS	70700.	90000.	100000.	100000.	100000.	100000.	100000.	100000.

VARIABLE	LOCE	LOCF	DIVR
TIME PERIOD	1- 6	1- 6	1- 6
COEFFICIENT	1.000	1.000	-1.000
FIXED VALUE	F	F	
UPPER BNDS	100000.	100000.	25000.

. LE . 0.0

CONSTRAINT NAME...MXFM 7 - 10

VARIABLE	PF1M	PF2M	PF3M	O	LOCA	LOCB	LOCC	LOCD
TIME PERIOD	1- 1	1- 1	1- 1	7-10	7-10	7-10	7-10	7-10
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	1.000	1.000	1.000
FIXED VALUE					F	F	F	F
UPPER BNDS	70700.	90000.	100000.	100000.	100000.	100000.	0.	0.

VARIABLE	LOCE	LOCF	DIVR
TIME PERIOD	7-10	7-10	7-10
COEFFICIENT	1.000	1.000	-1.000
FIXED VALUE	F	F	
UPPER BNDS	100000.	100000.	25000.

. LE . 0.0

CONSTRAINT NAME...MXFH 11 - 17

VARIABLE	PF1H	PF2H	PF3H	O	LOCA	LOCB	LOCC	LOCD
TIME PERIOD	1- 1	1- 1	1- 1	11-17	11-17	11-17	11-17	11-17
COEFFICIENT	-1.000	-1.000	-1.000	1.000	1.000	1.000	1.000	1.000
FIXED VALUE					F	F	F	F
UPPER BNDS	70700.	90000.	100000.	100000.	100000.	100000.	100000.	100000.

VARIABLE	LOCE	LOCF	DIVR
TIME PERIOD	11-17	11-17	11-17
COEFFICIENT	1.000	1.000	-1.000
FIXED VALUE	F	F	
UPPER BNDS	100000.	100000.	25000.

. LE . 0.0

Figure A-22
Constraint Family Output

```
SUMMARY OF CONSTRAINT FORMS

CONSTRAINT NAME...MOVL   1 -   6
---------------------

VARIABLE                 PV1L          PV2L          DIVR
TIME PERIOD               1- 1          1- 1          1- 6
COEFFICIENT              -1.000        -1.000         1.000
FIXED VALUE
UPPER BNDS               15000.        10000.        25000.                                   . LE .        0.0


CONSTRAINT NAME...MOVM   7 -  10
---------------------

VARIABLE                 PV1M          PV2M          DIVR
TIME PERIOD               1- 1          1- 1          7-10
COEFFICIENT              -1.000        -1.000         1.000
FIXED VALUE
UPPER BNDS               15000.        10000.        25000.                                   . LE .        0.0


CONSTRAINT NAME...MOVH  11 -  17
---------------------

VARIABLE                 PV1H          PV2H          DIVR
TIME PERIOD               1- 1          1- 1         11-17
COEFFICIENT              -1.000        -1.000         1.000
FIXED VALUE
UPPER BNDS               15000.        10000.        25000.                                   . LE .        0.0
```

Figure A-23
Constraint Family Output

```
SUMMARY OF CONSTRAINT FORMS

CONSTRAINT NAME...RATE   1 -  17
----------------------

VARIABLE                   O          S
TIME PERIOD             1-17       1-17
COEFFICIENT             1.000      -.966
FIXED VALUE                           F1
UPPER BNDS            100000.     27572.                                        . LE .      1930.0

CONSTRAINT NAME...RIPA   1 -  17
----------------------

VARIABLE                   O
TIME PERIOD             1-17
COEFFICIENT             1.000
FIXED VALUE
UPPER BNDS            100000.                                                   . GE .       100.0

CONSTRAINT NAME...STOR   2 -  17
----------------------

VARIABLE                   S          S          I          O
TIME PERIOD             2-17       1-15       1-16       1-16
COEFFICIENT            -1.000      1.000      1.000     -1.000
FIXED VALUE                           F1          F
UPPER BNDS             27572.     27572.    100000.    100000.                  . EQ .         0.0
```


Figure A-24
Constraint Family Output

1453

SUMMARY OF CONSTRAINT FORMS

CONSTRAINT NAME...DIVR   1 - 17

VARIABLE	DIVR	O	LOCA	LOCB	LOCC	LOCD	
TIME PERIOD	1-17	1-17	1-17	1-17	1-17	1-17	
COEFFICIENT	-1.000	1.000	1.000	1.000	1.000	1.000	
FIXED VALUE			F	F	F	F	
UPPER BNDS	100000.	100000.	100000.	100000.	100000.	100000.	. GE . 0.0

Figure A-24b
Constraint Family Output

CROSS REFERENCE OF ROW NAMES AND L/P INPUT MATRIX ROW NUMBERS

ROW NAME		ROW NO.
CBJT	1	1
MXAL	1	2
MXAL	2	3
MXAL	3	4
MXAL	4	5
MXAL	5	6
MXAL	6	7
MXAM	7	8
MXAM	8	9
MXAM	9	10
MXAH	10	11
MXAH	11	12
MXAH	12	13
MXAH	13	14
MXAH	14	15
MXAH	15	16
MXAH	16	17
MXAH	17	18
XBL	1	19
XBL	2	20
XBL	3	21
XBL	4	22
XBL	5	23
XBL	6	24
MXBM	7	25
MXBM	8	26
MXBM	9	27
MXBH	10	28
MXBH	11	29
MXBH	12	30
MXBH	13	31
MXBH	14	32
MXBH	15	33
MXBH	16	34
MXBH	17	35
MXCL	1	36
MXCL	2	37
MXCL	3	38
MXCL	4	39
MXCL	5	40
MXCL	6	41
MXCM	7	42
MXCM	8	43
MXCM	9	44
MXCH	10	45
MXCH	11	46
MXCH	12	47
MXCH	13	48
MXCH	14	49
MXCH	15	50

