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FRASER RIVER
UPSTREAM STORAGE STUDY

MATHEMATICAL SIMULATION MODEL FOR FLOOD REGULATION STUDIES

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Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

FRASER RIVER UPSTREAM STORAGE STUDY

TASKS #5 and #7

Define and Develop Mathematical Simulation Models for Flood Regulation Studies

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ABSTRACT

The development and use of mathematical models for flood routing in the Fraser River basin are described. The initial use of the "SSARR" computer program is discussed and a brief description of the river routing portions of that program is provided along with an evaluation of the SSARR program in terms of the needs of the Fraser River Upstream Storage Study. The subsequent development and use in these studies of a new streamflow modelling computer program known as "SIMPAK" is documented and examples of the program's operation are provided. A user's manual for the SIMPAK program is included. The report tabulates all the routing parameters and the model configurations required to apply either the SSARR or the SIMPAK programs to the Fraser River system.

RESUME

L'élaboration et l'utilisation des modèles mathématiques pour le calcul de la propagation des crues dans le fleuve Fraser sont décrites. La première utilisation du programme machine "SGARR" est examinée et une courte description des parties prévisionnelles d'un cours d'eau de ce programme est fournie y compris une évaluation du programme SSARR en fonction des besoins de l'étude de la retenue des eaux d'amont du fleuve Fraser. L'élaboration et l'utilisation ultérieures dans ces études d'un nouveau programme machine de modélisation d'un écoulement connu sous le nom de "SIMPAK" est documenté et des exemples de l'opération du programme sont fournis. Un manuel pour les usagers du programme SIMPAK est inclu.

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FRASER RIVER UPSTREAM STORAGE STUDY

Define and Develop Mathematical Simulation Models for Flood Regulation Studies

(Tasks #5 and #7)

1. Introduction

This report covers two tasks of the Fraser River Upstream Storage Study; Task #5, "Define Mathematical Simulation Models", and Task #7, "Develop Mathematical Model for Flood Regulation Studies". The first of these, Task #5, had the objective to assess the suitability of the SSARR (Streamflow Synthesis and Reservoir Regulation) computer model and determine whether a simpler model was needed. The second, Task #7, had the objective to develop a mathematical model of the Fraser basin that would be suitable to process flow data and to simulate a manner of reservoir operation for flood control that is equivalent to present day operating methods. Task #5 and the first part of Task #7, development of a mathematical model to process flow data, were carried out concurrently. Since they are highly inter-related, both these tasks are included in this report.

The second part of the Task #7 objective, to simulate a manner of reservoir operation that is equivalent to present day operating methods, was carried out separately by testing and refining procedures of reservoir regulation along with the modelling procedures developed to process flow data. The development of those regulating procedures has been carried out as a part of Task #35, "Test Simulation Models and Carry Out Detailed Studies", and will be included in the documentation of that task.

This report deals with the development and use of streamflow modelling computer programs for the Fraser River Upstream Storage Study The work was preceded by the adaptation of the U.S. Corps of Engineers' SSARR program to the computer system at the University of British Columbia. This computer program was then used to develop a flood routing mathematical model of the main-stem Fraser and Thompson Rivers. This model was used for preliminary tests of flood routing in the Fraser basin.

The preliminary use of the SSARR model indicated that a simpler program could be developed that would carry out similar river modelling functions, but in a manner more suited to the limited needs of the upstream storage studies. Subsequently, the SIMPAK computer modelling package for river simulation was developed. The SIMPAK program formed the basic framework for all modelling studies and was utilized in all regulation studies.

This report briefly describes the use of the SSARR computer program in preliminary Fraser River flood routing studies and defines the mathematical model that is used in that program to simulate the Fraser and Thompson Rivers. The report also describes the SIMPAK computer program, defines the mathematical models used in it for these studies and gives an example of the program's use. A User's Manual describing the use of the SIMPAK program is included as an appendix to this report.

2. SSARR Program

2.1 General Description

The Streamflow Synthesis and Reservoir Regulation (SSARR) computer program was developed by the U.S. Army Corps of Engineers and has been utilized in modelling streamflows in many areas around the world. The program has been used extensively in studies of the Columbia River basin and is currently used in forecasting flows for the operation of reservoirs on the Columbia River basin. The program is well suited to the task of modelling the Fraser River Basin.

The SSARR computer program is a generalized streamflow modelling system which contains several computational routines that each simulate a given hydrologic function. Each of these routines can be "called" with different parameters so that it may be used to simulate the hydrologic function in any given area by inputting the correct values of the parameters for that area. Each of these hydrologic functions operates on an input to produce an output; for example, a basin routing function operates on inputs of meteorological data to produce an output record of water discharge from the basin. Likewise, a reach routing function operates on an input of discharge at the upstream end of a river reach to produce an output discharge at the lower end of the reach.

The principal hydrologic functions in the program are listed below:

i) basin routing using meteorological data as input to produce a simulated basin runoff,

ii) river channel routing which simulates the attenuating action of a reach of river channel,

iii) lake routing which computes the outflows from a free-flow lake, knowing the inflows,

iv) reservoir routing which computes the outflow, elevation and current storage level of a reservoir, knowing the inflow to the reservoir as well as values for any one of these parameters as a control function,

v) extension of data through use of correlation curves relating the flows at two stations.

As well as these hydrological functions, the program handles many simple arithmetic operations such as adding the flows from two or more stations, subtracting one station's flows from another to determine the local inflow between them, converting the discharge at a station to the equivalent water elevation with or without backwater considerations, scaling the data values at a station by a constant factor, etc. All these operations are controlled by the configuration of the input basin model. The program automatically finds the correct data for each station and keeps track of all timing of the data (aligns data to the correct dates). Any time increments can be used and the program will interpolate within the input data to compute the applicable data values for those time increments.

Each component of the model is considered by the computer program as a "station". Stations may have several different functions, for example some stations simply hold data that has been input to the computer, others compute the outflow from a lake or channel section of a river, and others simply add together the data held in two or more other stations. Each station is identified by a station number which identifies all data associated with that component of the model.

The program outputs the data in a convenient form only at stations specified by the user. For the specified station, the discharge, elevation and storage values are listed, one value for each time increment. The program will also plot any data in the form of a computer printer-plot when specified.

All computations in the program are controlled and scheduled by the basin model. This model is input to the program in the form of control data made mainly of "characteristic data" and "configuration data" The basic framework of the model is given by the configuration data, while the type of operation to be performed at each station, and the parameter values to be used in these operations, are defined in the characteristic data.

The configuration data gives the linkages among all the stations in the model. These linkages are specified by showing for each station, all the other stations in the model which use the data from that station. The program then picks up all the required data from other stations according to the configuration list when computing the operations at each station. Care must be taken in setting up the model that each station is defined in the configuration list ahead of all other stations to which it is linked.

For each station in the model there is characteristic data input that tells the program what function is to be computed for that station and gives the values for the parameters required in the function. This characteristic data includes tables of storage/elevation relationships and backwater relationships where required. In other words, all the data required to fully define the characteristics of a part of the river model is input to the program as characteristic data for the station that represents that part of the basin.

By combining the characteristic data at each station with the configuration data, a full model of the basin is defined. The program works in sequence through the station configuration, computing the functions for each station, using as input to each function either the output from other stations as specified by the configuration list, or if there is no link with an upstream station, picking up input for the station from the input data file.

In this way the SSARR program provides a general framework in which any model can be set up to simulate the discharge characteristics of a river.

2.2 SSARR Routing Methods

In using the SSARR program for Fraser River Upstream Storage Study, only the river routing functions were utilized and no consideration was given to the basin routing portion of the program. Thus, no discussion will be provided here for the basin routing methods of the program. The following discussion describes briefly the operation of the lake routing, reservoir routing and channel (or reach) routing portions of the program. Much of this discussion has been abstracted from reference #3.

Routing streamflow through lakes or reservoirs on the basis of free-flow conditions may be applied wherever the relationship between discharge and storage is known. This relationship is fixed and can be determined for any uncontrolled lake or for a reservoir in which the discharge through the outlets is dependent only upon the water level of the reservoir. For free flow routing, the basic routing method relies on the law of continuity in the storage equation:

$$\left[\frac{I_1 + I_2}{2}\right] t - \left[\frac{O_1 + O_2}{2}\right] t = S_2 - S_1$$

where:

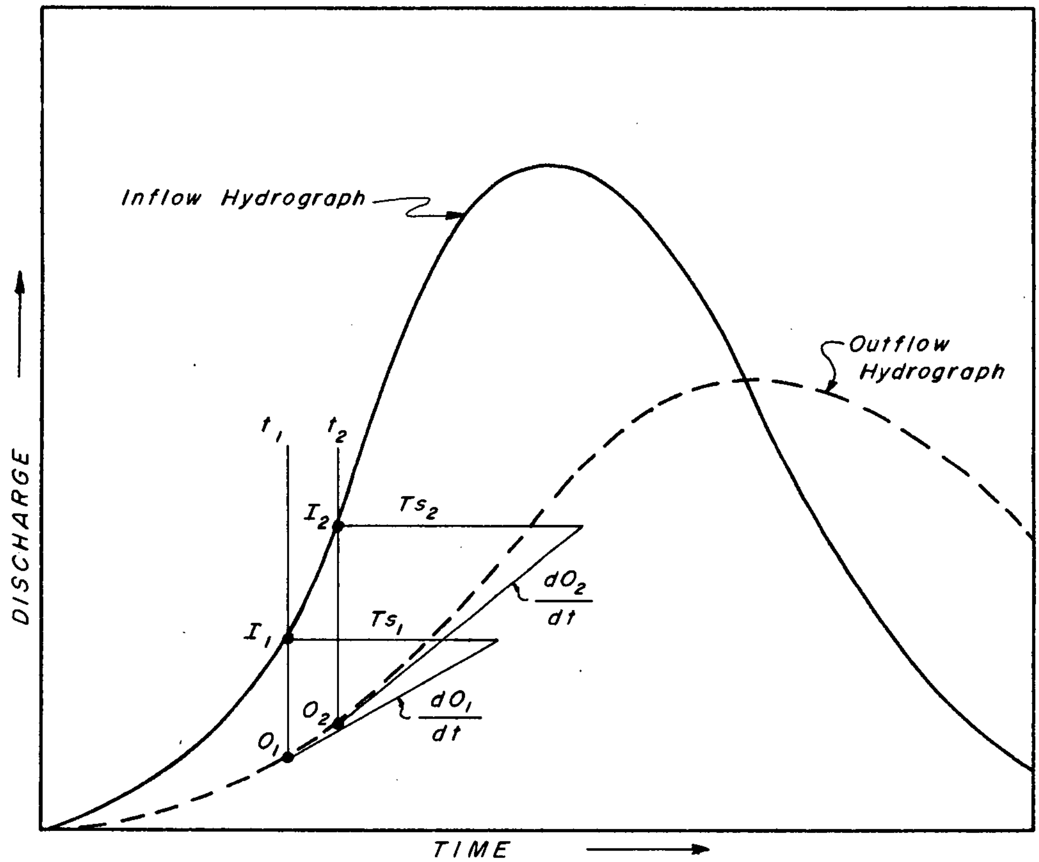
I = inflow

O = outflow

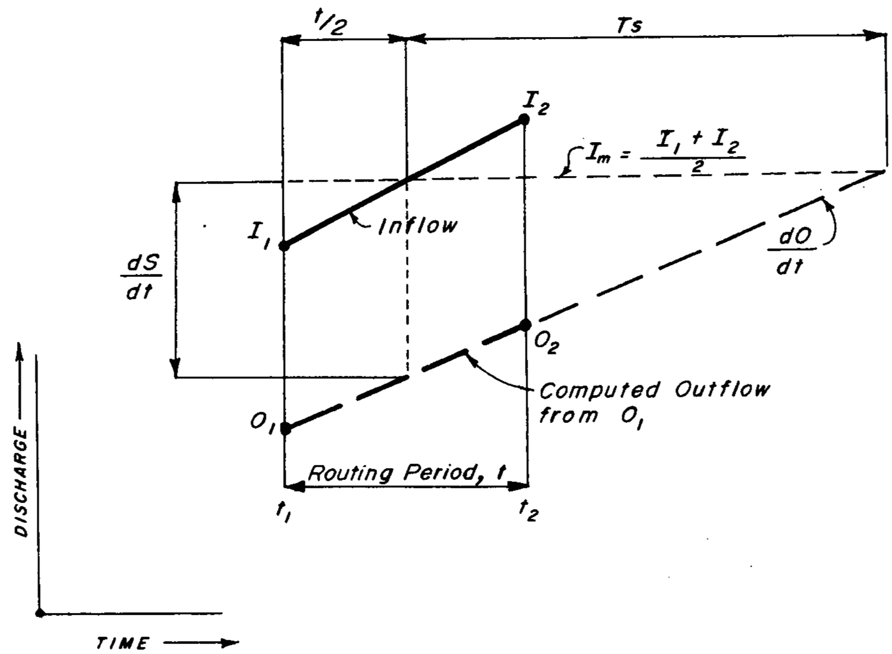
S = storage

The subscripts 1 and 2 refer to values at the beginning and end of the finite time period t.

In natural lakes or short reaches of channels, where wedge storage is negligible in comparison with prismatic storage, storage is a function of outflow, and T_s represents the proportionality factor as shown schematically below:



Each free-flow routing operation is carried out completely before proceeding to the next station in the model. In other words, the computations for all days in the run will be completed at a station before proceeding to the next station. However, in the case of reach routing stations, the computations may be broken into several sub-reaches or "increments of storage". Within the operations at one station, the computer operates on each specified increment of storage consecutively for one period at a time. The mathematical process by which routing is performed for one increment of storage for one period is illustrated in the following diagram:



The outflow (0_2) at the end of the period, for given values of inflow ($I_m = (I_1 + I_2)/2$) and outflow (0_1) at the beginning of the period, is given by

$$0_2 = \left[\frac{(I_m - 0_1)}{(T_s + t/2)}\right] t + 0_1$$

In the SSARR program, the value of $\frac{t}{(T_s + t/2)}$ is evaluated as a constant for a specified condition, and the difference between I_m and 0_1 is multiplied by this constant to obtain the incremental changes in outflows. In channel routing this computation is carried out for each increment or phase of the routing. The outflow computed from the first increment is treated as the inflow for the next increment. This step by step process is continued for the specified number of routing increments, and then the next period's routing is begun from specified inflows.

The SSARR program uses this basic method of routing for lakes, free-flowing reservoirs and channel routing. The only differences in these three cases is in the computation of the parameter T_s.

(a) Lake Routing

For natural lakes, the value of T_s is not constant, but can be evaluated from storage and outflow characteristics. From the above diagrams:

$$\frac{dS}{dt} = (T_s) \frac{d0}{dt}$$

The differential with respect to h yields the following equation:

$$T_s = \frac{dS/dh}{d0/dh}$$

in which T_s for a given elevation, h, is given in units of time, dS/dh represents the slope of the storage-elevation curve, and d0/dh is the slope of the discharge-elevation curve at elevation h. It can be shown that with zero inflow, the outflow recession is in the form

$$0_t = 0_1 e^{-t/T_s}$$

in which 0_1 is the initial outflow at time t = 0, 0_t is the outflow at time t, and T_s is the proportionality constant defined above corresponding to the value of 0_t. This is the typical decay-type function characteristic of streamflow recession, but with a varying recession co-efficient for this method. This can be shown to be equivalent to the "Puls Method" of lake routing.

Routing through natural lakes is always accomplished on the basis of free-flow routing. Outflow is computed for each period using the basic storage equation and the relationship between elevation, discharge and storage specified to the computer in the form of tables in the station characteristic input data. The values of T_s may also be specified in those tables, in which case the above equations are overridden by the specified values.

(b) Reservoir Routing

Man-made reservoirs may be designated as a "routing" or "non-routing" type. When the discharge from the reservoir is controlled only by the hydraulic head on the structure, and the discharge-storage relation is known, the reservoir is a "routing-type" reservoir and the routing is accomplished in the same manner as for a natural lake.

Other reservoirs having artificially controlled discharges are termed "non-routing" reservoirs, and for these, the tables of discharge and T_s values are not included in the characteristic data. Only the relationship between elevation and storage need be known in this case; however, the outflows or some other parameter that will allow the computation of the outflow must be specified as control data for the non-routing reservoir. The program user may specify any of the following values each day as control data:

(i) outflow

(ii) elevation

(iii) storage

(iv) change in discharge

(v) change in elevation

(vi) change in storage

If outflow specifications are omitted, the outflow discharge will be computed as being equal to inflow. Differences between inflow and outflow will be added (algebraically) each period to the initial reservoir storage values.

The reservoir will only operate between specified upper and lower bounds. If these are violated, the outflows will be adjusted to hold the reservoir within the specified bounds.

(c) Channel Routing

The time rate of change of streamflow in a river reach is evaluated by successive routings through small increments of reservoir-type storage. The number of increments making up a reach is designated "phases" in the model and the characteristics of these phases are constant throughout the reach. Outflow from each increment is computed by the same method as used for lakes except that the T_s value is determined differently. Outflow from each increment is used as inflow to the next downstream increment and the step by step procedure completed for each increment in each time period. The basic equation is:

$$0_2 = \left[\frac{(I_m - 0_1)}{(T_s + t/2)}\right] t + 0_1$$

0_1 and 0_2 = outflow at beginning and end of period
I_m = Mean inflow = $(I_1 + I_2)/2$
T_s = Time of storage in hours
t = Routing period in hours

Time of storage for channel routing increments may be specified in a table of time of storage versus discharge or may vary inversely as a power function of discharge. Normally the time of storage decreases as discharge increases, and it is convenient to express the relation from the following equation: $T_s = \frac{KTS}{Q^n}$

where: T_s = the time of storage per increment (in hours) determined by trial and error or by observations on observed hydrographs,

KTS = a constant determined by trial and error or by physical measurements of the channel storage,

Q = discharge in cubic feet per second (or in cubic meters per second when computing in the metric system),

n = a coefficient between zero and one determined mathematically or by trial and error reconstitution.

In the Columbia Basin it has been found that time of storage varies inversely with discharge in cubic feet per second approximately to the 0.2 power. Studies in the Fraser basin indicate that the same 0.2 value applies to most channel reaches.

The increments (or phases) may be thought of as representing a series of small reservoirs where the "wedge" storage is small in comparison with "prismatic" storage. The number of increments may be quite different for different streams.

In calibrating the Fraser River model, it was found that slow running reaches of channel could best be simulated by one increment of routing whereas fast running reaches were best handled by several increments. There appeared to be little relationship between the length of the reach and the number of increments needed to represent it in the model.

2.3 Assessment of the SSARR Program for Fraser Upstream Storage Study

The SSARR program is a complex computer program designed to handle several different hydrologic manipulations of river flow data. These can be classified into two basic subdivisions; river flow reconstitutions and forecasts in which flows are computed from an input of meteorological data, and reservoir regulation simulations in which the observed river flows are to be modified at various points in the river and the resulting changes down the river are to be computed. Basin routing functions are used only in the former of these subdivisions, while the simple lake, reservoir and channel routing functions are used in both. The work necessary for the Upstream Storage studies required only the reservoir regulation type of simulation .