Figure A-25
Row Name Cross Reference

CROSS REFERENCE OF ROW NAMES AND L/P INPUT MATRIX ROW NUMBERS

ROW NAME		ROW NO.
MXCH	16	51
MXCH	17	52
MXDL	1	53
MXDL	2	54
MXDL	3	55
MXDL	4	56
MXDL	5	57
MXDL	6	58
MXDM	7	59
MXDM	8	60
MXDM	9	61
MXDM	10	62
MXDH	11	63
MXDH	12	64
MXDH	13	65
MXDH	14	66
MXDH	15	67
MXDH	16	68
MXDH	17	69
MXEL	1	70
MXEL	2	71
MXEL	3	72
MXEL	4	73
MXEL	5	74
MXEL	6	75
MXEM	7	76
MXEM	8	77
MXEM	9	78
MXEM	10	79
MXEH	11	80
MXEH	12	81
MXEH	13	82
MXEH	14	83
MXEH	15	84
MXEH	16	85
MXEH	17	86
MXFL	1	87
MXFL	2	88
MXFL	3	89
MXFL	4	90
MXFL	5	91
MXFL	6	92
MXFM	7	93
MXFM	8	94
MXFM	9	95
MXFM	10	96
MXFH	11	97
MXFH	12	98
MXFH	13	99
MXFH	14	100

Figure A-26
Row Name Cross Reference

CROSS REFERENCE OF ROW NAMES AND L/P INPUT MATRIX ROW NUMBERS

ROW NAME		ROW NO.
MXFH	15	101
MXFH	16	102
MXFH	17	103
MOVL	1	104
MOVL	2	105
MOVL	3	106
MOVL	4	107
MOVL	5	108
MOVL	6	109
MOVM	7	110
MOVM	8	111
MOVM	9	112
MOVM	10	113
MOVH	11	114
MOVH	12	115
MOVH	13	116
MOVH	14	117
MOVH	15	118
MOVH	16	119
MOVH	17	120
RATE	1	121
RATE	2	122
RATE	3	123
RATE	4	124
RATE	5	125
RATE	6	126
RATE	7	127
RATE	8	128
RATE	9	129
RATE	10	130
RATE	11	131
RATE	12	132
RATE	13	133
RATE	14	134
RATE	15	135
RATE	16	136
RATE	17	137
RIPA	1	138
RIPA	2	139
RIPA	3	140
RIPA	4	141
RIPA	5	142
RIPA	6	143
RIPA	7	144
RIPA	8	145
RIPA	9	146
RIPA	10	147
RIPA	11	148
RIPA	12	149
RIPA	13	150

Figure A-27
Row Name Cross Reference

CROSS REFERENCE OF ROW NAMES AND L/P INPUT MATRIX ROW NUMBERS

ROW NAME		ROW NO.
RIPA	14	151
RIPA	15	152
RIPA	16	153
RIPA	17	154
STOR	2	155
STOR	3	156
STOR	4	157
STOR	5	158
STOR	6	159
STOR	7	160
STOR	8	161
STOR	9	162
STOR	10	163
STOR	11	164
STOR	12	165
STOR	13	166
STOR	14	167
STOR	15	168
STOR	16	169
STOR	17	170
CIVR	1	171
CIVR	2	172
CIVR	3	173
CIVR	4	174
CIVR	5	175
CIVR	6	176
CIVR	7	177
CIVR	8	178
CIVR	9	179
CIVR	10	180
CIVR	11	181
CIVR	12	182
CIVR	13	183
CIVR	14	184
CIVR	15	185
CIVR	16	186
CIVR	17	187

Figure A-28
Row Name Cross Reference

CROSS REFERENCE OF VARIABLE NAMES AND L/P INPUT MATRIX COLUMN NUMBERS

VARIABLE		NUMBER
PA1L	1	1
PA2L	1	2
PA3L	1	3
PA1M	1	4
PA2M	1	5
PA3M	1	6
PA1H	1	7
PA2H	1	8
PA3H	1	9
PB1L	1	10
PB2L	1	11
PB3L	1	12
PB1M	1	13
PB2M	1	14
PB3M	1	15
PB1H	1	16
PB2H	1	17
PB3H	1	18
PC1L	1	19
PC2L	1	20
PC1M	1	21
PC2M	1	22
PC1H	1	23
PC2H	1	24
PD1L	1	25
PD2L	1	26
PD1M	1	27
PD2M	1	28
PD1H	1	29
PD2H	1	30
PE1L	1	31
PE2L	1	32
PE3L	1	33
PE1M	1	34
PE2M	1	35
PE3M	1	36
PE1H	1	37
PE2H	1	38
PE3H	1	39
PF1L	1	40
PF2L	1	41
PF3L	1	42
PF1M	1	43
PF2M	1	44
PF3M	1	45
PF1H	1	46
PF2H	1	47
PF3H	1	48
PV1L	1	49
PV2L	1	50

Figure A-29
Variable Name Cross Reference

1163

CROSS REFERENCE OF VARIABLE NAMES AND L/P INPUT MATRIX COLUMN NUMBERS

VARIABLE		NUMBER
PV1M	1	51
PV2M	1	52
PV1H	1	53
PV2H	1	54
O	1	55
O	2	56
O	3	57
O	4	58
O	5	59
O	6	60
O	7	61
O	8	62
O	9	63
O	10	64
O	11	65
O	12	66
O	13	67
O	14	68
O	15	69
O	16	70
O	17	71
CIVP	1	72
CIVP	2	73
CIVP	3	74
CIVP	4	75
CIVP	5	76
CIVP	6	77
CIVP	7	78
CIVP	8	79
CIVP	9	80
CIVP	10	81
CIVP	11	82
CIVP	12	83
CIVP	13	84
CIVP	14	85
CIVP	15	86
CIVP	16	87
CIVP	17	88
PFIL	1	89
S	2	90
S	3	91
S	4	92
S	5	93
S	6	94
S	7	95
S	8	96
S	9	97
S	10	98
S	11	99
S	12	100

Figure A-30
Variable Name Cross Reference

CROSS REFERENCE OF VARIABLE NAMES AND L/P INPUT MATRIX COLUMN NUMBERS

VARIABLE	NUMBER
S 13	101
S 14	102
S 15	103
S 16	104
S 17	105

Figure A-31
Variable Name Cross Reference

1
ASSINIBOINE RIVER L/P FLOOD CONTROL OPTIMIZATION STUDY

```
187 106
   1500.0     1300.0   100000.0     1500.0     1300.0   100000.0     1500.0     1300.0
 100000.0     3000.0     1000.0   100000.0     3000.0     1000.0   100000.0     3000.0
   1000.0   100000.0     4000.0   100000.0     4000.0   100000.0     4000.0   100000.0
  10000.0   100000.0    10000.0   100000.0    10000.0   100000.0    10000.0    10000.0
 100000.0    10000.0    10000.0   100000.0    10000.0    10000.0   100000.0    70700.0
  90000.0   100000.0    70700.0    90000.0   100000.0    70700.0    90000.0   100000.0
  15000.0    10000.0    15000.0    10000.0    15000.0    10000.0   100000.0   100000.0
 100000.0   100000.0   100000.0   100000.0   100000.0   100000.0   100000.0   100000.0
 100000.0   100000.0   100000.0   100000.0   100000.0   100000.0   100000.0    25000.0
  25000.0    25000.0    25000.0    25000.0    25000.0    25000.0    25000.0    25000.0
  25000.0    25000.0    25000.0    25000.0    25000.0    25000.0    25000.0    25000.0
  70700.0    27572.0    27572.0    27572.0    27572.0    27572.0    27572.0    27572.0
  27572.0    27572.0    27572.0    27572.0    27572.0    27572.0    27572.0    27572.0
  27572.0
 -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1   1   1   1   1
  1   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   1   1   1   1   1   1   1   1   1   1   1
  1   1   1   1   1   1
  -1200.0    -1200.0     -100.0     -300.0     -300.0     -300.0     -100.0     -100.0
   -100.0     -100.0        0.0        0.0        0.0        0.0        0.0        0.0
      0.0    -2700.0    -7300.0    -2900.0    -2700.0    -3500.0    -3700.0    -4800.0
  -3800.0    -3100.0    -2700.0    -1619.0    -1363.0    -1234.0    -1071.0    -1054.0
  -1100.0    -1056.0    -5300.0   -10400.0    -8900.0    -5000.0    -5000.0    -5000.0
  -5000.0    -5400.0    -4800.0    -4400.0    -2770.0    -1910.0    -1673.0    -1414.0
  -1717.0    -1384.0    -1787.0    -8300.0   -26000.0   -19900.0   -14400.0   -12100.0
 -11600.0   -10600.0   -10100.0    -8800.0    -7200.0    -5225.0    -3503.0    -3639.0
  -3109.0    -2274.0    -2197.0    -2585.0    -8500.0   -26700.0   -20600.0   -14600.0
 -12500.0   -13200.0   -11400.0   -10700.0   -10100.0    -9500.0    -7593.0    -5345.0
  -4049.0    -3109.0    -2274.0    -2197.0    -2586.0   -33700.0   -64900.0   -59000.0
 -51300.0   -49400.0   -52200.0   -40600.0   -34600.0   -26400.0   -21400.0   -16129.0
 -11425.0    -8605.0    -6605.0    -5604.0    -6066.0    -5073.0        0.0        0.0
      0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
      0.0        0.0        0.0        0.0        0.0        0.0        0.0     2731.4
   1930.0     1931.0     1930.0     1930.0     1930.0     1930.0     1930.0     1930.0
   1930.0     1930.0     1930.0     1930.0     1930.0     1930.0     1930.0     1930.0
    100.0      100.0      100.0      100.0      100.0      100.0      100.0      100.0
    100.0      100.0      100.0      100.0      100.0      100.0      100.0      100.0
    100.0   -15043.0    -8300.0    -6000.0    -4200.0    -2300.0    -2500.0    -2900.0
  -2700.0    -1800.0     -900.0     -433.0     -241.0     -143.0      -77.0      -64.0
    -50.0    -8300.0   -26000.0   -19900.0   -14400.0   -12100.0   -11600.0   -10600.0
 -10100.0    -9800.0    -7200.0    -5225.0    -3503.0    -3639.0    -3109.0    -2274.0
  -2197.0    -2585.0
  1
  1  0.000  2   .050  3   .730  4  0.000  5   .090  6  1.090  7  0.000  8   .180
  9  2.180 10  0.000 11   .050 12   .620 13  0.000 14   .090 15   .930 16  0.000
 17   .150 18  1.850 19  0.000 20  1.330 21  0.000 22  2.000 23  0.000 24  4.000
 25  0.000 26   .250 27  0.000 28   .400 29  0.000 30   .790 31  0.000 32   .070
 33   .100 34  0.000 35   .100 36   .150 37  0.000 38   .200 39   .300 40  0.000
 41   .400 42   .400 43  0.000 44   .400 45   .400 46  0.000 47   .400 48   .400
 49   .030 50   .100 51   .050 52   .150 53   .100 54   .330
  1 -1.000  2 -1.000  3 -1.000 55  1.000
```