The largest part of the SSARR program concerns the basin routing computations. These include several complex simulations such as snowmelt determinations and water budget computations, and routing overland flow and ground-water flow to the river channel. Thus, most of the computations in the program are not required for the Fraser Upstream Storage studies. The program, however, is set up in such a way that these unused portions can not be removed. Although the input model does not require these computations in the case of a reservoir regulation model, it is nevertheless necessary to load the whole program into the computer, and when operating the program, much valuable computer time is used setting up the requirements of these unused routines. An attempt was made to separate out only those routines that were required for the reservoir simulations, but it was found that the basic framework of the program ran through all routines in such a way that they could not be separated without virtually re-writing the whole program. What was most desired for the Fraser River studies was the individual subroutines for each river routing function so that they could be fitted separately into any reservoir regulation system.

Other desired features that were not possible with the SSARR program can be summarized as follows:

(i) The ability to route increments of river flows to a downstream location (i.e. routing of reservoir holdouts) would greatly simplify the studies.

(ii) The ability to operate all reservoirs in the model on a day to day basis was required. In this program all reservoir outflows for the whole simulation period must be pre-determined.

(iii) A faster and more convenient method of data input and output was required for operating efficiency.

Several further factors were included in the SSARR program that were not necessary for these studies and that simply resulted in a slower and less efficient operation for the purposes of the Fraser River study. Therefore, it was decided that a simpler program, fitted more directly to the needs of this study should be produced. In developing this new program, the basic idea of the SSARR program was followed; i.e. a basic framework was set up for use with any generalized model. Also, several of the functions of the SSARR program were adapted to fit into the new program.

3. SIMPAK Program

3.1 General Description

Although the simulation package for river simulation (SIMPAK) was developed to meet the needs of the Fraser River Upstream Storage Studies, the computer program has been written so as to be completely general in nature, allowing it to be applied to any river basin. The program was developed using the IBM 360/67 duplex computer at the University of British Columbia, utilizing the Michigan Terminal System (MTS) operating system. The program could be easily adapted to any medium or large scale computer system.

The SIMPAK program is basically a package of individual programs or subroutines that each do some operation on a set of time dependent data representing river flows, elevations, storage values and change in storage values for each day of the simulation period. Each set of such data is set up in the main program as a "station" having a unique identification number, in the same manner as in the SSARR program. The various individual subprograms are then called in the main program from an input list of operation instructions, each instruction telling the type of operation to be performed and the stations and station parameter values with which it is to be performed. This set of operation instructions is similar to both the characteristic data and configuration data of the SSARR program combined into one list.

The program is set up in such a way that each type of operation can be removed from the program as a separate and complete subroutine that can be included in any other program to carry out the same operation on the data of that program. Because of this feature it has been possible to utilize these routines in other more specialized programs used in simulating reservoir operation for flood-control. The methods of data handling within the program are relatively simple so that it is easy for a user to add any desired additional operation to the program, or to maintain a number of auxiliary routines that can be added to the package at computer load time to carry out specialized tasks. These features make SIMPAK a very flexible tool for any task involving manipulation of streamflow data.

This report includes as an appendix the User's Manual for the SIMPAK program. The manual outlines briefly the basic framework of the program and gives detailed instructions as to the make-up of the input data and instructions to the program. The manual also describes the methods used in the different streamflow routing functions of the model. This manual provides a good understanding of the uses of the program. Further information is available from the Inland Waters Directorate, Pacific Region, in the form of a listing of the actual source instructions for the program and a Program Manual which discusses the data handling procedures used within the program.

3.2 Features of the SIMPAK Program

Some of the main features and capabilities of the SIMPAK program are discussed below:

(a) Data Input

The program will read the required streamflow data for the model from several different sources such as computer cards or card-image computer disc files, magnetic tape, and disc files holding unformatted data. On any of the data input units (i.e. cards, tape or disc) the data can be handled in any of three different data formats. these are:

- (i) W.S.C. format, the format used by the Water Survey of Canada on their computer data tapes,
- (ii) SSARR format, the format used in the SSARR program for data input,
- (iii) "long records" format, made up of data records consisting of unformatted (i.e. machine code form) data.

Input instructions to the program specify from which source the data is to be read and in what format the data is to be on each of the source units. The program will automatically search all the data from all the specified sources to find the data required for input to the model. Data may be in any station order and unused data may be included in the data files.

The program also has a subroutine entry point that allows the user to program his own data input routines. In most cases, however, it is preferable to translate the data separately into the long record format of the program and enter it in the normal manner.

A sample of input data is shown on page 1 of Figure 2.

(b) Data Output

The program outputs data in several forms. The most common data output is simply a listing of the discharges for each station in tables showing one month of data for eight stations per page, indexed by the calendar date. Examples of such output are shown in Figure 2.

The complete data for a station can also be printed; that is discharge, elevation, storage and change in storage.

The program will also output data to computer files in either SSARR format or the long record format. An associated program is available to convert either of these to the W.S.C. format.

Two different types of data plotting can be accomplished by the program. The most flexible type of plot included is the printer-plot, in which the printer output sheet is scaled and a hydrograph is "plotted" using printer symbols. This method provides a fast and inexpensive plot of any specified time-dependent data. Several stations can be plotted together to give a clear comparison of the data at those stations. Examples of this type of plot are shown in Figure 2.

The second type of plot that can be accomplished is the line plot produced on a Calcomp Plotter. The program will produce such a plot of any specific data, using either a specified scale or using an automatic scaling feature. Only two different sets of data may be plotted on any one graph using the present version of the program for line plots.

(c) Model Time Control

The program works on a fixed time increment of one day except in certain cases of the reach routing routine in which calculations are made for shorter time periods. All input flows are considered to be mean daily discharges. Values of elevation and storage are computed as the end-of-day values.

The time boundaries for any run of the program are input in the program control instructions. The program in its present form handles up to 200 days in any cycle, however, this could easily be extended by re-dimensioning the program. All data is checked for the correct time period and only the data within that period is selected from the databank. All data is input and output from the program in terms of its calendar (Gregorian) date.

Any run of the program can be cycled to provide additional simulations for different time boundaries using the same input model. In such cases, the data applicable to the new cycle time period will be picked up automatically from the input data files.

(d) Organization of the Program

The program is written as a series of independent subroutines, each to carry out a specified operation. Each operation uses data specified by station numbers that are supplied to the program as parameters in the input operation card list. Each of these subroutines can be removed from the program and used separately in any other program to carry out the same function within that program.

Each set of data within the program is indexed according to a unique station number. All operations of the program are then made by reference to these station numbers. Each operation of the program takes the data held in one or more stations, uses that data in carrying out the specified operation, and stores the computed values of the operation under another specified station number. In this way each operation specified in the program operation card list also specifies the configuration of the model.

For each station, there are four different types of data stored in the computer under index numbers as follows;

index 1 = discharges
" 2 = elevations
" 3 = storage
" 4 = change in storage

Thus, each station has a space in the computer reserved for each of these four types of data. They are not necessarily all filled in with meaningful data, depending upon the operations that are carried out using that station.

Each operation is specified by an input operation card which tells the program what type of operation to carry out and specifies the stations to use in the operation as well as the parameters to use for those stations. The operation card list controls the operation of the program and can be considered as the "model" of the basin. The method of specifying the operations through the operation cards is described in Appendix 1.

There also may be tables associated with any station. If the operation being carried out requires characteristic data or control data in addition to that specified on the control list, the program looks for a table having the station number as its identification.

(e) Operation of SIMPAK

The several operations that can be carried out by SIMPAK are summarized below. Each of these operations are initiated by an entry in the operation card list. The SIMPAK User's Manual, included here as Appendix 1, shows the specifications for the control cards. In many of these operations only one type of data for the station is operated on; the type may be specified in many cases. In other operations, such as lake routing, all types of data for the station are used. The operations available in SIMPAK are;

(i) route flows through a free flow lake, using the Modified Puls Method of lake routing,

(ii) route flows through a reservoir based on a control record consisting of specified values for any one of the four data types (discharge, elevation, storage or change in storage),

(iii) route flows through a river channel reach using the SSARR method of channel routing,

(iv) route river flows or reservoir holdouts to a downstream point in the river using a polynomial (or convolution) method of routing,

(v) sum the data from two or more stations,

(vi) subtract the data for one station from another,

(vii) multiply data for a station by any specified constant,

(viii) extend records on the basis of a correlation curve, using a specified station as a base record,

(ix) compute daily ratios between stations' data,

(x) extend records on the basis of input daily ratios between the base station and the extended station,

(xi) compute monthly means and totals of data values.

In addition to these operations, there is a dummy operation "USER" that allows a user to program his own routine to fit into the SIMPAK structure. Any other program may be called by the SIMPAK operation card list by identifying the program with the name "USER" and concatenating it to the SIMPAK program.

3.3 SIMPAK Routing Methods

The SIMPAK program carries out four types of streamflow routing; lake routing, reservoir routing, channel routing using the SSARR method, and channel routing using the polynomial method. Each of these methods is described in the SIMPAK user's Manual (see Appendix #1). A short description of these methods is given below.

(a) Lake Routing ("LAKE")

The SIMPAK program uses the Modified Puls Method of lake routing. This method is simply an application of the basic continuity equation

outflow = inflow - change in storage.

The inflow values are computed according to the model configuration in the operation control cards. The outflow and change in storage values are inter-dependent and are determined in the program by reference to a table relating lake elevation, lake storage and natural lake discharge. The derivation and operation of the Modified Puls Method of routing is shown in most textbooks of Hydrology, and is shown in Section VII of the SIMPAK User's Manual (see Appendix #1).

(b) Channel Routing by SSARR Method ("REAC")

The same computations used in the SSARR program for channel routing are included in the SIMPAK program under the "REAC" operation to route channel flows. These computations are discussed previously in this report under Section 2.2.

Basically, this method of routing considers a river reach to consist of several routing elements or "phases" each having the same effect on discharges as does a small lake. The characteristics of these routing elements are defined by the parameters N and KTS, and when combined with the number of elements "NPS" making up the river reach, they define the characteristics of the reach. This method neglects the wedge storage in river channels, however, good results are obtained in flow reconstitutions in spite of this simplification.

Using this type of channel routing, the same model can be used in both the SIMPAK and SSARR programs for river simulations.

(c) Polynomial Method of Routing ("WAVE")

This method of routing was adapted from the U.B.C. Watershed Model. The method utilizes a convolution type of calculation to compute the routed flows at a point downstream in the basin. The flow at any given day at the upstream location contributes over several days to the flow at the downstream location. The routed flow at the downstream location consists of the summation of the contributions from the upstream location over all previous days. This method is shown by the following equation:

$$Q_{D,t} = k_1 Q_{U,t} + k_2 Q_{U,t-1} + \cdots + k_{n+1} Q_{U,t-n}$$

or

$$Q_{D,t} = \sum_{n=0}^{\infty} k_{n+1} Q_{U,t-n}$$

where the subscripts represent the following;

D = downstream location

U = upstream location

t = current time period

Of course the contributions are significant only over a limited number of days so that the equation reduces to the form:

$$Q_{D,t} = \sum_{n=lag\ 1}^{lag\ 2} K_{n+1}\ Q_{U,t-n}$$

where lag 1 is the lag in days until the first significant contribution occurs and

lag 2 is the lag until the last significant contribution occurs

This method assumes that the constant values "k" do not change with the level of flow. This assumption limits the applicability of the method to a fairly narrow range of flows. It has been found, however, that in the Fraser River this method produces results just as accurate as the SSARR method of routing within the range of flows occuring over the periods in which flood-control reservoirs would be storing water.

A major advantage of this method for flood control computations is that any increment of flow can be routed directly from an upstream location to any point downstream. Also, negative flows (i.e. reservoir holdouts) can be routed in this way. Thus, this method provides a much simpler model and a much more flexible routing method for studying the effects of reservoir operation on a river such as the Fraser River.

Further information about this method of routing is given in Appendix 1 under Operation Code "WAVE".

4. Computer Models for Routing Flows of the Fraser River

Mathematical models to fit both the SSARR program and the SIMPAK program have been developed for the Fraser River system. These were developed by first separating the river system into components consisting of river channel reaches, lakes, and junction points. For each channel section routing parameters were derived using a trial and error procedure termed "calibration" of the model. This calibration was carried out using the observed flow data for the years 1966 and 1967.

A schematic diagram of the basic model for use with the SSARR program is given in Figure 1. This diagram, along with Table 1, gives all the information required to define the model. Figure 1 shows the stations used for the Fraser River model and gives the configuration of the model. Included at the relevant stations on the diagram are the values of the parameters required to define the routing characteristics of the river. The characteristics of Kamloops Lake, also a part of the basic model, are given in Table 1.

Data in the form of reservoir outflows at the upstream portions, and derived local inflows along the river, are input to this model to produce simulated discharges at all points along the river. Each of the local inflows shown in the model are computed by a separate model segment that can if necessary be included with the basic model. The local inflows are usually computed between two or more observed discharge stations. The procedure for this derivation of local flows is to route the observed upstream flows through the applicable section of the river, then subtract the routed flow from the observed flow at the downstream station to produce the local flow for that section of the river.

Using these procedures, a set of local flows is computed for any given set of flow data on the river. Then the flows to be tested at the reservoir sites are input to the model, along with the derived local flows, and are routed through the model to give the modified flows at all points along the river.

This SSARR model for the river can also be used in the SIMPAK program. However, the SIMPAK program also can route flows using the polynomial method of routing which requires a different type of model. In this case, the model may consist of a sub-model to compute the flow changes at the reservoir sites, then these flow increments are operated on by the "WAVE" routing operation to compute the relevant increments in the flows at any pre-selected downstream location. These increments are then added to or subtracted from the observed flows at the downstream location to provide the modified flows under operation of the reservoir. All reservoir regulation studies were carried out using this procedure.

In the polynomial method of routing, the routing parameters relate the upstream site directly to the selected downstream station.

These parameters may be derived by individual analysis of several sections of the river and combining the parameters for all reaches. The parameters can be estimated from observed channel characteristics. These parameters can also be determined from the SSARR routing model by routing a unit discharge through the model and examining the resulting routed discharge values at the downstream station.

The parameters for the polynomial method of routing can best be shown as routing equations. Such equations, relating some of the key points in terms of flood control on the Fraser River, are shown in Table 2.

These models give the basic requirements to use the SSARR program and the SIMPAK program for analyses on the Fraser River. Several further sub-models and associated computations are usually necessary in setting up a model to test a given operation, however, these vary from job to job.

This report, along with the SIMPAK User's Manual, describes the general characteristics of both the SSARR and SIMPAK programs and shows how they are applied in the Fraser River studies. A working knowledge of these programs, however, can be obtained only from experience in applying the programs to modelling problems.

REFERENCES

1) U.S. Army Engineer Division, North Pacific, Portland Oregon. Program Description and User's Manual for SSARR Model, Program 724-K5-G-0010, September 1972.

2) Kuehl, D.W. and Schermerhorn, V.P. Hydrologic Digital Model of Willamette Basin Tributaries for Operational River Forecasting, paper presented at A.S.C.E. National Meeting of Water Resource Engineering, New York, October 1967.

3) U.S. Army Corps of Engineers, North Pacific Division, Portland Oregon, Computer Applications to System Analysis, Lower Mekong River, August 1967.

4) Tanovan, B., Notes on the Generalized Basin Runoff Characteristics in the SSARR Program for IBM 360, U.S. Corps of Engineers, Mekong Committee, Portland, Oregon, July 1967.

5) Prairie Provinces Water Board, User's Manual SSARR Model for Riverflow Forecasts, South Saskatchewan River below the Confluence with the Red Deer River, Calgary, June 1973.

6) Chow, V.T., Handbook of Applied Hydrology, McGraw Hill, 1964.

7) Linsley, R.K., Kohler, M.A. and Paulhus, L.H., Applied Hydrology, McGraw-Hill, 1949.

TABLE 1

Kamloops Lake Characteristics Table

Stage (ft)	Discharge (cfs)	Storage (acre-ft)
2.59	4,480	0
3.50	6,300	13,010
4.00	7,310	20,160
4.32	8,110	25,165
6.00	12,235	48,760
6.15	12,630	55,910
8.00	17,650	77,360
9.00	20,660	91,660
9.50	22,395	100,100
10.00	24,410	107,750
12.50	34,920	148,700
13.00	37,125	157,500
13.50	39,385	166,300
14.00	41,760	175,500
14.50	44,370	185,300
16.00	52,480	214,700
17.50	60,900	244,100
18.00	63,910	254,000
21.50	85,620	325,000
22.50	92,030	347,000
25.00	108,540	402,000
29.37	138,256	500,000
35.00	176,540	625,000

TABLE 2

Polynomial Routing Equations for Use in the "WAVE" Routing Operation

terminology:

0 = discharge at the downstream station

I = discharge at the upstream station

j = the current day in the simulation

(a) Routing to Fraser River at Mission:

(i) from Lower McGregor Reservoir and from Grand Canyon Reservoir

$$O_j = .03\ I_{j-2} + .23\ I_{j-3} + .51\ I_{j-4} + .23\ I_{j-5}$$

(ii) from Cariboo Falls Reservoir

$$O_j = .02\ I_{j-1} + .22\ I_{j-2} + .52\ I_{j-3} + .24\ I_{j-4}$$

(iii) from Hemp Creek Reservoir (also used for Hobson Lake and Clearwater-Azure Reservoir)

$$O_j = .04\ I_j + .18\ I_{j-1} + .34\ I_{j-2} + .30\ I_{j-3} + .12\ I_{j-4} + .02\ I_{j-5}$$

(iv) from Nechako Reservoir (Skins Lake Spillway)

$$O_j = .03\ I_{j-4} + .06\ I_{j-5} + .09\ I_{j-6} + .11\ I_{j-7} + .11\ I_{j-8} + .11\ I_{j-9} + .10\ I_{j-10} + .09\ I_{j-11} + .08\ I_{j-12} + .08\ I_{j-13} + .06\ I_{j-14} + .05\ I_{j-15} + .03\ I_{j-16}$$

(v) from Bridge River

$$0_j = .18\ I_j + .55\ I_{j-1} + .27\ I_{j-2}$$

(b) Routing to Prince George

(i) from Lower McGregor Reservoir and from Grand Canyon Reservoir

$$0_j = .99\ I_{j-1} + .01\ I_{j-2}$$

(ii) from Nechako Reservoir (Skins Lake Spillway)

$$0_j = .04\ I_{j-1} + .06\ I_{j-2} + .09\ I_{j-3} + .11\ I_{j-4} + .13\ I_{j-5} + .12\ I_{j-6} + .10\ I_{j-7} + .09\ I_{j-8} + .08\ I_{j-10} + .07\ I_{j-11} + .05\ I_{j-12} + .04\ I_{j-13} + .02\ I_{j-14}$$