Figure A-32
Input Data to L/P Algorithm

1	-1.000	2	-1.000	3	-1.000	55	1.000
1	-1.000	2	-1.000	3	-1.000	57	1.000
1	-1.000	2	-1.000	3	-1.000	58	1.000
1	-1.000	2	-1.000	3	-1.000	59	1.000
1	-1.000	2	-1.000	3	-1.000	60	1.000
4	-1.000	5	-1.000	6	-1.000	61	1.000
4	-1.000	5	-1.000	6	-1.000	62	1.000
4	-1.000	5	-1.000	6	-1.000	63	1.000
4	-1.000	5	-1.000	6	-1.000	64	1.000
7	-1.000	8	-1.000	9	-1.000	65	1.000
7	-1.000	8	-1.000	9	-1.000	66	1.000
7	-1.000	8	-1.000	9	-1.000	67	1.000
7	-1.000	8	-1.000	9	-1.000	68	1.000
7	-1.000	8	-1.000	9	-1.000	69	1.000
7	-1.000	8	-1.000	9	-1.000	70	1.000
7	-1.000	8	-1.000	9	-1.000	71	1.000
10	-1.000	11	-1.000	12	-1.000	55	1.000
10	-1.000	11	-1.000	12	-1.000	56	1.000
10	-1.000	11	-1.000	12	-1.000	57	1.000
10	-1.000	11	-1.000	12	-1.000	58	1.000
10	-1.000	11	-1.000	12	-1.000	59	1.000
10	-1.000	11	-1.000	12	-1.000	60	1.000
13	-1.000	14	-1.000	15	-1.000	61	1.000
13	-1.000	14	-1.000	15	-1.000	62	1.000
13	-1.000	14	-1.000	15	-1.000	63	1.000
13	-1.000	14	-1.000	15	-1.000	64	1.000
16	-1.000	17	-1.000	18	-1.000	65	1.000
16	-1.000	17	-1.000	18	-1.000	66	1.000
16	-1.000	17	-1.000	18	-1.000	67	1.000
16	-1.000	17	-1.000	18	-1.000	68	1.000
16	-1.000	17	-1.000	18	-1.000	69	1.000
16	-1.000	17	-1.000	18	-1.000	70	1.000
16	-1.000	17	-1.000	18	-1.000	71	1.000
19	-1.000	20	-1.000	55	1.000		
19	-1.000	20	-1.000	56	1.000		
19	-1.000	20	-1.000	57	1.000		
19	-1.000	20	-1.000	58	1.000		
19	-1.000	20	-1.000	59	1.000		
19	-1.000	20	-1.000	60	1.000		
21	-1.000	22	-1.000	61	1.000		
21	-1.000	22	-1.000	62	1.000		
21	-1.000	22	-1.000	63	1.000		
21	-1.000	22	-1.000	64	1.000		
23	-1.000	24	-1.000	65	1.000		
23	-1.000	24	-1.000	66	1.000		
23	-1.000	24	-1.000	67	1.000		
23	-1.000	24	-1.000	68	1.000		
23	-1.000	24	-1.000	69	1.000		
23	-1.000	24	-1.000	70	1.000		
23	-1.000	24	-1.000	71	1.000		
25	-1.000	26	-1.000	55	1.000	72	-1.000
25	-1.000	26	-1.000	56	1.000	73	-1.000
25	-1.000	26	-1.000	57	1.000	74	-1.000
25	-1.000	26	-1.000	58	1.000	75	-1.000
25	-1.000	26	-1.000	59	1.000	76	-1.000
25	-1.000	26	-1.000	60	1.000	77	-1.000
27	-1.000	28	-1.000	61	1.000	78	-1.000
27	-1.000	28	-1.000	62	1.000	79	-1.000
27	-1.000	28	-1.000	63	1.000	80	-1.000
27	-1.000	28	-1.000	64	1.000	81	-1.000
29	-1.000	30	-1.000	65	1.000	82	-1.000
29	-1.000	30	-1.000	66	1.000	83	-1.000
29	-1.000	30	-1.000	67	1.000	84	-1.000

Figure A-33
Input Data to L/P Algorithm

29	-1.000	30	-1.000	68	1.000	85	-1.000		
29	-1.000	30	-1.000	69	1.000	86	-1.000		
29	-1.000	30	-1.000	70	1.000	87	-1.000		
29	-1.000	30	-1.000	71	1.000	88	-1.000		
31	-1.000	32	-1.000	33	-1.000	55	1.000	72	-1.000
31	-1.000	32	-1.000	33	-1.000	56	1.000	73	-1.000
31	-1.000	32	-1.000	33	-1.000	57	1.000	74	-1.000
31	-1.000	32	-1.000	33	-1.000	58	1.000	75	-1.000
31	-1.000	32	-1.000	33	-1.000	59	1.000	76	-1.000
31	-1.000	32	-1.000	33	-1.000	60	1.000	77	-1.000
34	-1.000	35	-1.000	36	-1.000	61	1.000	78	-1.000
34	-1.000	35	-1.000	36	-1.000	62	1.000	79	-1.000
34	-1.000	35	-1.000	36	-1.000	63	1.000	80	-1.000
34	-1.000	35	-1.000	36	-1.000	64	1.000	81	-1.000
37	-1.000	38	-1.000	39	-1.000	65	1.000	82	-1.000
37	-1.000	38	-1.000	39	-1.000	66	1.000	83	-1.000
37	-1.000	38	-1.000	39	-1.000	67	1.000	84	-1.000
37	-1.000	38	-1.000	39	-1.000	68	1.000	85	-1.000
37	-1.000	38	-1.000	39	-1.000	69	1.000	86	-1.000
37	-1.000	38	-1.000	39	-1.000	70	1.000	87	-1.000
37	-1.000	38	-1.000	39	-1.000	71	1.000	88	-1.000
89	-1.000	41	-1.000	42	-1.000	55	1.000	72	-1.000
89	-1.000	41	-1.000	42	-1.000	56	1.000	73	-1.000
39	-1.000	41	-1.000	42	-1.000	57	1.000	74	-1.000
89	-1.000	41	-1.000	42	-1.000	58	1.000	75	-1.000
39	-1.000	41	-1.000	42	-1.000	59	1.000	76	-1.000
89	-1.000	41	-1.000	42	-1.000	60	1.000	77	-1.000
43	-1.000	44	-1.000	45	-1.000	61	1.000	78	-1.000
43	-1.000	44	-1.000	45	-1.000	62	1.000	79	-1.000
43	-1.000	44	-1.000	45	-1.000	63	1.000	80	-1.000
43	-1.000	44	-1.000	45	-1.000	64	1.000	81	-1.000
46	-1.000	47	-1.000	48	-1.000	65	1.000	82	-1.000
46	-1.000	47	-1.000	48	-1.000	66	1.000	83	-1.000
46	-1.000	47	-1.000	48	-1.000	67	1.000	84	-1.000
46	-1.000	47	-1.000	48	-1.000	68	1.000	85	-1.000
46	-1.000	47	-1.000	48	-1.000	69	1.000	86	-1.000
46	-1.000	47	-1.000	48	-1.000	70	1.000	87	-1.000
46	-1.000	47	-1.000	48	-1.000	71	1.000	88	-1.000
49	-1.000	50	-1.000	72	1.000				
49	-1.000	50	-1.000	73	1.000				
49	-1.000	50	-1.000	74	1.000				
49	-1.000	50	-1.000	75	1.000				
49	-1.000	50	-1.000	76	1.000				
49	-1.000	50	-1.000	77	1.000				
51	-1.000	52	-1.000	78	1.000				
51	-1.000	52	-1.000	79	1.000				
51	-1.000	52	-1.000	80	1.000				
51	-1.000	52	-1.000	81	1.000				
53	-1.000	54	-1.000	82	1.000				
53	-1.000	54	-1.000	83	1.000				
53	-1.000	54	-1.000	84	1.000				
53	-1.000	54	-1.000	85	1.000				
53	-1.000	54	-1.000	86	1.000				
53	-1.000	54	-1.000	87	1.000				
53	-1.000	54	-1.000	88	1.000				
55	1.000								
56	1.000	90	-.066						
57	1.000	91	-.066						
58	1.000	92	-.066						
59	1.000	93	-.066						
60	1.000	94	-.066						
61	1.000	95	-.066						
62	1.000	96	-.066						

Figure A-34
Input Data to L/P Algorithm

63	1.000	97	-.066		
64	1.000	98	-.066		
65	1.000	99	-.066		
66	1.000	100	-.066		
67	1.000	101	-.066		
68	1.000	102	-.066		
69	1.000	103	-.066		
70	1.000	104	-.066		
71	1.000	105	-.066		
55	1.000				
56	1.000				
57	1.000				
58	1.000				
59	1.000				
60	1.000				
61	1.000				
62	1.000				
63	1.000				
64	1.000				
65	1.000				
66	1.000				
67	1.000				
68	1.000				
69	1.000				
70	1.000				
71	1.000				
90	-1.000	55	-1.000		
91	-1.000	90	1.000	56	-1.000
92	-1.000	91	1.000	57	-1.000
93	-1.000	92	1.000	58	-1.000
94	-1.000	93	1.000	59	-1.000
95	-1.000	94	1.000	60	-1.000
96	-1.000	95	1.000	61	-1.000
97	-1.000	96	1.000	62	-1.000
98	-1.000	97	1.000	63	-1.000
99	-1.000	98	1.000	64	-1.000
100	-1.000	99	1.000	65	-1.000
101	-1.000	100	1.000	66	-1.000
102	-1.000	101	1.000	67	-1.000
103	-1.000	102	1.000	68	-1.000
104	-1.000	103	1.000	69	-1.000
105	-1.000	104	1.000	70	-1.000
72	-1.000	55	1.000		
73	-1.000	56	1.000		
74	-1.000	57	1.000		
75	-1.000	58	1.000		
76	-1.000	59	1.000		
77	-1.000	60	1.000		
78	-1.000	61	1.000		
79	-1.000	62	1.000		
80	-1.000	63	1.000		
81	-1.000	64	1.000		
82	-1.000	65	1.000		
83	-1.000	66	1.000		
84	-1.000	67	1.000		
85	-1.000	68	1.000		
86	-1.000	69	1.000		
87	-1.000	70	1.000		
88	-1.000	71	1.000		

Figure A-35
Input Data to L/P Algorithm

APPENDIX B

REPORT WRITER

APPENDIX B - REPORT WRITER

B-1 Introduction

This program translates the output from the linear programming solution algorithm into a readily readable and understandable format.

B-2 Program Logic

The report writer program assembles and reduces the output from the linear programming solution algorithm into a concise meaningful format. Optimal operating schedules for the components of the Assiniboine River flood control system are presented. As well, the program calculates flows that would occur without regulation or diversion by the Assiniboine River Flood Control System. These flow values are referred to as natural flows in the report writer program. All flow values are in terms of mean c.f.s. - weeks. A listing of the program is provided on Figures B-1 to B-4 inclusive.

B-3 Capacity and Limitations

1. A maximum of twenty time periods in the analysis.
2. A maximum of one hundred twenty five unique variables in the analysis.

Problems involving either a greater number of time periods or a greater number of unique variables than noted above will require minor program modifications.

B-4 Input

Sample input to the program is shown on Figure B5.

An input deck consists of the following:

1. Date Card

This card identifies the first calendar date of the analysis. It is printed on each page of output as a sub-heading.

Columns	Description	Example
1-80	First date of analysis	April 17, 1974

2. Number of Timer Periods Card

This card inputs the number of time periods in the analysis.

Columns	Description	Example
1-10	Number of time periods	17

3. Required Variables Card(s)

This card inputs the variables required for output. One family of variables is described per card. Only non-constant variables may be requested for output.

Columns	Description	Example
2-5	Variable family name	S
6-10	Initial time period	2
11-15	Final time period	17

B-5 Output

The resultant output from the report writer program is shown on Figures B-6 to B-8 inclusive.

The first section of output, shown on Figure B-6, shows all inflows to the Assiniboine River System for the problem under analysis.

The second section of the output, shown on Figure B-7 shows the natural flow values throughout the river system for the problem under analysis.