(c) Routing to Quesnel

(i) from Lower McGregor Reservoir and from Grand Canyon Reservoir

$$0_j = .11\ I_{j-1} + .89\ I_{j-2}$$

(ii) from Cariboo Falls Reservoir

$$0_j = .06\ I_j + .94\ I_{j-1}$$

(iii) from Nechako Reservoir (Skins Lake Spillway)

$$0_j = .03\ I_{j-2} + .06\ I_{j-3} + .09\ I_{j-4} + .11\ I_{j-5} + .12\ I_{j-6} + .11\ I_{j-7} + .10\ I_{j-8} + .09\ I_{j-9} + .08\ I_{j-10} + .07\ I_{j-11} + .06\ I_{j-12} + .05\ I_{j-13} + .03\ I_{j-14}$$

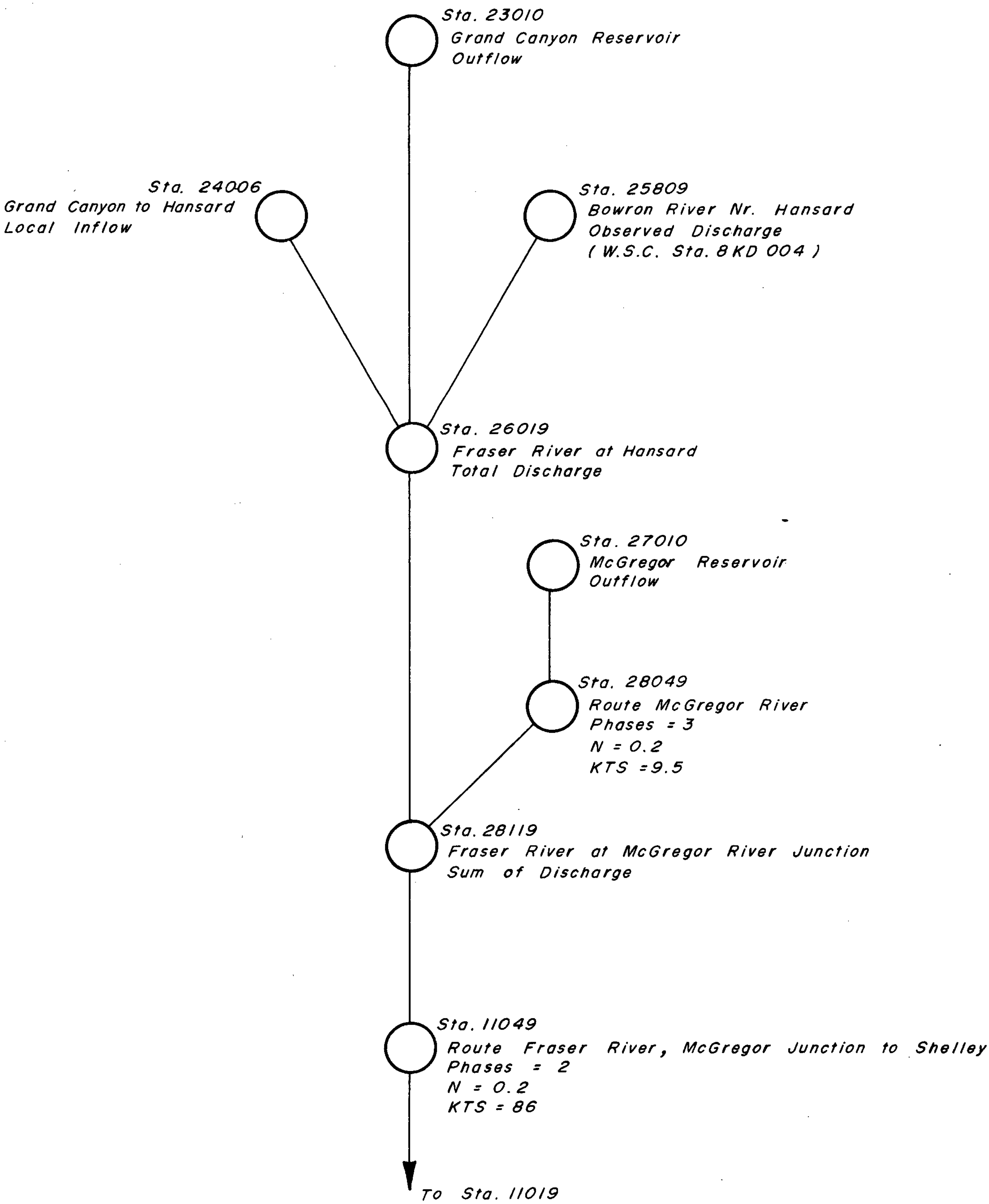
(d) Routing to Kamloops

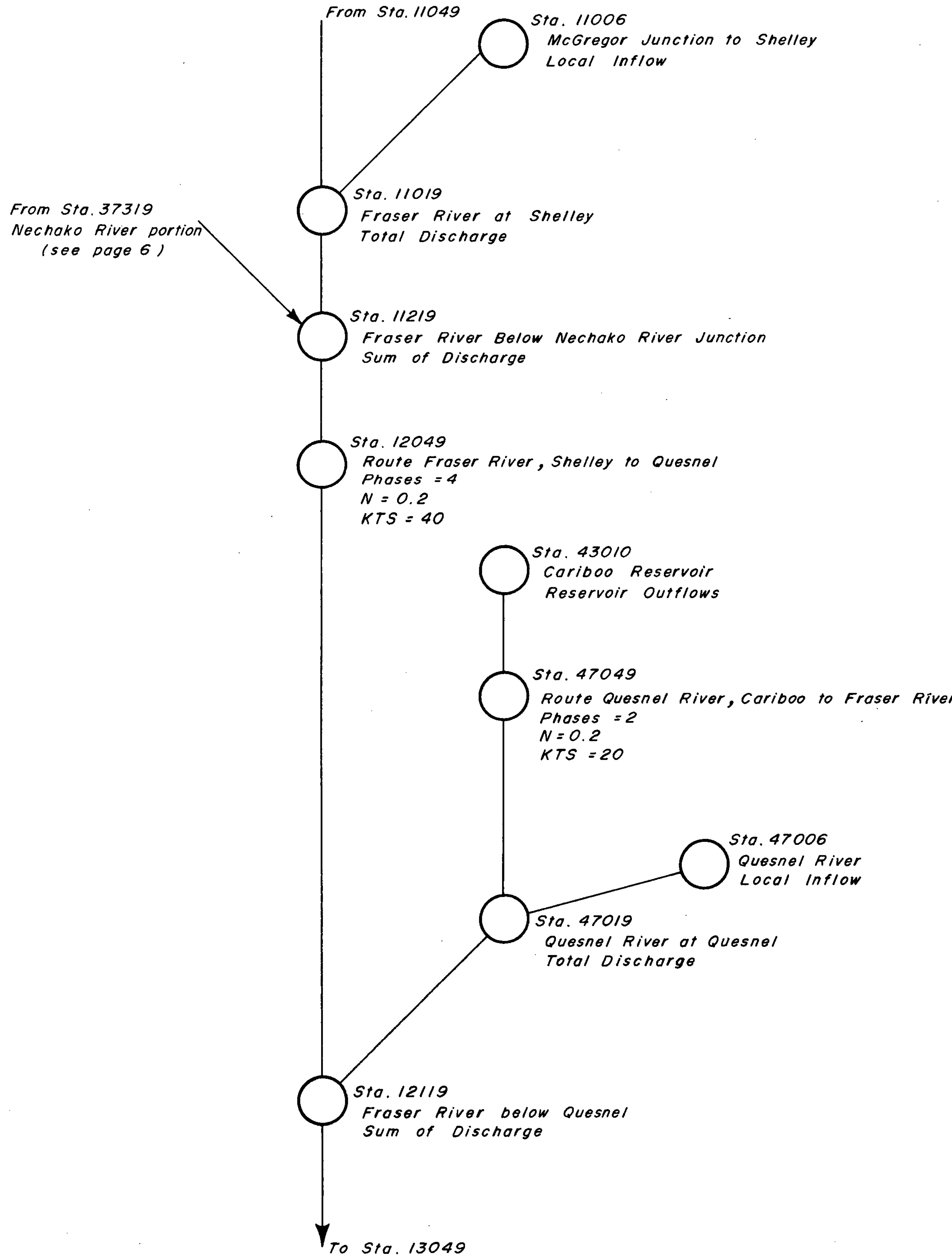
(i) from Hemp Creek Reservoir (also used for Hobson Lake and Clearwater-Azure Reservoir)

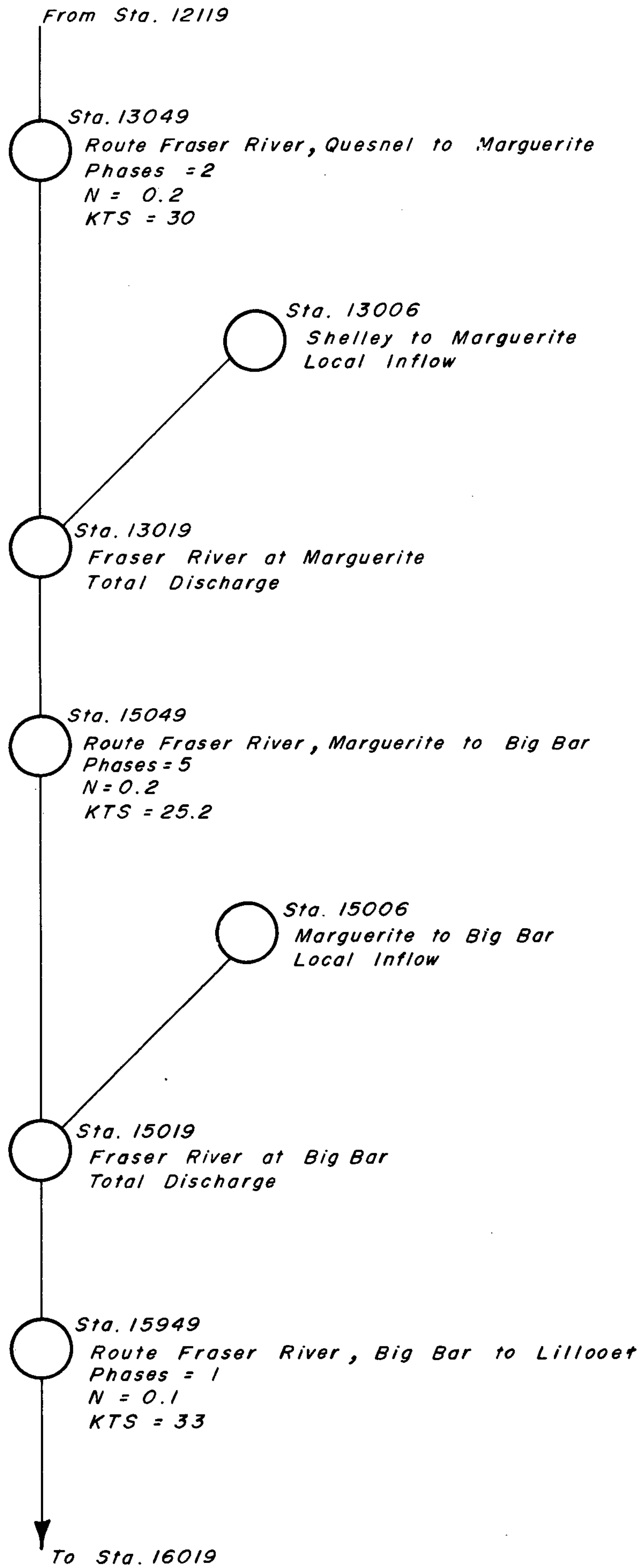
$$O_j = .34\ I_j + .46\ I_{j-1} + .17\ I_{j-2} + .02\ I_{j-3}$$

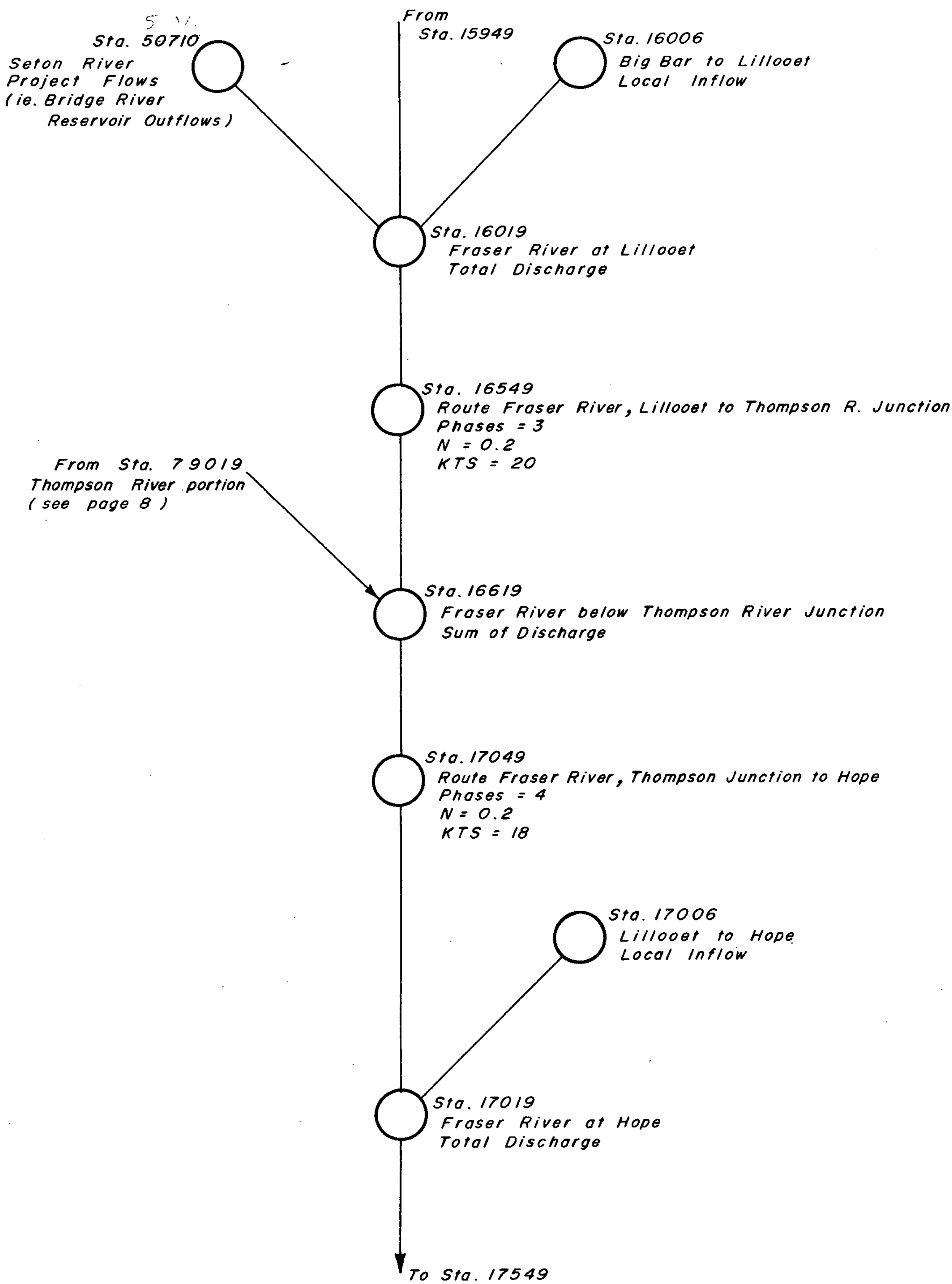
BASIC FRASER RIVER SSARR MODEL

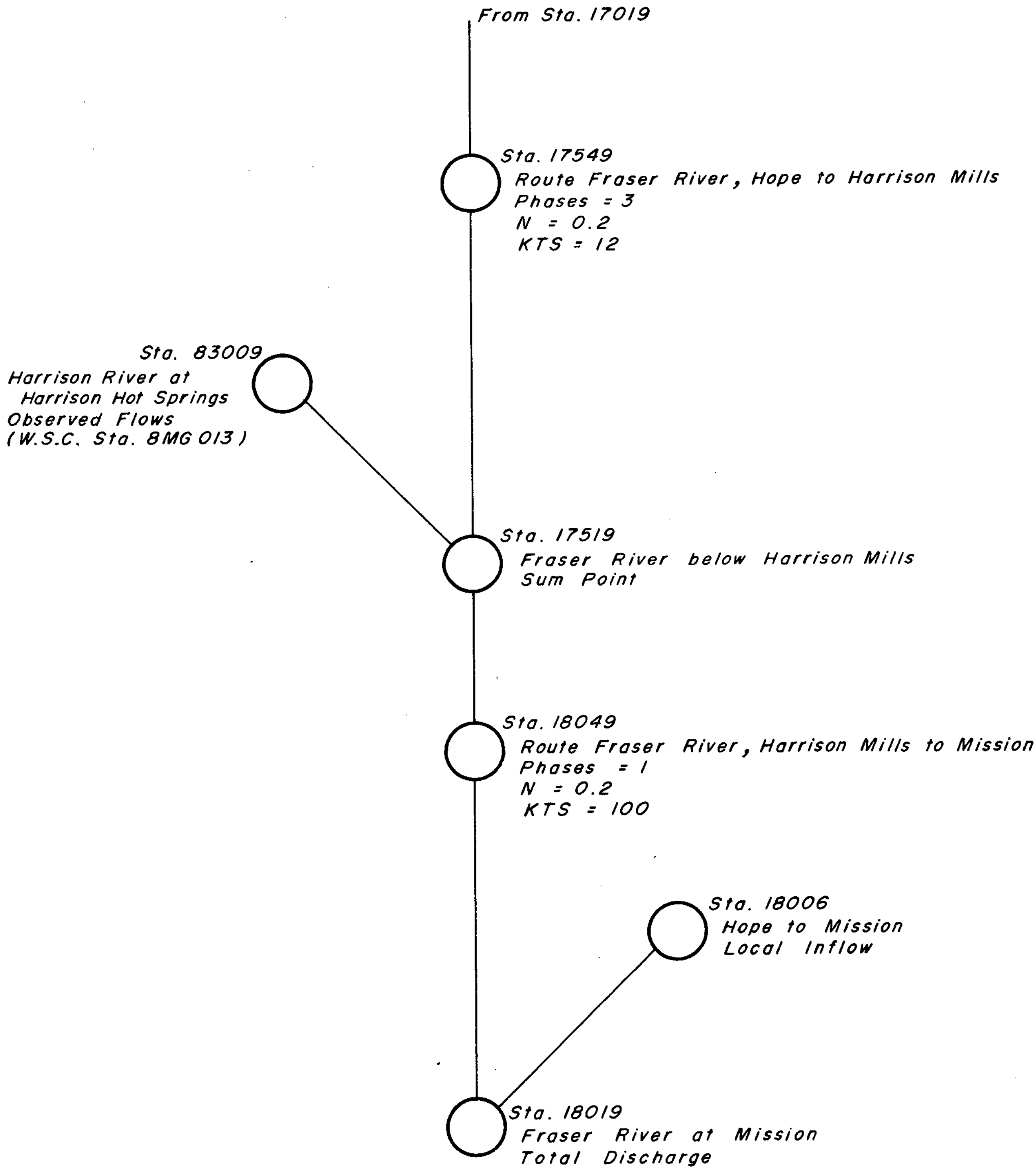
a) FRASER RIVER PORTION :