The third section of the output, shown on Figure B-8, shows the optimal operating schedules determined for the individual flood control system components, Shellmouth Reservoir and the Assiniboine River Diversion, and the resultant flow throughout the river system.

```
      PROGRAM REPORT(TAPE1,TAPE2,INPUT,TAPE5=INPUT,TAPE3,
     *              OUTPUT,TAPE6=OUTPUT,TAPE10)
C
C     PROGRAM TO WRITE REPORT FOR ASSINIBOINE RIVER LINEAR PROGRAMMING
C     FLOOD CONTROL STUDY
C
      REAL OUTFLO,INFLO,LOCA,LOCB,LOCC,LOCC,LOCE,LOCF
      REAL NATA,NATB,NATC,NATD,NATF,NATE
      INTEGER EEND,VARNM,TEST,TESTR,HILMT,C,S,DIVRN
      DIMENSION QA(20),QB(20),QC(20),QD(20),QE(20),QF(20),TEST(125,2),
     *          TESTR(125),OUTFLO(20),STORAGE(20),DIVR(20),RESULT(125)
      DIMENSION INFLO(20),LOCA(20),LOCB(20),LOCC(20),LOCD(20),LOCE(20),
     *         LOCF(20)
      DIMENSION NATA(20),NATB(20),NATC(20),NATD(20),NATE(20),NATF(20)
      DIMENSION HEADNG(8)
      DATA O/4H    O/,S/4H    S/,DIVRN/4HDIVR/,EEND/4HEEND/
C
C     INPUT CROSS REFERENCE ARRAY
C
      ITOT=0
  400 ITOT=ITOT+1
      IF(ITOT.GT.125) GO TO 902
      READ(10,103) TEST(ITOT,1),TEST(ITOT,2),TESTR(ITOT)
      IF(EOF(10)) 401,400
  401 TEST(ITOT,1)=EEND
C
C     INPUT HEADING CARD(TO BE USED TO IDENTIFY FIRST DATE OF
C     ANALYSIS
C
      READ(5,104)(HEADNG(I),I=1,8)
C
C     INPUT INITIAL SYSTEM VALUES
C     I.E SHELLMOUTH STORAGE
C         INITIAL SHELLMOUTH OUTFLOW
C         INITIAL DIVERSION FLOW
C
      READ(3,100) STORAGE(1)
      IF(EOF(3)) 410,411
  411 READ(3,100) OUTFLO(1)
      IF(EOF(3)) 410,412
  412 READ(3,100) DIVR(1)
      IF(EOF(3)) 410,413
  413 GO TO 410
C
C     INPUT NUMBER OF TIME PERIODS IN ANALYSIS
C
  410 READ(5,101) NPRDS
C
C     INPUT SYSTEM INFLOWS
C
      DO 300 J=1,7
      DO 333 I=1,NPRDS
      IF(J.EQ.1) READ(1,100) INFLO(I)
      IF(J.EQ.2) READ(1,100) LOCA(I)
      IF(J.EQ.3) READ(1,100) LOCB(I)
      IF(J.EQ.4) READ(1,100)LOCC(I)
      IF(J.EQ.5) READ(1,100) LOCD(I)
```

Figure B-1
Report Writer Program Listing

1327

```
      IF(J.EQ.6) READ(1,100) LOCE(I)
      IF(J.EQ.7) READ(1,100) LOCF(I)
  303 CONTINUE
  300 CONTINUE
C
C     INPUT L/P RESULTS
C
      I1=1
      I2=8
  402 READ(2,102)(RESULT(I),I=I1,I2)
      IF(EOF(2)) 404,403
  403 I1=I1+8
      I2=I2+8
      GO TO 402
  404 CONTINUE
C
C     ASSEMBLE REQUIRED OUTPUT
C
      NVAR=1
  405 READ(5,103) VARNM,LOWLMT,HILMT
      IF(EOF(5)) 800,406
  406 DO 301 I=LOWLMT,HILMT
      ICNT=0
  407 ICNT=ICNT+1
      IF(TEST(ICNT,1).EQ.EEND) GO TO 900
      IF(TEST(ICNT,1).EQ.VARNM) GO TO 408
      GO TO 407
  408 IF(TEST(ICNT,2).EQ.I) GO TO 409
      GO TO 407
C
C     VARIABLE FOUND IN CROSS REFERENCE
C
  409 IF(VARNM.EQ.O) GO TO 4001
      IF(VARNM.EQ.S) GO TO 4002
      IF(VARNM.EQ.DIVRN) GO TO 4003
 4001 OUTFLO(I)=RESULT(TESTR(ICNT))
      GO TO 301
 4002 STORAGE(I)=RESULT(TESTR(ICNT))
      GO TO 301
 4003 DIVR(I)=RESULT(TESTR(ICNT))
  301 CONTINUE
      GO TO 405
C
C     CALCULATE FLOWS AT DAMAGE CENTERS
C
  800 DO 302 I=1,NPROS
      QA(I)=OUTFLO(I)+LOCA(I)
      QB(I)=QA(I)+LOCB(I)
      QC(I)=QB(I)+LOCC(I)
      QD(I)=QC(I)+LOCD(I)-DIVR(I)
      QE(I)=QD(I)+LOCE(I)
      QF(I)=QE(I)+LOCF(I)
  302 CONTINUE
C
C     CALCULATE SYSTEM NATURAL FLOWS
C
      DO 307 I=1,NPROS
```

Figure B-2
Report Writer Program Listing

```
      NATA(I)=INFLO(I)+LOCA(I)
      NATB(I)=NATA(I)+LOCB(I)
      NATC(I)=NATB(I)+LOCC(I)
      NATD(I)=NATC(I)+LOCD(I)
      NATE(I)=NATD(I)+LOCE(I)
      NATF(I)=NATE(I)+LOCF(I)
  307 CONTINUE
C
C     OUTPUT SYSTEM INFLOWS
C
      WRITE(6,250)
      WRITE(6,262)(HEADNG(I),I=1,8)
      WRITE(6,254)
      WRITE(6,255)
      WRITE(6,256)
      WRITE(6,257)
      DO 305 I=1,NPRDS
      WRITE(6,258) I,INFLO(I),LOCA(I),LOCB(I),LOCC(I),LOCD(I),LOCE(I),
     *LOCF(I)
  305 CONTINUE
C
C     OUTPUT NATURAL FLOWS
C
      WRITE(6,250)
      WRITE(6,262)(HEADNG(I),I=1,8)
      WRITE(6,261)
      WRITE(6,259)
      DO 306 I=1,NPRDS
      WRITE(6,260) I,NATA(I),NATB(I),NATC(I),NATD(I),NATE(I),NATF(I)
  306 CONTINUE
C
C     OUTPUT RESULTS
C
      WRITE(6,250)
      WRITE(6,262)(HEADNG(I),I=1,8)
      WRITE(6,251)
      WRITE(6,253)
      WRITE(6,252)
      DO 304 I=1,NPRDS
      WRITE(6,253) I,INFLO(I),OUTFLO(I),STORAGE(I),QA(I),QB(I),QC(I),
     *             CIVR(I),QD(I),QE(I),QF(I)
  304 CONTINUE
      STOP
C
C     TERMINATION CONDITIONS
C
  900 WRITE(6,270) VARNM,I
      STOP
  902 WRITE(6,271)
      STOP
C
C     FORMAT STATEMENTS
C
  100 FORMAT(10X,F10.0)
  101 FORMAT(I10)
  102 FORMAT(8F13.4)
  103 FORMAT(1X,A4,I5,I5)
```

Figure B-3
Report Writer Program Listing

```
      104 FORMAT(8A10)
      250 FORMAT(*1*,*ASSINIBOINE RIVER LINEAR PROGRAMMING FLOOD CONTROL OPT
         *IMIZATION STUDY*)
      251 FORMAT(*-*,*TIME*,5X,*SHELLMOUTH RESERVOIR*,40X,
         **SYSTEM HYDROGRAPHS*)
      252 FORMAT(*-*,            9X,*INFLOW*,2X,*OUTFLOW*,2X,*STORAGE*,
         *10X,*RUSSELL*,2X,*MINIOTA*,2X,*BRANDON*,2X,*PORTAGE DIVERSION*,
         *2X,*PORTAGE LA PRAIRIE*,2X,*HEADINGLY*,2X,*WINNIPEG*//)
      253 FORMAT(* *,I4,3X,F7.0,2X,F7.0,2X,F7.0,10X,F7.0,2X,F7.0,2X,F7.0,
         *5X,F7.0,14X,F7.0,7X,F7.0,4X,F7.0)
      254 FORMAT(*-*,*SYSTEM INFLOWS*)
      255 FORMAT(*-*,9X,*SHELLMOUTH*,2X,*SHELLMOUTH*,2X,*RUSSELL*,2X,
         **MINIOTA*,2X,*BRANDON*,12X,*PORTAGE LA PRAIRIE*,2X,*HEADINGLY*)
      256 FORMAT(* *,*TIME*,20X,*TO*,8X,*TO*,6X,*TO*,9X,*TO*,17X,*TO*,
         *18X,*TO*)
      257 FORMAT(* *,*PERIOD*,3X,*INFLOW*,7X,*RUSSELL*,3X,*MINIOTA*,2X,
         **BRANDON*,2X,*PORTAGE LA PRAIRIE*,2X,*HEADINGLY*,11X,*WINNIPEG*//)
      258 FORMAT(* *,2X,I2,6X,F7.0,5X,F7.0,3X,F7.0,2X,F7.0,7X,F7.0,13X,
         *F7.0,8X,F7.0)
      259 FORMAT(*-*,*TIME PERIOD*,2X,*RUSSELL*,2X,*MINIOTA*,2X *BRANDON*,
         *2X,*PORTAGE LA PRAIRIE*,2X,*HEADINGLY*,2X,*WINNIPEG*//)
      260 FORMAT(* *,4X,I2,7X,F7.0,2X,F7.0,2X,F7.0,8X,F7.0,8X,F7.0,4X,F7.0)
      261 FORMAT(*-*,*NATURAL(UNREGULATED) SYSTEM FLOW VALUES*)
      262 FORMAT(* *,8A10)
      263 FORMAT(* *,*PERIOD*)
      270 FORMAT(*1*,*VARIABLE*,1X,A4,I4,1X,*NOT FOUND*)
      271 FORMAT(*1*,*MORE THAN 125 VARIABLES ENCOUNTERED,EXECUTION TERMINAT
         *ED*)
          END


   SYMBOLIC REFERENCE MAP (R=3)

ENTRY POINTS    DEF LINE     REFERENCES
14422  REPORT       1

VARIABLES     SN  TYPE           RELOCATION
17212  RIVR       REAL       ARRAY          REFS       10       107       154   DEFINED       41       97
15036  DIVRN      INTEGER                   REFS        9        92   DEFINED        16
15037  SEND       INTEGER                   REFS        9        25        82   DEFINED       16
17433  HEADNG     REAL       ARRAY          REFS       15       126       139       149  DEFINED       30
15545  HILMT      INTEGER                   REFS        9        79   DEFINED        77
15547  I          INTEGER                   REFS       30        53        54        55       56       57       58
                                              59       67        85        93        95       97    3*104    3*105
                                           3*106    4*107     3*108     3*109     3*115    3*116    3*117    3*118
                                           3*119    3*120       126     8*132       139    7*143      149   11*154
                                             161  DEFINED        30        52        67       73      103      114
                                             126      131       139       142       149      153
15556  ICNT       INTEGER                   REFS       81        82        83        85       93       95       97
                                         DEFINED       80        81
15603  INFLO      REAL       ARRAY          REFS        7        12       115       132
                                         DEFINED       53
15546  ITOT       INTEGER                   REFS       21        22      3*23        25  DEF
15552  I1         INTEGER                   REFS       67        69   DEFINED        65
```