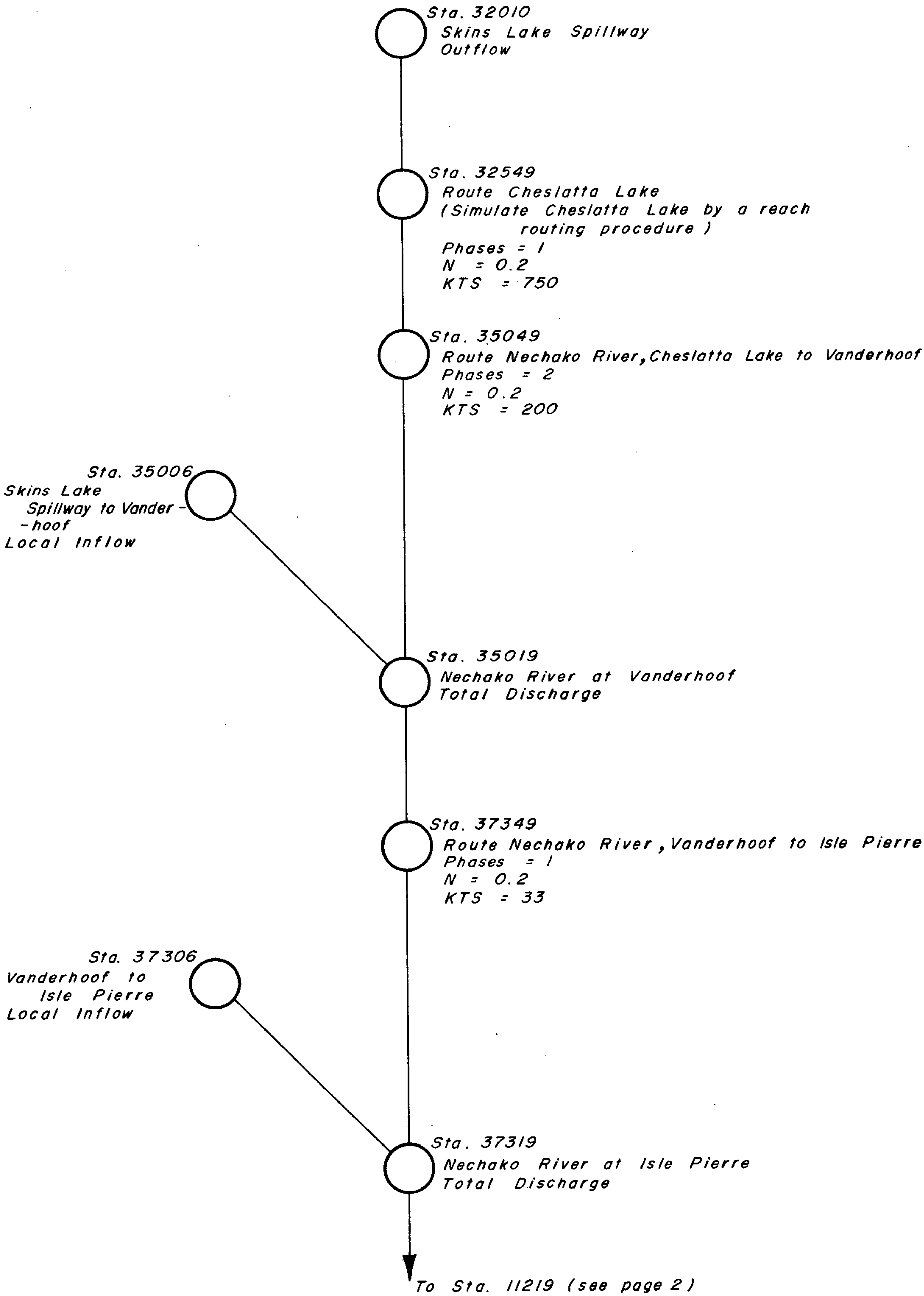

From Sta. 11049
Sta. 11006
McGregor Junction to Shelley
Local Inflow
Sta. 11019
Fraser River at Shelley
Total Discharge
From Sta. 37319
Nechako River portion
(see page 6)
Sta. 11219
Fraser River Below Nechako River Junction
Sum of Discharge
Sta. 12049
Route Fraser River, Shelley to Quesnel
Phases = 4
N = 0.2
KTS = 40
Sta. 43010
Cariboo Reservoir
Reservoir Outflows
Sta. 47049
Route Quesnel River, Cariboo to Fraser River
Phases = 2
N = 0.2
KTS = 20
Sta. 47006
Quesnel River
Local Inflow
Sta. 47019
Quesnel River at Quesnel
Total Discharge
Sta. 12119
Fraser River below Quesnel
Sum of Discharge
To Sta. 13049


From Sta. 12119
Sta. 13049
Route Fraser River, Quesnel to Marguerite
Phases = 2
N = 0.2
KTS = 30
Sta. 13006
Shelley to Marguerite
Local Inflow
Sta. 13019
Fraser River at Marguerite
Total Discharge
Sta. 15049
Route Fraser River, Marguerite to Big Bar
Phases = 5
N = 0.2
KTS = 25.2
Sta. 15006
Marguerite to Big Bar
Local Inflow
Sta. 15019
Fraser River at Big Bar
Total Discharge
Sta. 15949
Route Fraser River, Big Bar to Lillooet
Phases = 1
N = 0.1
KTS = 33
To Sta. 16019

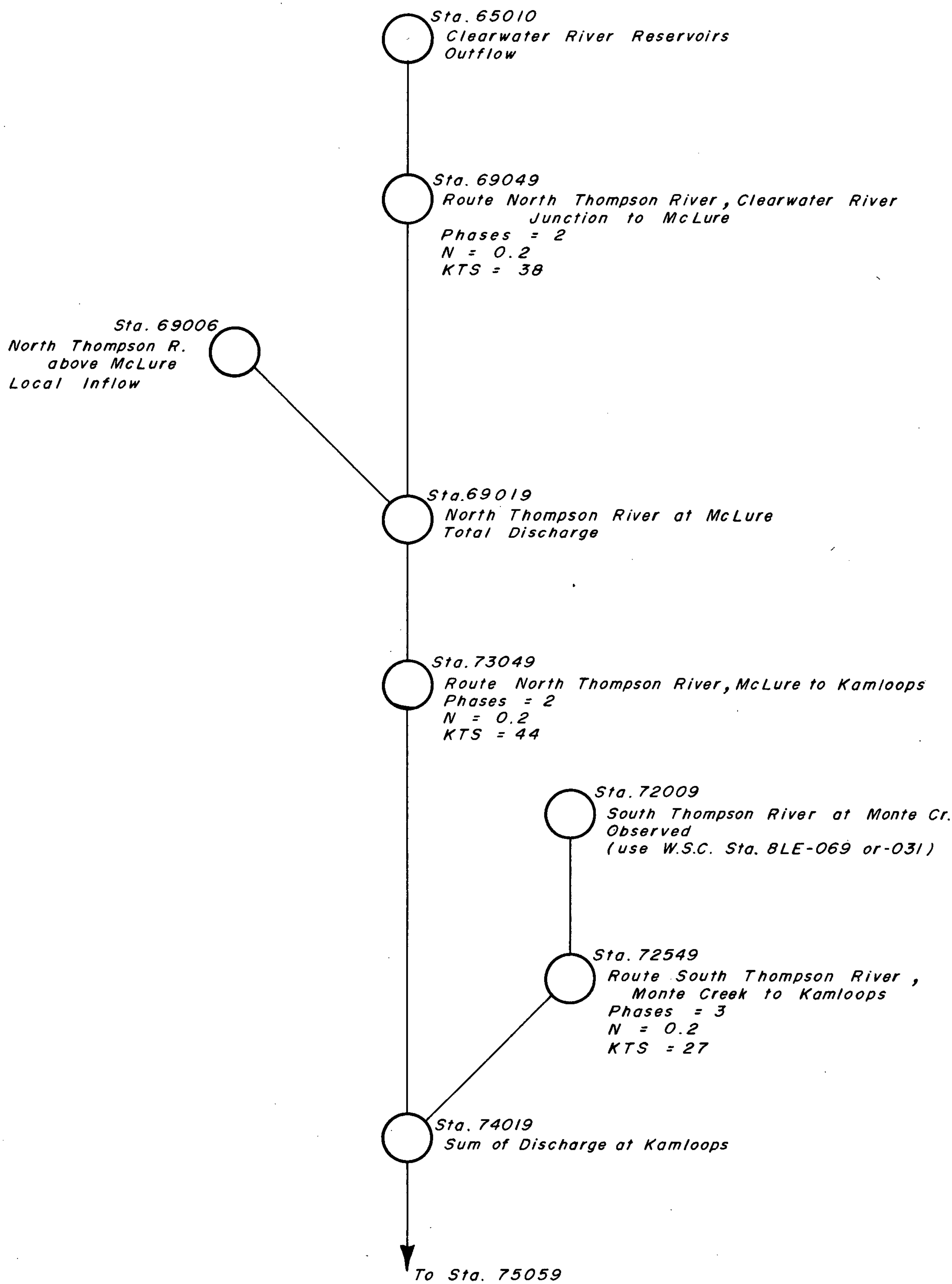

From
Sta. 15949
Sta. 50710
Seton River
Project Flows
(ie. Bridge River
Reservoir Outflows)
Sta. 16006
Big Bar to Lillooet
Local Inflow
Sta. 16019
Fraser River at Lillooet
Total Discharge
Sta. 16549
Route Fraser River, Lillooet to Thompson R. Junction
Phases = 3
N = 0.2
KTS = 20
From Sta. 79019
Thompson River portion
(see page 8)
Sta. 16619
Fraser River below Thompson River Junction
Sum of Discharge
Sta. 17049
Route Fraser River, Thompson Junction to Hope
Phases = 4
N = 0.2
KTS = 18
Sta. 17006
Lillooet to Hope
Local Inflow
Sta. 17019
Fraser River at Hope
Total Discharge
To Sta. 17549

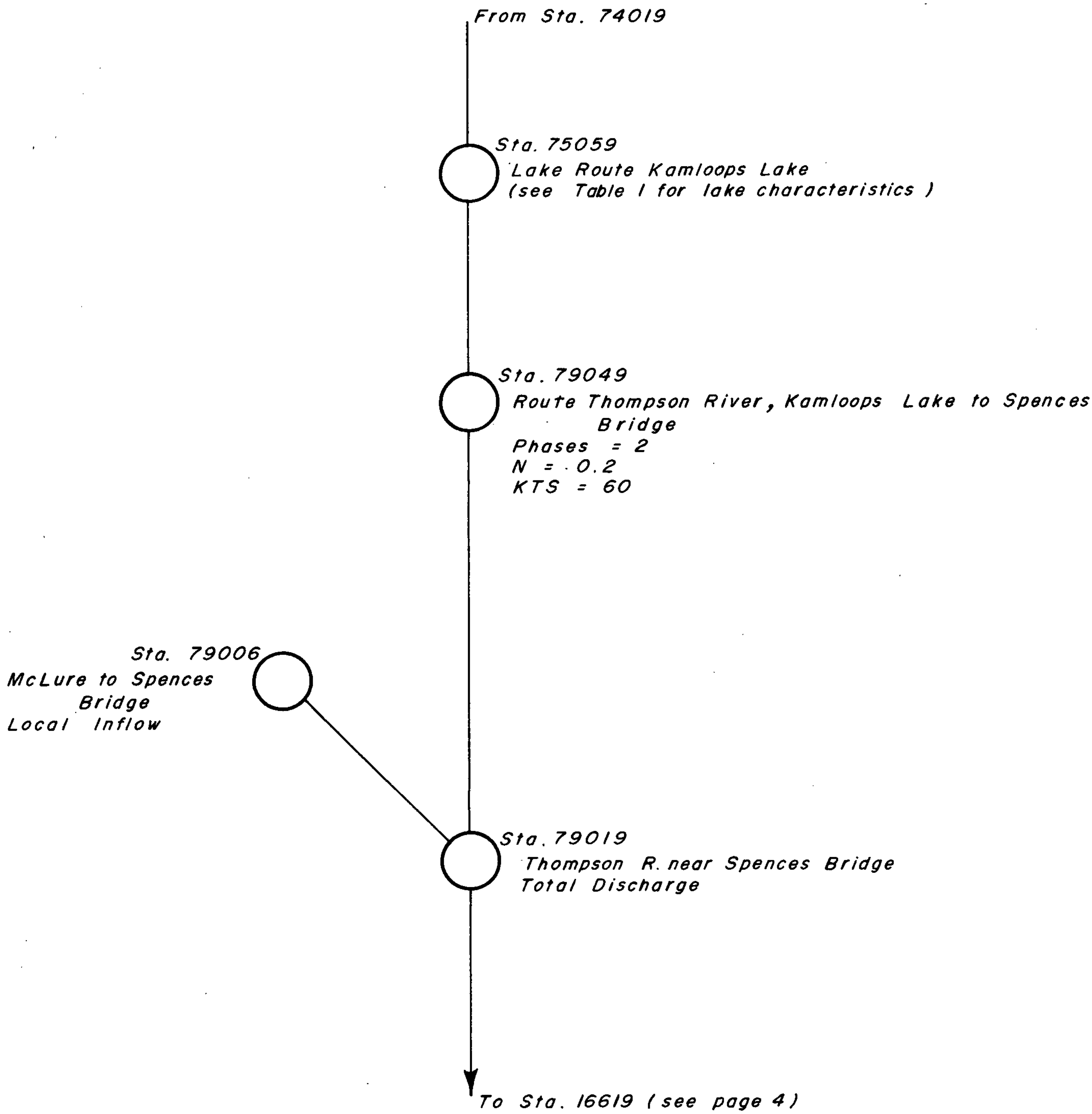

From Sta. 17019
Sta. 17549
Route Fraser River, Hope to Harrison Mills
Phases = 3
N = 0.2
KTS = 12
Sta. 83009
Harrison River at
Harrison Hot Springs
Observed Flows
(W.S.C. Sta. 8MG 013)
Sta. 17519
Fraser River below Harrison Mills
Sum Point
Sta. 18049
Route Fraser River, Harrison Mills to Mission
Phases = 1
N = 0.2
KTS = 100
Sta. 18006
Hope to Mission
Local Inflow
Sta. 18019
Fraser River at Mission
Total Discharge

b) NECHAKO RIVER PORTION:



c) THOMPSON RIVER PORTION:




From Sta. 74019
Sta. 75059
Lake Route Kamloops Lake
(see Table 1 for lake characteristics)
Sta. 79049
Route Thompson River, Kamloops Lake to Spences Bridge
Phases = 2
N = 0.2
KTS = 60
Sta. 79006
McLure to Spences Bridge
Local Inflow
Sta. 79019
Thompson R. near Spences Bridge
Total Discharge
To Sta. 16619 (see page 4)

SAMPLE RUN OF "SIMPAK" PROGRAM

a) INPUT DATA

```
PLCT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION
        67009         1     CLEARWATER RIVER AT CLEARWATERSTATION
        18C49         1     ROUTE CL. R. AT CL.STN. TO MISSION
$END
01 05 1948  31 07 1948                                        1
WAVE   18049     67009                   0 5
 .04 .18 .34 .30 .12 .02
PLOT                              2
         67009   1    O          70CCC
         18049   1    R          70000
$END
CYCLE  01 05 1971  31 07 1971
CYCLE  C1 05 1972  31 07 1972
$END
```

b) OUTPUT FROM THIS RUN IS SHOWN ON PAGES 2 TO 16 FOLLOWING.

```
SIMPAK VERSION OF MAY 18,1972
RUN DATE 12-05-73                     PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

                  A LIST OF THE STATIONS IN THE MODEL:

                                 67009     CLEARWATER RIVER AT CLEARWATER STATION
                                 18049     ROUTE CL. R. AT CL. STN. TO MISSION
EOF ENCOUNTERED ON SEQUENTIAL FILE READ* RETURN*

                 CONFIGURATION:

CODE      STA1      STA2      STA3      STA4 V1V2V3    PAR1      PAR2      PAR3
WAVE      18049     67009                   0 5
  .04  .18  .34  .30  .12  .02
PLOT                                        2
          67009    1    D               70000
          18049    1    R               70000

INITIAL TIME CONTROL :    1    5 1948 TO    31    7 1948
```

FIGURE 2

O 67009 CLEARWATER RIVER AT CLEARWATER STATION CFS

VARIABLE 1 0. 7000. 14000. 21000. 28000. 35000. 42000. 49000. 56000. 63000. 70000.

R 18049 ROUTE CL. R. AT CL. STN. TO MISSION CFS

VARIABLE 1 0. 7000. 14000. 21000. 28000. 35000. 42000. 49000. 56000. 63000. 70000.

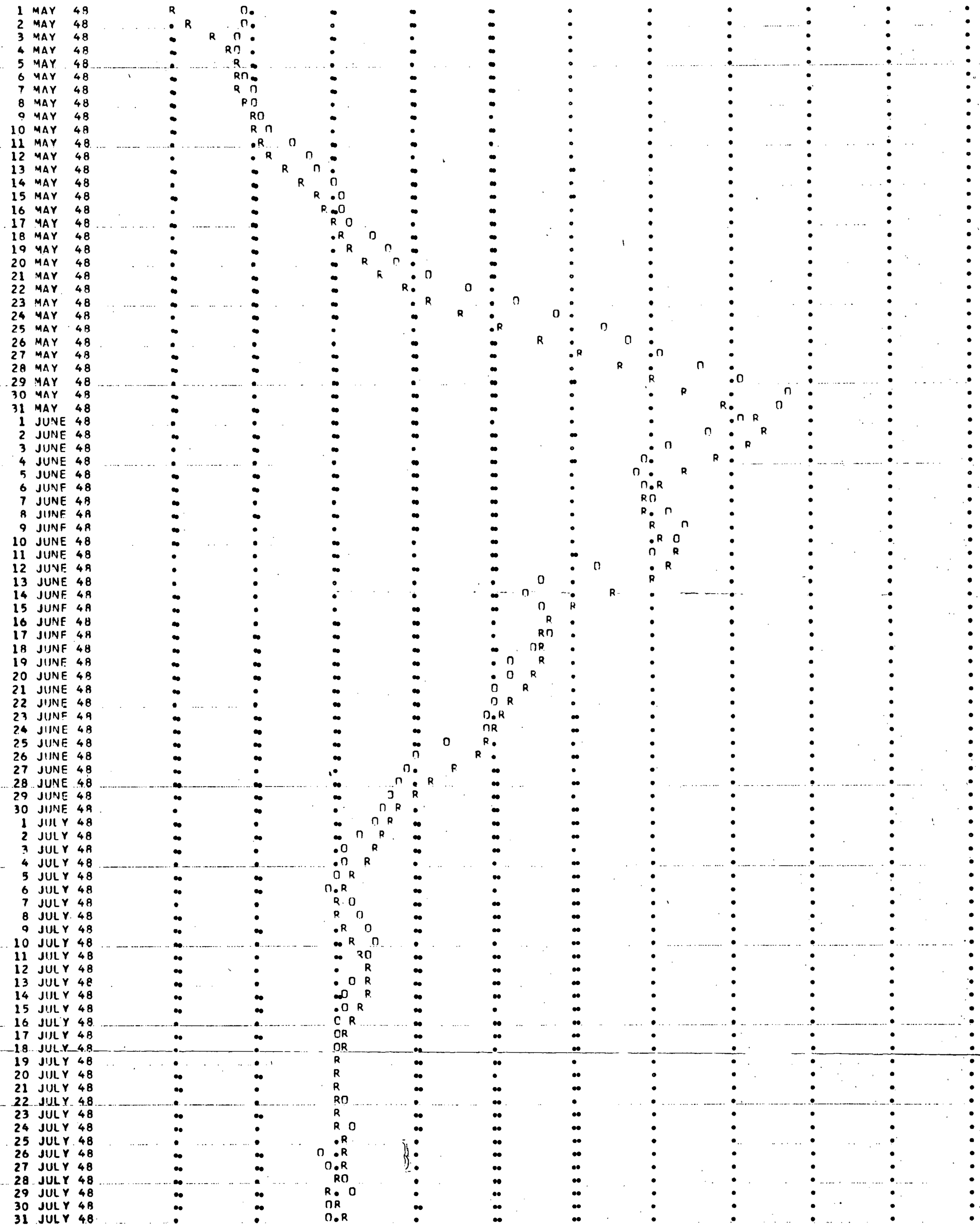


FIGURE 2
Page 3 of 16

PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

OUTFLOW (CFS)

67009 CLEARWATER RIVER AT CLEARWATER STATION
18049 ROUTE CL. R. AT CL. STN. TO MISSION

DATE	STATION 67009	STATION 18049	STATION	STATION	STATION	STATION	STATION	STATION
1 MAY 1948	5384.00	255.36						
2 MAY 1948	6048.00	1391.04						
3 MAY 1948	5670.00	3486.00						
4 MAY 1948	5418.00	5208.84						
5 MAY 1948	5670.00	5710.32						
6 MAY 1948	6375.00	5672.15						
7 MAY 1948	6885.00	5777.45						
8 MAY 1948	7224.00	6160.31						
9 MAY 1948	8004.00	6662.53						
10 MAY 1948	3722.00	7189.65						
11 MAY 1948	10440.00	7829.81						
12 MAY 1948	11625.00	8715.45						
13 MAY 1948	12730.00	9872.85						
14 MAY 1948	14157.00	11148.89						
15 MAY 1948	14600.00	12375.19						
16 MAY 1948	14443.00	13441.89						
17 MAY 1948	15656.00	14197.16						
18 MAY 1948	17640.00	14767.72						
19 MAY 1948	19133.00	15631.59						
20 MAY 1948	19741.00	16953.12						
21 MAY 1948	22518.00	18418.89						
22 MAY 1948	25970.00	19973.79						
23 MAY 1948	30013.00	22102.29						
24 MAY 1948	33318.00	25071.82						
25 MAY 1948	39115.00	28614.22						
26 MAY 1948	39960.00	32357.87						
27 MAY 1948	42784.00	35979.60						
28 MAY 1948	46047.00	39162.30						
29 MAY 1948	49761.00	42053.61						
30 MAY 1948	53590.00	45149.24						
31 MAY 1948	52900.00	48428.30						

PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

OUTFLOW (CFS)

67009 CLEARWATER RIVER AT CLEARWATER STATION
18049 ROUTE CL. R. AT CL. STN. TO MISSION

DATE	STATION 67009	STATION 18049	STATION	STATION	STATION	STATION	STATION	STATION
1 JUNE 1948	50025.00	51053.20						
2 JUNE 1948	46690.00	51827.34						
3 JUNE 1948	43240.00	50438.30						
4 JUNE 1948	41400.00	47741.08						
5 JUNE 1948	40767.00	44852.26						
6 JUNE 1948	41400.00	42645.34						
7 JUNE 1948	42032.00	41536.64						
8 JUNE 1948	43240.00	41434.24						
9 JUNE 1948	45080.00	42017.30						
10 JUNE 1948	44102.00	42973.00						
11 JUNE 1948	42320.00	43802.18						
12 JUNE 1948	37375.00	43660.70						
13 JUNE 1948	31970.00	41900.08						
14 JUNE 1948	31107.00	38596.20						
15 JUNE 1948	31970.00	34920.78						
16 JUNE 1948	33120.00	32578.16						
17 JUNE 1948	33120.00	32072.18						
18 JUNE 1948	31395.00	32441.42						
19 JUNE 1948	29670.00	32493.22						
20 JUNE 1948	29152.00	31730.76						
21 JUNE 1948	28060.00	30512.84						
22 JUNE 1948	28060.00	29415.66						
23 JUNE 1948	27485.00	28624.48						
24 JUNE 1948	26967.00	28076.01						
25 JUNE 1948	23690.00	27514.78						
26 JUNE 1948	20987.00	26446.34						
27 JUNE 1948	20240.00	24591.35						
28 JUNE 1948	19550.00	22453.50						
29 JUNE 1948	19032.00	20840.11						
30 JUNE 1948	18342.00	19870.66						

FIGURE 2

PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

OUTFLOW (CFS)

67009 CLEARWATER RIVER AT CLEARWATER STATION
18049 ROUTE CL. R. AT CL. STN. TO MISSION

DATE	STATION 67009	STATION 18049	STATION	STATION	STATION	STATION	STATION	STATION
1 JULY 1948	17365.00	19180.57						
2 JULY 1948	16330.00	18475.57						
3 JULY 1948	14777.00	17612.00						
4 JULY 1948	14547.00	16585.11						
5 JULY 1948	13742.00	15541.95						
6 JULY 1948	13512.00	14700.01						
7 JULY 1948	15180.00	14175.57						
8 JULY 1948	16215.00	14139.85						
9 JULY 1948	16675.00	14740.47						
10 JULY 1948	17365.00	15659.47						
11 JULY 1948	17135.00	16436.93						
12 JULY 1948	16905.00	16916.48						
13 JULY 1948	15180.00	17010.79						
14 JULY 1948	14950.00	16635.89						
15 JULY 1948	14375.00	15902.18						
16 JULY 1948	14260.00	15166.19						
17 JULY 1948	14145.00	14664.79						
18 JULY 1948	13742.00	14354.27						
19 JULY 1948	13915.00	14141.44						
20 JULY 1948	14145.00	13984.96						
21 JULY 1948	14250.00	13952.39						
22 JULY 1948	14364.00	14055.29						
23 JULY 1948	14294.00	14190.41						
24 JULY 1948	15624.00	14332.33						
25 JULY 1948	14430.00	14551.57						
26 JULY 1948	12540.00	14708.02						
27 JULY 1948	13025.00	14374.15						
28 JULY 1948	14850.00	13691.85						
29 JULY 1948	15301.00	13519.60						
30 JULY 1948	13621.00	14048.90						
31 JULY 1948	13125.00	14447.90						

FIGURE 2

```
CYCLE FOR PERIOD:  1  5 1971 31  7 1971
EOF ENCOUNTERED ON SEQUENTIAL FILE READ* RETURN*
```

FIGURE 2

O 67009 CLEARWATER RIVER AT CLEARWATER STATION CFS

VARIABLE 1 0. 7000. 14000. 21000. 28000. 35000. 42000. 49000. 56000. 63000. 70000.

R 18049 ROUTE CL. R. AT CL. STN. TO MISSION CFS

VARIABLE 1 0. 7000. 14000. 21000. 28000. 35000. 42000. 49000. 56000. 63000. 70000.

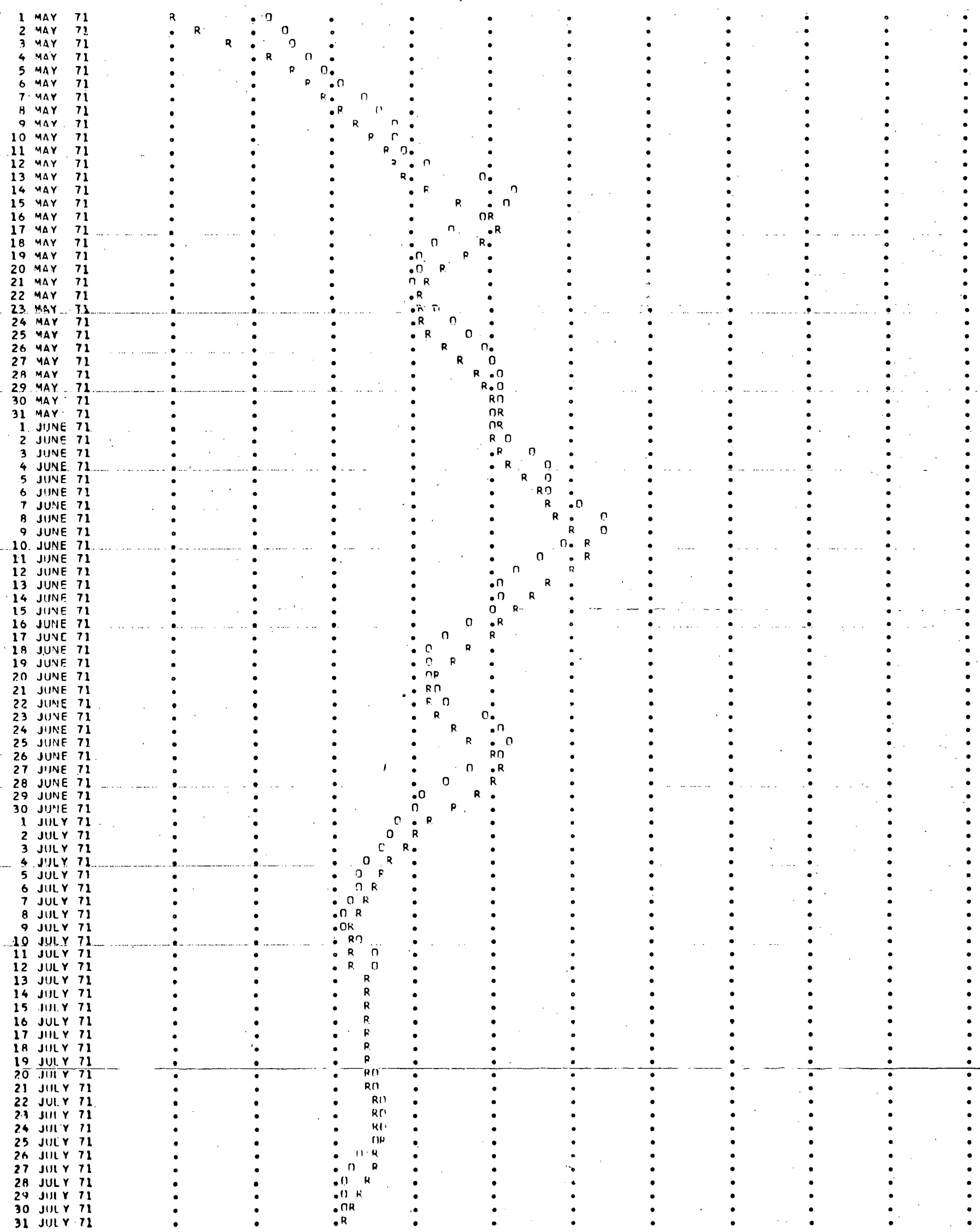


FIGURE 2
Page 8 of 16

PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

OUTFLOW (CFS)

67009 CLEARWATER RIVER AT CLEARWATER STATION
18049 ROUTE CL. R. AT CL. STN. TO MISSION

DATE	STATION 67009	STATION 18049	STATION	STATION	STATION	STATION	STATION	STATION
1 MAY 1971	8660.00	346.40						
2 MAY 1971	9610.00	1943.20						
3 MAY 1971	10700.00	5102.20						
4 MAY 1971	12200.00	8279.39						
5 MAY 1971	13600.00	10300.19						
6 MAY 1971	15000.00	11732.39						
7 MAY 1971	16500.00	13120.18						
8 MAY 1971	18500.00	14567.98						
9 MAY 1971	19300.00	16087.98						
10 MAY 1971	19600.00	17569.98						
11 MAY 1971	20400.00	18735.98						
12 MAY 1971	22200.00	19563.98						
13 MAY 1971	27500.00	20597.98						
14 MAY 1971	30200.00	22563.98						
15 MAY 1971	29200.00	25453.98						
16 MAY 1971	27100.00	27929.98						
17 MAY 1971	24700.00	28597.98						
18 MAY 1971	22800.00	27505.98						
19 MAY 1971	21800.00	25611.98						
20 MAY 1971	21400.00	23777.98						
21 MAY 1971	21200.00	22457.98						
22 MAY 1971	21500.00	21721.98						
23 MAY 1971	22900.00	21485.98						
24 MAY 1971	24800.00	21787.98						
25 MAY 1971	26200.00	22719.98						
26 MAY 1971	27000.00	24101.98						
27 MAY 1971	27900.00	25501.98						
28 MAY 1971	28800.00	26647.98						
29 MAY 1971	28800.00	27561.98						
30 MAY 1971	23400.00	28245.98						
31 MAY 1971	27800.00	28543.98						

FIGURE 2

PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

OUTFLOW (CFS)

67009 CLEARWATER RIVER AT CLEARWATER STATION
18049 ROUTE CL. R. AT CL. STN. TO MISSION

DATE	STATION 67009	STATION 18049	STATION	STATION	STATION	STATION	STATION	STATION
1 JUNE 1971	28000.00	28433.98						
2 JUNE 1971	29600.00	28227.98						
3 JUNE 1971	31800.00	28443.98						
4 JUNE 1971	33100.00	29415.98						
5 JUNE 1971	32800.00	30877.98						
6 JUNE 1971	33000.00	32129.98						
7 JUNE 1971	35800.00	32861.98						
8 JUNE 1971	37900.00	33627.98						
9 JUNE 1971	37700.00	34999.98						
10 JUNE 1971	34600.00	36411.98						
11 JUNE 1971	32200.00	36659.98						
12 JUNE 1971	30100.00	35337.98						
13 JUNE 1971	29000.00	33187.98						
14 JUNE 1971	28900.00	31175.98						
15 JUNE 1971	27700.00	29755.98						
16 JUNE 1971	25600.00	28791.98						
17 JUNE 1971	23700.00	27725.98						
18 JUNE 1971	22500.00	26227.98						
19 JUNE 1971	22300.00	24581.98						
20 JUNE 1971	22700.00	23307.98						
21 JUNE 1971	22800.00	22685.98						
22 JUNE 1971	23900.00	22641.98						
23 JUNE 1971	27100.00	23073.98						
24 JUNE 1971	29000.00	24173.98						
25 JUNE 1971	29100.00	25957.98						
26 JUNE 1971	28400.00	27687.98						
27 JUNE 1971	26000.00	28475.98						
28 JUNE 1971	23500.00	28027.98						
29 JUNE 1971	21700.00	26529.98						
30 JUNE 1971	20800.00	24517.98						

FIGURE 2

PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

OUTFLOW (CFS)

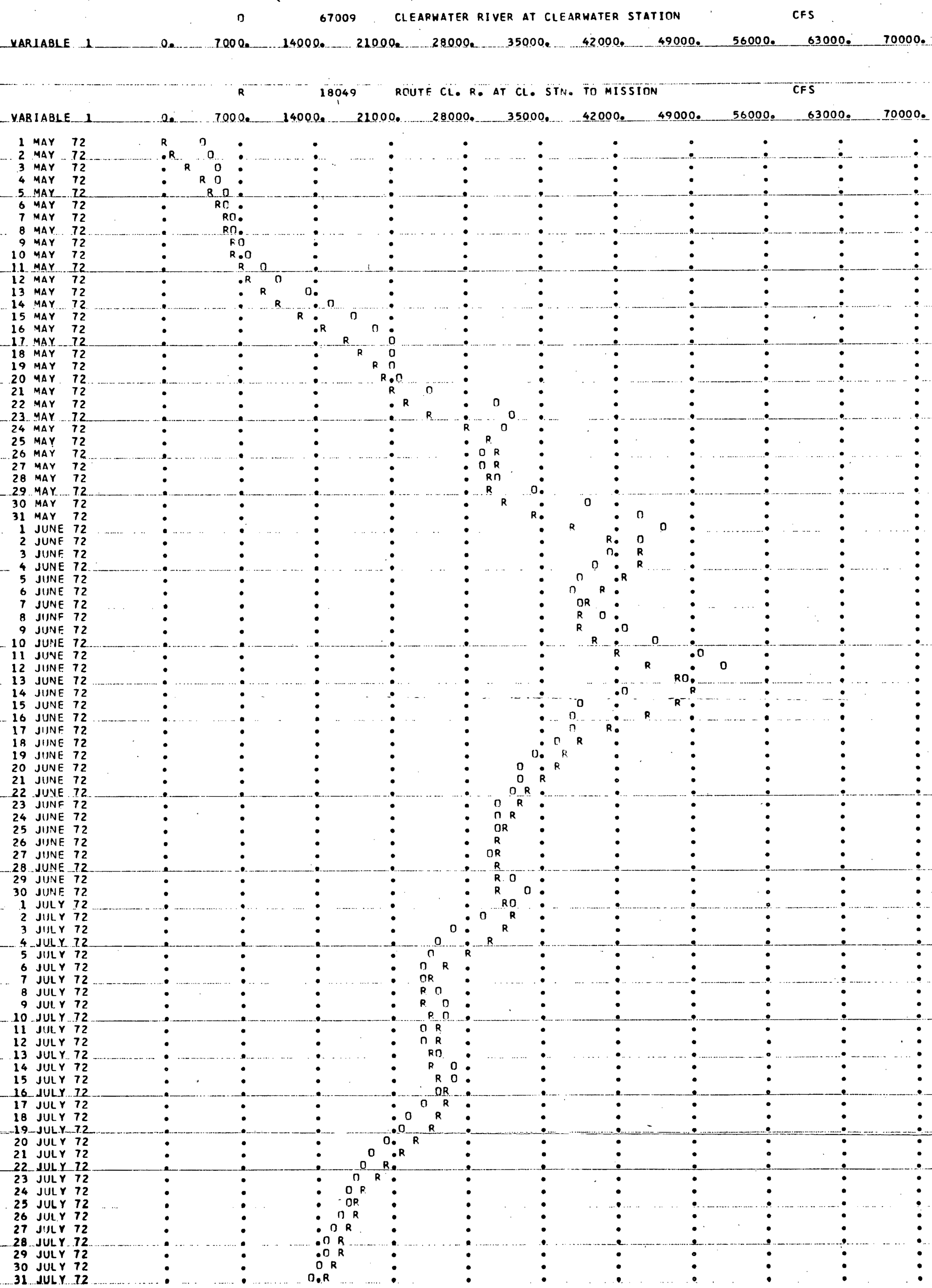
67009 CLEARWATER RIVER AT CLEARWATER STATION
18049 ROUTE CL. R. AT CL. STN. TO MISSION