Figure B-4
Report Writer Program Listing

```
FIRST DATE OF ANALYSIS...APRIL 15,1974
        17
    S    2    17
    O    1    17
 DIVR    1    17
```

Figure B-5
Input to Report Writer

ASSINIBOINE RIVER LINEAR PROGRAMMING FLOOD CONTROL OPTIMIZATION STUDY
FIRST DATE OF ANALYSIS...APRIL 15,1974

SYSTEM INFLOWS

TIME PERIOD	SHELLMOUTH INFLOW	SHELLMOUTH TO RUSSELL	RUSSELL TO MINIOTA	MINIOTA TO BRANDON	BRANDON TO PORTAGE LA PRAIRIE	PORTAGE LA PRAIRIE TO HEADINGLY	HEADINGLY TO WINNIPEG
1	2900.	1200.	1500.	3600.	2000.	200.	25200.
2	9300.	1200.	6100.	3100.	15500.	700.	38200.
3	6000.	100.	2800.	6000.	11000.	700.	38400.
4	4200.	300.	2400.	2300.	9400.	200.	36700.
5	2900.	300.	3200.	1500.	7100.	400.	36900.
6	2500.	300.	3400.	1300.	6600.	1600.	39000.
7	2900.	100.	4700.	200.	5500.	800.	29200.
8	2700.	100.	3700.	1600.	4700.	600.	23900.
9	1800.	100.	3000.	1700.	4000.	1300.	16300.
10	900.	100.	2600.	1700.	2800.	2300.	11900.
11	433.	0.	1619.	1151.	2455.	2368.	8536.
12	241.	0.	1363.	547.	1593.	1842.	6130.
13	143.	0.	1204.	469.	1966.	410.	4556.
14	77.	0.	1071.	343.	1595.	0.	3496.
15	64.	0.	1054.	663.	557.	0.	3330.
16	50.	0.	1100.	284.	813.	0.	3959.
17	36.	0.	1055.	731.	799.	0.	2487.

Figure B-6
Report Writer Output

ASSINIBOINE RIVER LINEAR PROGRAMMING FLOOD CONTROL OPTIMIZATION STUDY
FIRST DATE OF ANALYSIS...APRIL 15,1974

NATURAL(UNREGULATED) SYSTEM FLOW VALUES

TIME PERIOD	RUSSELL	MINIOTA	BRANDON	PORTAGE LA PRAIRIE	HEADINGLY	WINNIPEG
1	4100.	5600.	9200.	11200.	11400.	36600.
2	9500.	15600.	19700.	34300.	35000.	73200.
3	6100.	8900.	14900.	25900.	26600.	65000.
4	4500.	6900.	9200.	19600.	18800.	55500.
5	3200.	5400.	7900.	15000.	15400.	52300.
6	2900.	6200.	7500.	14100.	15700.	54700.
7	3000.	7700.	7900.	13500.	14300.	43500.
8	2800.	6500.	8100.	12800.	13400.	37300.
9	1900.	4300.	5600.	10600.	11900.	28200.
10	1000.	3600.	5300.	8100.	10400.	22300.
11	433.	2052.	3203.	5658.	8026.	16562.
12	241.	1604.	2151.	3744.	5585.	11666.
13	143.	1347.	1815.	3782.	4192.	8748.
14	77.	1148.	1491.	3186.	3186.	6682.
15	64.	1118.	1781.	2338.	2338.	5668.
16	50.	1150.	1434.	2247.	2247.	6116.
17	35.	1092.	1923.	2622.	2622.	5109.

Figure B-7
Report Writer Output

ASSINIBOINE RIVER LINEAR PROGRAMMING FLOOD CONTROL OPTIMIZATION STUDY
FIRST DATE OF ANALYSIS...APRIL 15,1974

SYSTEM HYDROGRAPHS

TIME PERIOD	SHELLMOUTH RESERVOIR INFLOW	OUTFLOW	STORAGE	RUSSELL	MINIOTA	BRANDON	PORTAGE DIVERSION	PORTAGE LA PRAIRIE	HEADINGLY	WINNIPEG
1	2900.	2731.	12143.	3931.	5431.	9031.	1031.	10000.	10200.	35400.
2	8300.	100.	12312.	1300.	7400.	10500.	16100.	10000.	10700.	48900.
3	6020.	1600.	20512.	1700.	4500.	10500.	11500.	10000.	10700.	49100.
4	4200.	3574.	24912.	3874.	6274.	8574.	7974.	10000.	10200.	46900.
5	2900.	3615.	25537.	3915.	7115.	8615.	5715.	10000.	10400.	47300.
6	2500.	3568.	24822.	3868.	7268.	8568.	6658.	8500.	10100.	49100.
7	2900.	1261.	23754.	1361.	6061.	6261.	2661.	9200.	10000.	39200.
8	2700.	861.	25333.	961.	4661.	6261.	1561.	9400.	10000.	33900.
9	1810.	1461.	27233.	1561.	4561.	6261.	1561.	8700.	10000.	26300.
10	900.	1417.	27572.	1517.	4117.	5817.	917.	7700.	10000.	21900.
11	433.	100.	27055.	100.	1719.	2870.	0.	5325.	7693.	16229.
12	241.	100.	27388.	100.	1463.	2010.	0.	3603.	5445.	11525.
13	143.	100.	27529.	100.	1304.	1773.	0.	3739.	4149.	8705.
14	77.	100.	27572.	100.	1171.	1514.	0.	3209.	3209.	6705.
15	64.	100.	27549.	100.	1154.	1817.	0.	2374.	2374.	5704.
16	50.	100.	27513.	100.	1203.	1484.	0.	2297.	2297.	6156.
17	36.	100.	27463.	100.	1156.	1887.	0.	2686.	2685.	5173.

Figure B-8
Report Writer Output

-1573

BIBLEOGRAPHY

BIBLEOGRAPHY

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