DATE	STATION 67009	STATION 18049	STATION	STATION	STATION	STATION	STATION	STATION
1 JULY 1971	19700.00	22647.98						
2 JULY 1971	19000.00	21227.98						
3 JULY 1971	17900.00	20147.98						
4 JULY 1971	16800.00	19193.98						
5 JULY 1971	16400.00	18245.98						
6 JULY 1971	16100.00	17351.98						
7 JULY 1971	15500.00	16661.98						
8 JULY 1971	14800.00	16149.98						
9 JULY 1971	14700.00	15655.98						
10 JULY 1971	15900.00	15219.98						
11 JULY 1971	17300.00	15155.98						
12 JULY 1971	17500.00	15681.98						
13 JULY 1971	16700.00	16499.98						
14 JULY 1971	16700.00	17003.98						
15 JULY 1971	16600.00	16989.98						
16 JULY 1971	16600.00	16785.98						
17 JULY 1971	16600.00	16659.98						
18 JULY 1971	16600.00	16613.98						
19 JULY 1971	16800.00	16609.98						
20 JULY 1971	17300.00	16663.98						
21 JULY 1971	17700.00	16837.98						
22 JULY 1971	18000.00	17151.98						
23 JULY 1971	18000.00	17515.98						
24 JULY 1971	17900.00	17797.98						
25 JULY 1971	17200.00	17899.98						
26 JULY 1971	16200.00	17743.98						
27 JULY 1971	15500.00	17273.98						
28 JULY 1971	15000.00	16565.98						
29 JULY 1971	14700.00	15839.98						
30 JULY 1971	14500.00	15263.98						
31 JULY 1971	14400.00	14867.98						

FIGURE 2

```
CYCLE FOR PERIOD:  1  5 1972 31  7 1972
EOF ENCOUNTERED ON SEQUENTIAL FILE READ* RETURN*
```

FIGURE 2



O 67009 CLEARWATER RIVER AT CLEARWATER STATION CFS
VARIABLE 1 0. 7000. 14000. 21000. 28000. 35000. 42000. 49000. 56000. 63000. 70000.
R 18049 ROUTE CL. R. AT CL. STN. TO MISSION CFS
VARIABLE 1 0. 7000. 14000. 21000. 28000. 35000. 42000. 49000. 56000. 63000. 70000.
1 MAY 72
2 MAY 72
3 MAY 72
4 MAY 72
5 MAY 72
6 MAY 72
7 MAY 72
8 MAY 72
9 MAY 72
10 MAY 72
11 MAY 72
12 MAY 72
13 MAY 72
14 MAY 72
15 MAY 72
16 MAY 72
17 MAY 72
18 MAY 72
19 MAY 72
20 MAY 72
21 MAY 72
22 MAY 72
23 MAY 72
24 MAY 72
25 MAY 72
26 MAY 72
27 MAY 72
28 MAY 72
29 MAY 72
30 MAY 72
31 MAY 72
1 JUNE 72
2 JUNE 72
3 JUNE 72
4 JUNE 72
5 JUNE 72
6 JUNE 72
7 JUNE 72
8 JUNE 72
9 JUNE 72
10 JUNE 72
11 JUNE 72
12 JUNE 72
13 JUNE 72
14 JUNE 72
15 JUNE 72
16 JUNE 72
17 JUNE 72
18 JUNE 72
19 JUNE 72
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24 JUNE 72
25 JUNE 72
26 JUNE 72
27 JUNE 72
28 JUNE 72
29 JUNE 72
30 JUNE 72
1 JULY 72
2 JULY 72
3 JULY 72
4 JULY 72
5 JULY 72
6 JULY 72
7 JULY 72
8 JULY 72
9 JULY 72
10 JULY 72
11 JULY 72
12 JULY 72
13 JULY 72
14 JULY 72
15 JULY 72
16 JULY 72
17 JULY 72
18 JULY 72
19 JULY 72
20 JULY 72
21 JULY 72
22 JULY 72
23 JULY 72
24 JULY 72
25 JULY 72
26 JULY 72
27 JULY 72
28 JULY 72
29 JULY 72
30 JULY 72
31 JULY 72

FIGURE 2

PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

OUTFLOW (CFS)

67009 CLEARWATER RIVER AT CLEARWATER STATION
18049 ROUTE CL. R. AT CL. STN. TO MISSION

DATE	STATION 67009	STATION 18049	STATION	STATION	STATION	STATION	STATION	STATION
1 MAY 1972	3760.00	150.40						
2 MAY 1972	4190.00	844.40						
3 MAY 1972	4740.00	2222.20						
4 MAY 1972	5110.00	3610.20						
5 MAY 1972	5510.00	4460.00						
6 MAY 1972	5900.00	4965.19						
7 MAY 1972	6180.00	5368.19						
8 MAY 1972	6480.00	5738.59						
9 MAY 1972	7030.00	6082.20						
10 MAY 1972	7890.00	6456.39						
11 MAY 1972	9000.00	6973.99						
12 MAY 1972	10500.00	7732.79						
13 MAY 1972	13000.00	8810.19						
14 MAY 1972	15500.00	10317.39						
15 MAY 1972	17400.00	12293.78						
16 MAY 1972	19300.00	14513.98						
17 MAY 1972	20700.00	16637.98						
18 MAY 1972	20900.00	18463.98						
19 MAY 1972	21000.00	19827.98						
20 MAY 1972	21800.00	20631.98						
21 MAY 1972	24700.00	21191.98						
22 MAY 1972	30800.00	22311.98						
23 MAY 1972	32200.00	24707.98						
24 MAY 1972	31300.00	27965.98						
25 MAY 1972	30100.00	30425.98						
26 MAY 1972	29100.00	31073.98						
27 MAY 1972	29100.00	30505.98						
28 MAY 1972	31100.00	29805.98						
29 MAY 1972	34600.00	29843.98						
30 MAY 1972	39400.00	31201.98						
31 MAY 1972	44000.00	34019.98						

FIGURE 2

PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

OUTFLOW (CFS)

67009 CLEARWATER RIVER AT CLEARWATER STATION
18049 ROUTE CL. R. AT CL. STN. TO MISSION

DATE	STATION 67009	STATION 18049	STATION	STATION	STATION	STATION	STATION	STATION
1 JUNE 1972	46000.00	37849.98						
2 JUNE 1972	44300.00	41605.98						
3 JUNE 1972	41600.00	43857.98						
4 JUNE 1972	39700.00	44005.98						
5 JUNE 1972	38200.00	42507.98						
6 JUNE 1972	37800.00	40601.98						
7 JUNE 1972	38200.00	39107.98						
8 JUNE 1972	40700.00	38411.98						
9 JUNE 1972	42500.00	38731.98						
10 JUNE 1972	45600.00	40071.98						
11 JUNE 1972	49400.00	42183.98						
12 JUNE 1972	51600.00	44857.98						
13 JUNE 1972	48100.00	47601.98						
14 JUNE 1972	42600.00	49047.98						
15 JUNE 1972	38700.00	47889.98						
16 JUNE 1972	37500.00	44559.98						
17 JUNE 1972	37600.00	40995.98						
18 JUNE 1972	36200.00	38649.98						
19 JUNE 1972	34100.00	37409.98						
20 JUNE 1972	33000.00	36319.98						
21 JUNE 1972	33000.00	34975.98						
22 JUNE 1972	32100.00	33769.98						
23 JUNE 1972	31000.00	32953.98						
24 JUNE 1972	30500.00	32255.98						
25 JUNE 1972	30700.00	31507.98						
26 JUNE 1972	30900.00	30943.98						
27 JUNE 1972	30200.00	30719.98						
28 JUNE 1972	30700.00	30659.98						
29 JUNE 1972	32500.00	30657.98						
30 JUNE 1972	33500.00	31009.98						

FIGURE 2

PLOT HYDROGRAPHS BEFORE AND AFTER ROUTING TO MISSION

OUTFLOW (CFS)

67009 CLEARWATER RIVER AT CLEARWATER STATION
18049 ROUTE CL. R. AT CL. STN. TO MISSION

DATE	STATION 67009	STATION 18049	STATION	STATION	STATION	STATION	STATION	STATION
1 JULY 1972	31900.00	31807.98						
2 JULY 1972	29300.00	32341.98						
3 JULY 1972	26800.00	31755.98						
4 JULY 1972	25000.00	30025.98						
5 JULY 1972	24200.00	27867.98						
6 JULY 1972	23700.00	25997.98						
7 JULY 1972	23600.00	24739.98						
8 JULY 1972	24900.00	24097.98						
9 JULY 1972	26000.00	24059.98						
10 JULY 1972	25600.00	24577.98						
11 JULY 1972	23900.00	25179.98						
12 JULY 1972	23900.00	25221.98						
13 JULY 1972	25500.00	24745.98						
14 JULY 1972	26900.00	24553.98						
15 JULY 1972	26300.00	25113.98						
16 JULY 1972	25000.00	25875.98						
17 JULY 1972	23700.00	25997.98						
18 JULY 1972	22600.00	25297.98						
19 JULY 1972	21400.00	24175.98						
20 JULY 1972	20200.00	22979.98						
21 JULY 1972	19000.00	21795.98						
22 JULY 1972	18100.00	20617.98						
23 JULY 1972	17400.00	19493.98						
24 JULY 1972	17100.00	18521.98						
25 JULY 1972	16700.00	17775.98						
26 JULY 1972	16300.00	17243.98						
27 JULY 1972	15600.00	16815.98						
28 JULY 1972	15000.00	16359.98						
29 JULY 1972	14500.00	15819.98						
30 JULY 1972	13900.00	15235.98						
31 JULY 1972	13300.00	14661.98						

STOP 0
EXECUTION TERMINATED
T=14.24 DR=543

FIGURE 2

APPENDIX #1

FRASER RIVER UPSTREAM STORAGE STUDY

Tasks #5 and #7

SIMPAK Computer Program

User's Manual

Appendix to the Report

"Define and Develop Mathematical Simulation Models for Flood Regulation Study"

Department of the Environment
Inland Waters Directorate, Pacific & Yukon Region
Water Planning and Management Branch
March 1974

Note: Any updates to this manual will be available from the Inland Waters Directorate, Pacific & Yukon Region.

SIMPAK User's Manual

The following pages of documentation are intended to introduce the user to 'SIMPAK', the river simulating package.

The introductory section is directed to the uninitiated. The practicing hydrologist may wish to skip this part. However, it is often safer to assume ignorance rather than leave the user groping for missing background material.

As a set of programs 'SIMPAK' is written almost entirely in Fortran. There are, however, a few subprograms written in Assembler. Originally the routines were developed to run on the IBM 360/67 duplex system at U.B.C., however the routines are general enough that they can be run on any medium to large scale machine which supports Fortran. To the user this means that he can use 'SIMPAK' in almost any scientific computing environment to model a river system.

Hopefully this manual will serve two purposes:

1. To introduce the user to 'SIMPAK'.
2. To act as a handbook or 'users guide' in setting up river models.

An auxiliary manual 'SIMPAK PROGRAM GUIDE' is also available. This volume along with the source listings should satisfy the user who wishes to delve into the actual programming and logistic details of 'SIMPAK'. It covers everything from the assignment of logical units to the handling of input and output devices.

The SIMPAK program has evolved during the course of the Fraser River Upstream Storage Study to the form presented herein. This manual presents the program as of March 1974. Several further changes to the program are planned to provide additional capabilities. Information as to the current state of SIMPAK at any time can be obtained from the Inland Waters Directorate, Pacific & Yukon Region.

SIMPAK User's Manual

Contents

I Introduction

The purpose of this package of computer routines is to compute the streamflow characteristics of a river system for any given water input to the river. The computations have the same effect as a physical model. They will tell for any given configuration of the river system the effect the system itself has in delaying or manipulating flows.

In this way the program simulates or more accurately speaking "models" streamflow. Study with a model is useful when attempting to design efficient methods for controlling water flow.

Of course the model is not exact since the real life situation is never perfectly described by the model parameters. It can, however, give a good approximation and indication of what control action should be taken, and in this way helps in planning and evaluating the method of operation of various types of control works within a river system.

'SIMPAK' has also proved to be useful in manipulating streamflow data. Since all input data and output data is automatically given the correct date and station number it has been found to be a convenient method for making simple extensions to daily flow data, plotting hydrographs and computing river elevations corresponding to river flows.

A river system is usually monitored at observation points or stations. At these points the usual parameter measured is the water surface elevation relative to some prechosen datum. The river flow is obtained by relating flow to elevation through a continually updated scatter plot (rating curve). The rating curve must be updated because the physical attributes of the channel can change with time.

A hydrograph for a channel is a plot of flow as a function of time. Hydrograph data for various stations along a river system are made available by a monitoring agency, such as the Water Survey of Canada, who reduce observed water surface elevations to flow values through rating curves.

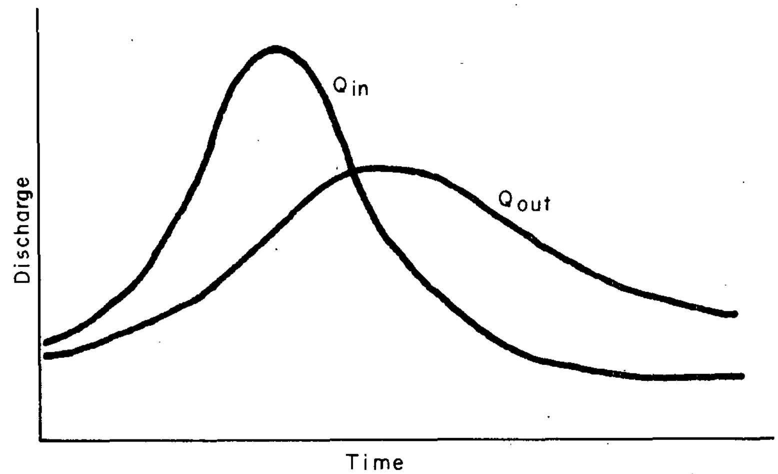
A river system is made up of a linked network of 3 main components:

1. the reach or length of channel,
2. the lake,
3. and the reservoir.

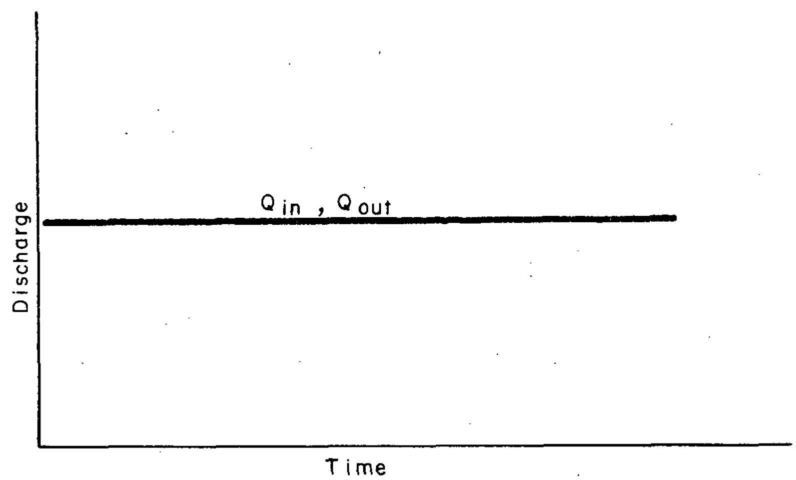
A property common to each component is that it introduces 'flow delay' into the composite river system through temporary or permanent storage. To the neophyte the storing effect and its associated component of the total flow delay introduced by a reservoir is quite familiar but usually not so the temporary storing effects introduced by lakes and reaches.

In the above we referred to a component of the total flow delay. The total flow delay introduced by a reach is due firstly to the time of travel of the flood wave through the channel and secondly to the temporary storing effect within the channel caused by the limitations on the discharging capacity.

Consider the following lake inflow and outflow hydrographs.

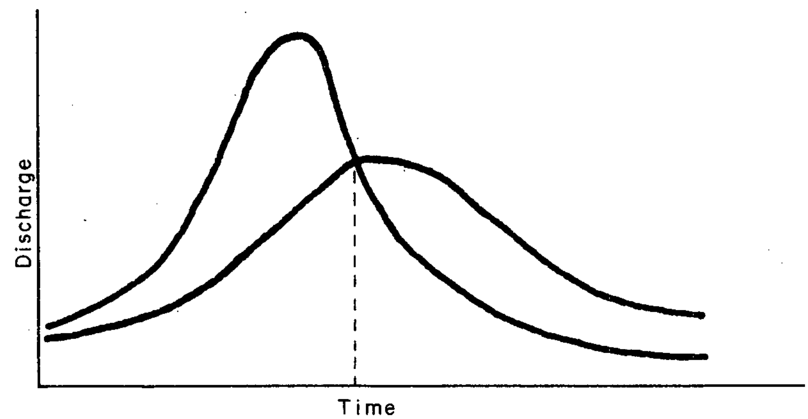


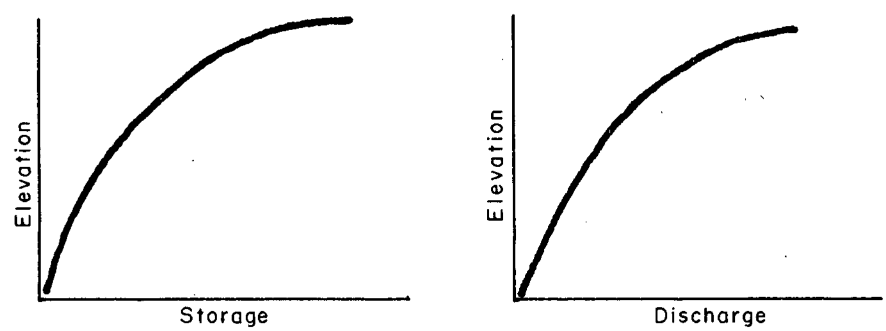
If the lake were in the steady state the ideal inflow and outflow hydrographs would be as follows:



However this is not the usual case. In real life the inflow to the lake is dynamically rising or falling. The outflow channel of the lake has a volume capacity which is a function of its physical constraints and the driving head. Should the inflow rise above the discharge capacity the excess is stored and the water surface elevation rises. If for a given elevation and discharge the inflow drops below the discharge, the lake level drops and the water previously stored is discharged. Thus one can conclude that for a lake the discharge and storing effect are both functions of lake elevation and due to the temporary storing effect, the lake can introduce downstream flow delay.

Overlaying the inflow and outflow hydrographs graphically, as below, shows the period of storing and discharging. Included are the characteristic discharging and storing functions of lake elevation, upon which the lake storing characteristics depend.





A reach also displays this property of introducing through temporary storage a component to the total flow delay. The secondary component is due to the time required for an inflow to physically traverse the reach.

In the case of the **reservoir** the discharge is not a function of surface elevation. The discharge hydrograph is forcefully controlled. However for any fixed discharge and inflow there can be a rise or fall in elevation and an increase or decrease in storage.

To the practicing hydrologist the passing of a flow through any of these components is termed routing. The inflow is routed through the

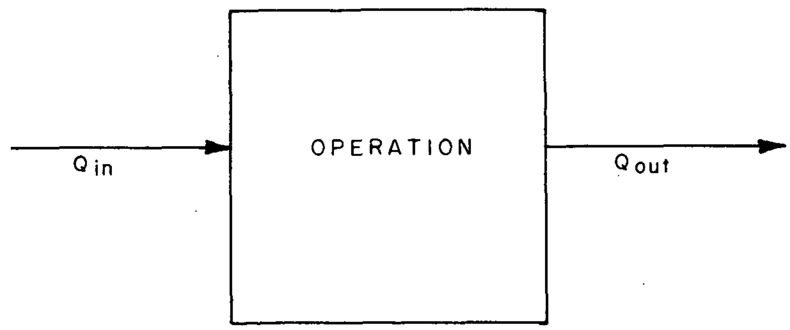
i) reach
ii) lake, or
iii) reservoir.

II 'SIMPAK' Modelling

1. Introduction to 'SIMPAK' conceptually:

In the previous section the concept of routing inflow through components to produce an outflow was introduced. This is the main task performed by 'SIMPAK'. It performs operations on inflows to produce outflows and through chaining, the outflow can become the inflow to the next downstream component etc., etc. The outflow is termed a routed outflow.

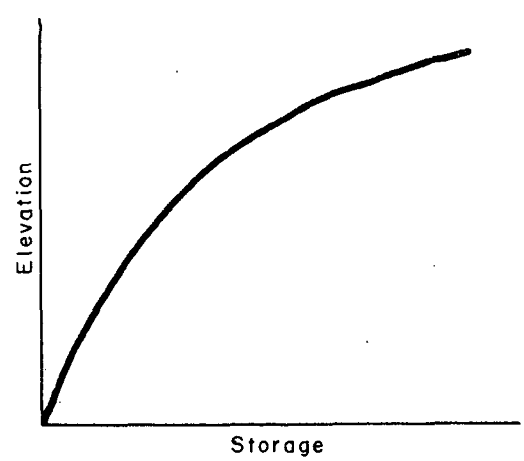
This operation equivalent can be drawn diagramatically as:



At the outflow station (where the routed flows exist) other stream flow characteristics such as water surface elevation and storage values can be computed. 'SIMPAK' can perform a lake, reservoir or reach routing calculation on an inflow hydrograph and complete the description of the outflow station given the characteristic discharge limitation. In the case of a reservoir these limitations are controlled. They can be specified as controlled values of discharge, reservoir elevations, storage or changes in storage. However the equation of continuity,

OUTFLØW = INFLØW - CHANGE IN STØRAGE

links storages to discharge. The characteristic storage elevation curve, as illustrated below, must be known in order to complete the description of the reservoir station.



The concept of 'operating on a station' hydrograph allows for the extension to any meaningful operation. The discussion to this point has included routing only, however, obviously other operations could be envisaged. For example to compute the net flow where two reaches join, the flows routed to the junction could be 'added'. To compute the local flow between 2 stations, the upstream station would be 'subtracted' from the downstream station.

'SIMPAK' incorporates many operations which will be discussed individually and in detail in a special section. This is, however, the basic idea behind all 'SIMPAK' models. Each component or meaningful operation is defined as operating upon specified hydrographs or other streamflow characteristics known at specified stations to produce either characteristics at other stations (routed flows, locals or correlations) or helpful auxiliary information (plots).

2. Description of a Station

A station is a point along the river system at which streamflow characteristics are either known or to be calculated. For example an

a. input station at which flow is known
b. a reservoir station at which
    (1) discharge flow is known
    (2) elevations are to be calculated
    (3) storages are to be calculated
    (4) changes in storage are to be calculated
c. a lake station at which
    (1) the discharge as a function of elevation is known
    (2) the storage as a function of elevation is known
    (3) the discharge is to be calculated
    (4) the storages are to be calculated
    (5) the elevations are to calculated
    (6) the change in storage is to be calculated

Each station is identified by a unique number refered to as the station number. These numbers usually obey certain naming conventions:

e.g. Water Survey of Canada numbers
Streamflow Synthesis and Reservoir Regulation
(WSC numbers or SSARR numbers)

As it is often convenient to access data for a station under a different numbering convention than the one used within the model, a cross-reference table can be set up to facilitate this.

3. Time Base:

The 'SIMPAK' model operates over a specified period of time. The beginning and ending dates of the model period must be made known to 'SIMPAK'. It assumes that streamflow characteristics must be calculated for that period only. To the user, dates are specified as Gregorian dates although internally the program logic uses the Julian calendar.

4. Closing Remarks

Having discussed the general concepts of river streamflow modelling and to some extent including 'SIMPAK' in the discussion, it is time to move on to the details of setting up and invoking a 'SIMPAK' model. Naturally the program has shortcomings and idiosyncracies which may not be covered in the next section. The only way to become aware of these, plus the flexibility and auxiliary uses of the modelling program, is to actually set up and compute flow characteristics for oneself.

III Setting Up the Model

Let us go back and restate that

(i) 'SIMPAK' - computes streamflow characteristics at stations specified for any given input to the river system,

(ii) 'SIMPAK' - operates on data which is identified by station number to produce (a) data at another station
(b) auxiliary information,

(iii) all stations in a model, be they initial condition stations or a station to be calculated, must be made known to 'SIMPAK'.

'SIMPAK' quite simply scans the list of all stations and automatically retrieves from the databanks the initial input to the river system. It then executes the specified operations be they calculating data at another station or producing auxiliary information. As has already been mentioned, the program operates in a specified model time period. However, it is capable, upon completion of the model for that period, of reinitializing the stations to another time period and executing the model for the new time base.

IV Control Cards

The user communicates with 'SIMPAK' via a deck of control cards. These cards describe all stations within the model, specify operations and can set the recycle option on. The following pages describe these control cards.

1. Preamble:

delimiters and other concepts:

(1.a) often when the number of cards read can not be anticipated there must be a 'that's all' flag. This is called an end of file delimiter. 'SIMPAK' delimiters take the form $END.

(1.b) 'SIMPAK' is capable of calculating up to four streamflow characteristic variables at any station. They are:
1 = flows (cfs)
2 = elevations (feet)
3 = storages (acre feet)
4 = changes in storages (cfs - days)
These are referred to as variables (i.e.) VARIABLE3=STØRAGES

(1.c) A file is a group of records of data. For example a file of flow data in WSC card image format.

(1.d) A 'volume' is a physical unit upon which the data is stored.

e.g. a card deck,
a magnetic tape or a disc pack

(1.e) Numbers: real or floating - have a decimal point which can be written (i.e.) 14.713
if not expressed it defaults to the right
14713 = 14713.
integer numbers - do not have a decimal point written. It is assumed to be right justified
1313 = 1313.

2. Title Card:

The title card is the first card in the deck. The information on it is title information which will appear on the top of each page of printed output.

3. Station Cards:

These cards follow the title card and are closed with the delimeter ($END). They are order free but should follow a natural modelling order. Each and every station must appear in this set of cards.

Column	Description
5 - 13	----- The station number.
24	----- The variables to be printed for this station upon completion of model.

e.g. value		what is printed
1	=	1
2	=	2, 1
3	=	3, 1
4	=	4, 1
5	=	1, 2, 3
6	=	1, 2, 4
7	=	1, 3, 4
9	=	all
0	=	NO PRINTØUT
where 1	=	flows
2	=	elevations
3	=	storages
4	=	changes in storage

31 - 80	---------- An alphanumeric description of the station which appears in the listing.

4. The Initialization Card:

This card follows the station delimiter ($END). It sets up the time boundaries of the model and also defines the type of input files.

Column		Description
1 - 2		initial day of model period
4 - 5		initial month of model period
7 - 10		initial year of model period
13 - 14		final day of model period
16 - 17		final month of model period
19 - 22		final year of model period
25 - 29	blank or 0	= no retrieval from WSC databank (tape)
	1	= retrieval from 1st volume of databank
	2	= retrieval from 2nd volume of databank
	3	= retrieval from 1st and 2nd volume of databank
30 - 34	blank or 0	= no data retrieved from a disk file
	1	= data to be retrieved from a SSARR file
	2	= data to be retrieved from a SSARR file and from a WSC file
	3	= data to be retrieved from a WSC file

Note: In a SSARR file card image data is in the SSARR format. In a WSC file card images are in the WSC format. If WSC data is used a cross reference between the station numbers on the description cards (SSARR by convention) and the corresponding WSC numbers in the data file must be supplied. The cross reference file name is WSC.DICT. For a writeup on WSC.DICT see the Appendices.

35 - 39	----	To compute storages and elevations at lake and reservoir stations the characteristic functions of elevations for those stations must be read in: 0 = no tables to be read in 1 = read tables For a description of the table format see the Appendices. These tables can be used for other purposes such as flow correlations.
40 - 44	----	The lead time used by the 'wave' operation. See the writeup on WAVE blank = 0
45 - 49	----	for future use
50 - 54	----	If this flag is on,data is retrieved from a specially formated file called 'a long record file'. Data within this file is created by reformatting the WSC or SSARR card formats to another format which can be read faster thus reducing the computing cost.

5. The Operation Cards:

The operation cards specify what operation is to be done and upon what stations. It may also specify a station number to be assigned at the output of the operation. Thus it is a set of these linked operations which define the model.

They all take the same form but for each operation the significance of each field is different.

Standard format for all operation cards:

Column		Description
1 - 4		---- the 'code' of the operation
6 - 15	STA1	---- station number to assign to results of operation
16 - 25	STA2	---- the upstream station
26 - 35	STA3	---- a second upstream station (if required)
36 - 45	STA4	---- a third upstream station (if required)
46 - 47	VAR1	
48 - 49	VAR2	---- 'integer' parameters that may be required by the operation
50 - 51	VAR3	
52 - 60	PAR1	
61 - 70	PAR2	---- 'floating point' parameter that may be required by the operation
71 - 80	PAR3	

These operation cards are stacked after the data initialization card and are followed by the delimiter $END. Each operation will be described separately. The columns to specify will be identified by name.

i.e. STA1 = 6 - 15
STA2 = 16 - 25
VAR3 = 50 - 51

When 'SIMPAK' encounters an operation card it performs the operation specified which may be generating a plot or calculating values for a station. The operations which define the model are taken in sequential order.

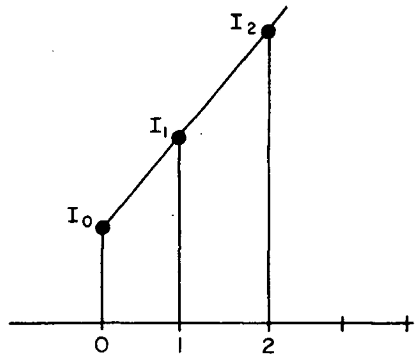
(5.a) Operation Code 'REAC'

When 'SIMPAK' encounters this operation code the sub-program to do a reach routing by the SSARR method is invoked. The fields to specify are:

STA1 = the reach route station number
STA2 = the upstream station
STA3 = a second upstream station which will be added to station 2 to form the inflow hydrograph (if required)

PAR1 = SSARR 'N' parameter
PAR2 = SSARR 'KTS' parameter
VAR1 = SSARR 'NPS' parameter (number of phases)
PAR3 = the starting inflow. If not specified starting inflow is determined by backward extrapolation from day 1.

i.e.



STA4 = the starting outflow and if not specified STA4 = PAR3

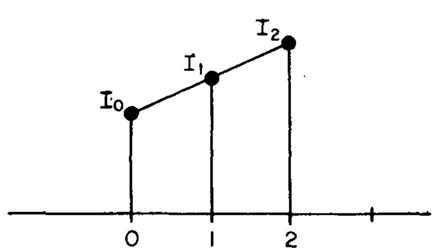
Note:
(i) If STA2 and STA3 are both specified they are added together to form the inflow hydrograph.
(ii) 'VAR1' phases are established and inflow values for each phase are initialized by interpolation between PAR3 and STA4.
(iii) Routing is performed for each day in the model period using the SSARR method (see Sect. VII for a discussion of this method).

(5.b) Operation Code 'LAKE'

When 'SIMPAK' encounters this operation code the sub-program to do a 'LAKE ROUTE' is invoked, (see Sect. VII). The fields to specify are:

STA1 = the 'lake route station'
STA2 = the upstream station
STA3 = a second upstream station (if required)
PAR1 = the initial inflow. If this value is not specified it is assumed to be equal to the value obtained by extrapolating back from day one.

i.e.



PAR2 = the initial outflow (if PAR2 not specified, PAR2 = PAR1)

Note: (i) Lake routing is performed for each day of the model period (See Sec. VII)
(ii) The 'lake station' description will be completed. Elevation, storage and changes in storage will be calculated for each day of the model period. The description is completed by using the Tables read in for the lake station.

(5.c) Operation Code 'LOCA'

When 'SIMPAK' encounters this operation code the sub-program to calculate a 'local' is invoked, (see Sect. VII). The fields to specify are:

STA1 = the 'local' station
STA2 = the upstream station to be subtracted
STA3 = the second upstream station to be subtracted (if required)
STA4 = the station from which stations 2 and 3 are subtracted.

Note: (i) FLØW(STA1) = FLØW(STA4) - (FLØW(STA3) + FLØW(STA2))
(ii) If STA3 is not specified it will not enter into the calculation.

(5.d) Operation Code 'SUBT'

When 'SIMPAK' encounters this operation code the sub-program which performs a 'generalized subtraction' over the model period is invoked. The fields to specify are:

STA1 = the 'subtract' station
STA2 = station to be subtracted from
STA3 = station to be subtracted
STA4 = a second station to be subtracted (if required)
VAR1 = variable for station 1 (i.e. flow, elevation, storage or change in storage)
VAR2 = variable for station 2
VAR3 = variable for stations 3 and 4.

Note: (i) At any station, up to four variables are available for use in SUBT. These variables are:
1 = flows
2 = elevation
3 = storage
4 = change in storage

(5.e) Operation Code 'RESE'

When 'SIMPAK' encounters this operation the sub-program to do a 'reservoir route' (see Sect. VII) is invoked. The fields to specify are:

STA1 = the 'reservoir route' station
STA2 = the upstream station
STA3 = a second upstream station (if required)
VAR1 = type of 'control' data (or rather the variable used) for expressing the discharge control
  1 = flows
  2 = elevations
  3 = storage
  4 = changes in storage
PAR1 = the initial value of 'storage' in acre feet. If this value is not specified when VAR1 = 1 or 4, an error will occur.

Note:
(i) If STA2 and STA3 are both specified they are added together.
(ii) The 'reservoir station' description will be completed. Elevation, storage and changes in storage will be calculated for each day of the simulation period using the elevation tables.
(iii) The control function for a reservoir is a time series. It must be concatenated or included in the data file. 'SIMPAK' uses the inflow hydrograph plus the control function to complete the description of the reservoir route station.

(5.f) Operation Code 'ADD'

When 'SIMPAK' encounters this operation the sub-program which performs a generalized 'add' over the period of the model is invoked. The fields to specify are:

STA1 = the 'ADD' operation station number
STA2 = the station to add
STA3 = the station to add
STA4 = the station to add
VAR1 = the variable added at each station
  1 = flows
  2 = elevations
  3 = storages
  4 = changes in storage

Note:
(i) The number of variables for a station can be up to 4 as mentioned in the 'subtract'. VAR1 points to which variable that is to enter into the add operation.
(ii) The add operation runs over the period of the model.

(5.g) Operation Code 'TRSF'

When 'SIMPAK' encounters this operation code it transfers and scales data over the model period. The fields to specify are:

STA1 = the station number of the 'TRSF' operation
STA2 = station to be multiplied
VAR1 = variable for STA1
VAR2 = variable for STA2
PAR1 = the scaling factor

Note: (i) The number of variables for a station can be up to 4. VAR2 points to which variable is scaled and VAR1 to where it is to be stored.
VAR1(STA1) = VAR2(STA2) * PAR1
(ii) The default value of PAR1 = 1.0

(5.h) Operation Code 'SET'

When 'SIMPAK' encounters this operation code the sub-program to set a variable to a constant is invoked. The fields to specify are:

STA1 = the 'set' station number
PAR1 = the constant to store
VAR1 = variable number where results are stored

Note: (i) There are up to 4 variables known at any station. VAR1 indicates which of the 4 are to be set to a constant.
1 = flows
2 = elevations
3 = storage
4 = changes in storage
VAR1(STA1) = PAR1
(ii) The setting to a constant value runs over the period of the model.

(5.i) Operation Code 'FILE'

When 'SIMPAK' encounters this operation code the sub-program to write a SSARR file is invoked. The fields to specify are:

STA1 = the station number for which data is to be written
VAR1 = the variable for station STA1 to be written

Note: (i) Data for the entire period of the model will be written. VAR1 is the variable number to write,

Variable Number
1 = flows

2 = elevations
3 = storages
4 = changes in storage
9 = all four

(ii) Note the written data is in SSARR Format.

(5.j) Operation Code 'PRIN'

When 'SIMPAK' encounters this operation code the sub-program to print variables with Gregorian dates is invoked. The fields to specify are:

STA1 = the station to be printed
VAR1 = controls what will be printed. The legal values and what they print are the same as values on the station cards.

Note:

(i) The data will be printed for the indicated (station, variable(s)) over the period of the model. The print out will be paged on a monthly basis.

(5.k) Operation Code'WAVE'

When 'SIMPAK' encounters this operation code it invokes a 'reach route' by the polynomial method (see Sect. VII). The fields to specify are:

STA1 = the 'wave routing' station
STA2 = the primary upstream station
STA3 = a second upstream station, (if required)
VAR1 = the beginning day relative to the time origin (see Sect. VII)
VAR2 = the final day relative to the time origin (see Sect. VII)

Note:

(i) The routing coefficients for the 'wave' routine are coded on a fixed format card. This card must follow the 'wave' operation card in the control deck. The format of the card is discussed in the Sect. VII.

(5.l) Operation Code 'EXTN'

When 'SIMPAK' encounters this operation code the sub-program to generate flows for station STA1 from the 'correlation' curve relating flows at station STA1 to STA2 is invoked. The correlation curve must be read in as a characteristic table for Station STA1. The fields to specify are:

STA1 = the station for which flows are to be generated
STA2 = the station whose flows are input to the correlation curve to determine flows at STA1

(5.m) Operation Code 'PLOT'

When this operation code is encountered the 'SIMPAK' will produce a 'printer plot' of selected variables (flow, elevation, storages, changes in storage) with calendar dating. The fields to specify are:

VAR1 = the number of plots to generate.

Directly following the plot operation card are the plot cards (one card for each hydrograph to be plotted on the same page).

Column	Plot Card Description
7 - 15	Station number to be plotted
20	Variable number to be plotted
25	Character to plot at the data points
26 - 35	Beginning scale (lowest value)
36 - 45	Ending scale (highest value)

Note: (i) The scales, labels, characters and units are printed out for each variable.
(ii) One data card 'plot card' is required for each plot line.

(5.n) Operation Code 'USER'

This is a special operation code which would not normally be used. When 'SIMPAK' encounters this code a message is written on the printed output to indicate that a call to 'USER' was made, however, no operation is performed on any data. This operation code does have a very important use which is discussed in the 'SIMPAK Program Guide'. It is this operation code which allows the user to create his own routines,

e.g.
- reservoir regulation
- streamflow forecasting

while taking full advantage of 'SIMPAK's' I/O handling facilities as well as the other operational commands.

(5.o) Operation Code 'SARP'

When 'SIMPAK' encounters this operation code, calcomp pen plots for specified station(s) are produced. The fields to specify are:

STA1 = this station will be plotted (variable 1)
STA2 = this station will be plotted (variable 1)
If STA2 is not specified it will not be plotted

VAR1 = a switch to define the time scale;
1 = 4 days/inch,
any other value = 40 days per inch.

VAR2 = a switch to define the discharge scale;
0 = automatic scaling to fit ten inch plot,
non zero = a scale card must be read.

Format of the scale card

Column	Description
1 - 5	the minimal flow value
6 - 10	cfs/plot inch
11 - 15	days/plot inch

Note: (i) All values in the scale card must be specified, and they will supersede values given in the plot card.

(ii) The scale card, if it is to be read, must follow directly behind the SARP card.

(5.p) Operation Code 'MEAN'

When 'SIMPAK' encounters this command it computes mean monthly flows for specified months. Fields to specify are:

STA1 = station for which means are calculated
VAR1 = 0 print means only
= 1 print means to a file
= 2 means and totals are written to 2 separate files
VAR2 = 0 = write flows in CFS
= 1 = write flows in KCFS

The month control card must follow the mean card. It specifies for which months means are calculated. (Zero or blank, means not calculated.)

Column	Description
1 - 2	1st month of a year (January)
3 - 4	2nd " " " "
5 - 6	3rd "
7 - 8	4th
9 - 10	5th
11 - 12	6th
13 - 14	7th
15 - 16	8th
17 - 18	9th
19 - 20	10th
21 - 22	11th
23 - 24	12th

Only months falling within the model period should be specified.

Note: (i) VAR2 is applicable only when VAR1 = 0 or 1

(5.q) <u>Operation Code 'RATI'</u>

This operation code requests 'SIMPAK' to calculate the ratios between daily flow values. The fields to specify are:

STA1 = the station number of the ratios
STA2 = the station number of the numerator
STA3 = the station number of the divisor

<u>Note</u>:

(i) Only ratios of flows are computed.

(5.r) <u>Operation Code 'LOOK'</u>

This operation code requests 'SIMPAK' to determine the variable value at a station given a general correlation curve. The fields to specify are:

STA1 = the station for which values are generated
STA2 = the station entering the table
VAR2 = variable used at station STA2
VAR1 = variable used at station STA1

This operation is designed for use with the standard stage/storage/discharge tables that can be input for a station. It is usually used to determine river stages from discharges or vice-versa, and in such cases STA1 and STA2 are the same. It can apply from one station to another, but in that case special care is required in its use.

(5.s) Operation Code 'WLNR'

When 'SIMPAK' encounters this operation, data for specified station(s) is data written in the 'EDPR long record' format. These are the most efficient records to write. If reread they can reduce the input time by up to 60%. The fields to specify are:

STA1 = this station will be written if specified
STA2 = " " " " " " "
STA3 = " " " " " " "
STA4 = " " " " " " "
VAR1 = variable to be written for station STA1
VAR2 = " " " " " " STA2
VAR3 = " " " " " " STA3
PAR1 = " " " " " " STA4

6. End Card :

Because it is impossible to know apriori how many operations define a model the delimiter $END follows the last operation command.

7. Cycle Card:

Having invoked all the operations the modelling process has been completed for this time period, however through the use of a 'cycle' card the user can cause 'SIMPAK' to reinitialize the same stations with new time base data and invoke the operation commands again. In effect the user is running the same model for a different model period.

The number of cycles is arbitrary. However, the last cycle must be followed with a delimiter $END. If there are no cycles the operations are thus followed by two $END cards.

The format of the 'cycle' card:

Column	Description
1 - 4	'CYCL' must appear
11 - 12	initial day of cycle
14 - 15	initial month of cycle
17 - 20	initial year of cycle
22 - 23	final day of cycle
25 - 26	final month of cycle
28 - 31	final year of cycle
32 - 37	for future use
38 - 45	if a different tape is to be used for this 'cycle' (i.e.) a different number of the data bank volume, it can be specified here. (See Columns 25 - 29 of initialization card.)

V Deck Setup

Based on what has been mentioned above, what would a 'SIMPAK' deck look like for any arbitrary model?

```
JOB TITLE CARD
STATION 1  DESCRIPTION CARD
        2
        3
        :
STATION N  DESCRIPTION
$END
INITIALIZATION CARD
OPERATION 1 CARD
    :
OPERATION K CARD
$END
CYCLE CARD
$END
```

It is as simple as that. No control card deck varies from this setup. It might perhaps be useful to consult the example volume of a 'SIMPAK' run. Look only at the general setup and verify that it follows the general form stated.

VI Automatic Data Handling

The source type of data is made known to 'SIMPAK' on the data initialization card. For example a 1 in card columns 25 - 29 would tell 'SIMPAK' that the initial data is in a file of which each record is on the SSARR card image format. There are many input data combinations which if specified correctly will cause 'SIMPAK' to automatically retrieve the correct (station, time) values. For example a 1 in card column 54 and a 2 in 25 - 29 tell 'SIMPAK' that

(i) some of the initial data is in a 'long record file'
(ii) some of the initial data is in a SSARR file
(iii) some of the initial data is in a WSC file

'SIMPAK' will automatically search each file in an attempt to find all of the initial station values.

Files are accessed by logical units. These can be thought of as data paths. There are units for all input output servicing. For example, the unit number or the number of the data path for reading SSARR files is 0, for writing on the printer is 6, for writing out long records is 15. A detailed list of the logical assignments is in the Appendices of the 'SIMPAK Program Guide'.

The user must assign all the units required for running a specific model on his run card.

The run card format is:

```
$R        Program name        Logical assignments
```

For example, if within a run the user wishes to

(i) read SSARR data from file FDS.18009
(ii) read WSC data from file FDW.18077
(iii) write on the printer
(iv) read his control deck through the card reader
(v) write long records to a File FDL.130017
(vi) read tables from a file TDF.16007

the run might look like

```
$R  PO.SIMPAK   0 = FDS.18009    1 = FDW.18077
                6 = *SINK*       5 = *SØURCE*
                8 = TDF.16007   15 = FDL.130017
```

These logical assignments establish the data paths required by PO.SIMPAK. *SINK* and *SØURCE* are the default values for 6 and 5 so this card can be condensed to read

```
$R PO.SIMPAK 0 = FDS.18009  1 = FDW.18077  8 = TDF.16007  15 = FDL.130017
```

It is virtually impossible to lay out all the options for the logical assignments. Familiarity will be gained through the experience of running various models. The programming staff should aid in showing the user more about the concepts and alternatives behind logical assignments.

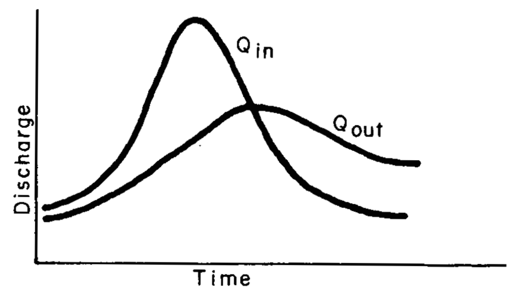
Note:

In the above example it is assumed that the user is running his model at U.B.C. under MTS.

VII Additional Notes

1. 'Lake Routing'

The object of performing a 'lake routing' calculation is to determine the outflow hydrograph of the lake given the inflow hydrograph and the 'flow delay' or discharge characteristics of the lake itself. As the flood passes through the lake the inflow hydrograph is modified by 'temporary storage' to produce the outflow hydrograph.



The figure above shows the respective hydrographs and displays the 'storing' effect.

The reason for 'routing' the flow through the lake is that in general the outflow or discharge hydrograph is the inflow hydrograph to the next downstream station.

There are many ways of performing the lake routing all of which depend upon the equation of continuity,

$$I = 0 \pm \Delta S$$

where I = the total inflow
0 = the total outflow
ΔS = the change in storage.

The method used by 'SIMPAK' is a version of 'Puls Method', which is described in most text books on hydrology.

Consider a routing period(T_2, T_1), such that $T = T_2 - T_1$ is of short duration. Equation 1 can then be written as,

$$I = \frac{0_1 + 0_2}{2} + S_2 - S_1$$

where I is the mean inflow over the period $T_2 - T_1$.

$$I = S_2 + \frac{0_2}{2} - S_1 + \frac{0_1}{2} - \frac{0_1}{2} + \frac{0_1}{2}$$

or

$$S_2 + \frac{0_2}{2} = I + (S_1 + \frac{0_1}{2}) - 0_1 \qquad \text{.....(1)}$$

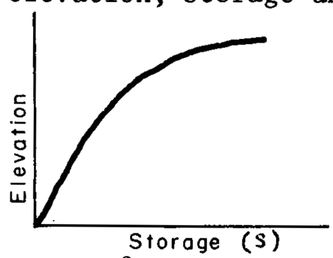
This equation is the basic routing equation.

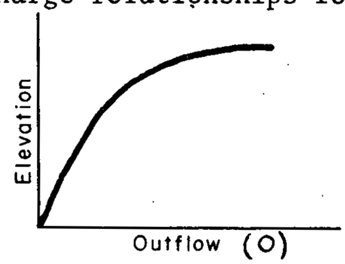
Next let $Y = S + \frac{0_2}{2}$

then $Y_{k+1} = f(\hat{I}(k, k+1), Y_k, 0_k)$ implies that Y at the end of the k^{th} period is Y at the beginning of the period modified by equation (1).

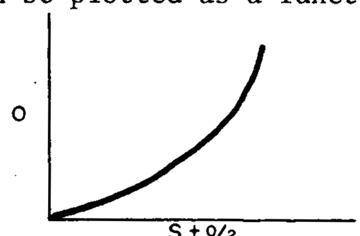
A method for determining 0_2 would involve calculating Y_k for each period T and knowing 0_k and I(k, k+1) calculate by (1) Y_{k+1}. Y_{k+1} however determines the value of 0_{k+1} from a Y(0) function.

The elevation, storage and discharge relationships for the lake are known;

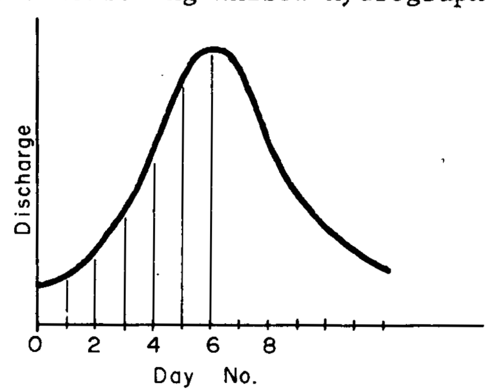




from these a $Y = S + \frac{0}{2}$ can be plotted as a function of 0.



For any Y_{k+1} the value of 0 can be determined from this function. For example, consider the following inflow hydrograph;



by (1) if $k+1 = 1$

$$Y_1 = I(0,1) + Y_0 - 0_0,$$

(Note that values of I_0 and 0_0 are the initial conditions.)

calculate $Y_0 = S_0 + \frac{0_0}{2}$ and Y_1

from Y as function of 0 determine 0,

<u>$k = k+1 = 2$</u>

$Y_2 = \hat{I}(1,2) + Y_1 - 0_1$, Y_1 and 0_1 from previous step

Y as function of 0 determine 0_2,

<u>$k = k+1 = 3$</u>

$Y_3 = \overset{\Delta}{I}_{(3,2)} + Y_2 - 0_2$, Y_2 and 0_2 from previous step

from Y as function of 0 determine 0_3,

<u>$k = k+1 = 4$</u>

etc.

By continuing in this fashion step wise across the inflow hydrograph the outflow hydrograph can be determined. The changes in elevation, storage and changes in storage as functions of time can be determined knowing the outflow hydrograph (discharge) and the storage and discharge expressed as functions of elevation.

2. '<u>Reservoir Routing</u>'

The object of performing a 'reservoir' routing calculation is to determine the outflow hydrograph of the reservoir given the inflow hydrograph and the 'flow delay' characteristics of the reservoir itself. As a flood passes through the reservoir the inflow hydrograph is modified by 'controllable storage' to produce the outflow hydrograph. In the case of a lake, the discharge as a function of time is not controllable; in the case of a reservoir the discharge is controlled.

The reservoir route calculation of 'SIMPAK' can follow one of four paths depending upon how the reservoir control is expressed.

The equation of continuity is the fundamental equation used:

$$I = 0 \pm \Delta S$$

where
I = the inflow
0 = the outflow
S = the storage

This equation can be written as:

$$\frac{I_{k+1} + I_k}{2} = \frac{0_{k+1} + 0_k}{2} + S_{k+1} - S_k \quad \text{for a routing period}$$

$$\Delta T = T_{k+1} - T_k$$

The reservoir storing effect is expressed by the S(E) where,

S = the storage
E = the reservoir elevation

if $\frac{I_{k+1} + I_k}{2} = \hat{I}_{k+1}$, $\frac{0_{k+1} + 0_k}{2} = \hat{0}_{k+1}$, $S_{k,k+1} = S_k - S_{k+1}$

and S_o is an initial condition of storage. The recursive equations then depend upon the reservoir control which may be specified in one of four ways:

(a) discharge control

$$S_{k,k-1} = \hat{I}_k - \hat{0}_k$$

$$S_k = S_{k-1} + S_{k,k-1}$$

$$E_k = E(S_k)$$

(b) elevation control

$$S_k = S(E_k)$$

$$S_{k,k-1} = S_k - S_{k-1}$$

$$\hat{0}_k = \hat{I}_k - S_{k,k-1}$$

(c) storage control

$$E_k = E(S_k)$$

$$S_{k,k-1} = S_k - S_{k-1}$$

$$\hat{0}_k = \hat{I}_k - S_{k,k-1}$$

(d) if change in storage control

$$S_k = S_{k,k-1} - S_{k-1}$$

$$E_k = S(E_k)$$

$$\hat{0}_k = \hat{I}_k - S_{k,k-1}$$

Note:

The type of control will govern the method of calculating the missing variables to completely describe the reservoir.

3. 'Reach Routing'

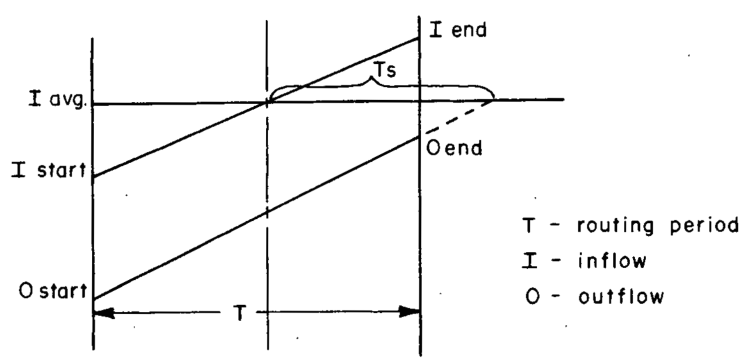
(a) 'SSARR Method'

The object of performing a 'reach route' is to determine the outflow hydrograph of the reach given the inflow and the 'flow delay' characteristics of the reach itself.

This method assumes that the reach can be considered as the sum of 1 to 10 storage elements called "phases". Each storage element operates as a simple lake. The outflow characteristics of these "lakes" is specified by a "time of storage" (T_s) determined by two input parameters.

$$T_s = \frac{KTS}{Q^n}$$

The outflow from each "phase" is determined using T_s in a linear relationship as shown below.



The initial conditions required are:

STARTing outflow O_0

STARTing inflow I_0

This method of performing a reach route is somewhat more sophisticated than 'WAVE' method, however, the end results are similar.

(b) 'Wave Method'

The object of performing a 'reach' routing calculation is to route the inflow hydrograph over the length of reach given the 'flow delay' characteristics of the reach itself.

The flow is routed using a linear routing method in which the outflow of the reach on any particular day is defined as a linear function of the inflows to the reach over a number of days.

i.e. $0_j = aI_j + bI_{j-1} + cI_{j-2} + \ldots etc.$ ...(1)

where 0 = the outflow
I = the inflow
a,b,c,....are the 'flow delay' CØNSTANTS

The routing constraints do not change from day to day nor with level of flow, but are constant for a given length of reach. From equation (1) it can be seen that the outflow on day J is controlled by:

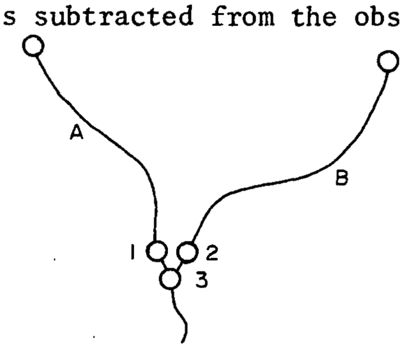
(i) the weighting constants
(ii) the length of 'memory' (M) of the equation

$$o(t) = \sum_{\lambda = t-M+1}^{t} i(\lambda)\ w(t-\lambda+1)$$

if $\lambda < 1$, $\lambda = 1$

4. 'Local Calculations'

To calculate the 'local' flow at a station the routed flow for all upstream stations is subtracted from the observed net flow at the station.



For Example: If STATIØN1 contains the flow routed over branch A and STATIØN2 the flow routed over B, then the local at STATIØN3 is defined as:

Local flow at STATIØN3 = net flow (STATIØN3) - (flow(STATIØN1) + flow(STATIØN2))

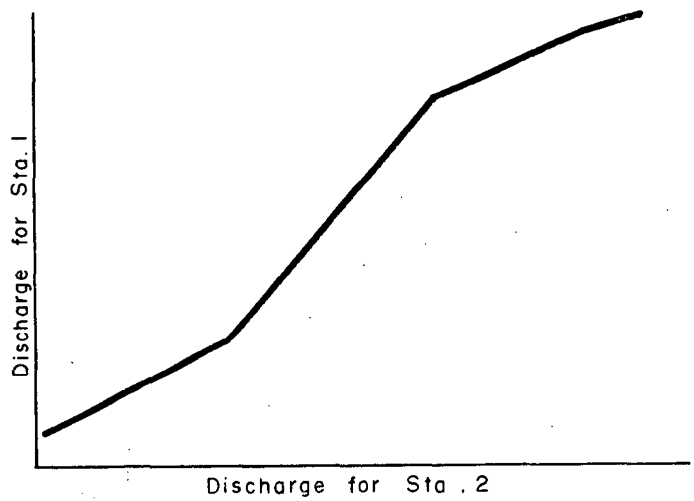
or Local = Net Flow - Routed Upstream Flow

5. Correlating Flows

If flows for STATION2 are not known from t_1 to t_2, but known for STATION1, it is possible to determine flows for STATION2 from t_1 to t_2 if;

(i) a correlation curve is known.

(ii) it is assumed that the correlation law is valid over t_1 to t_2.



Using this method in the operation 'EXTN' missing data can be generated.

6. WSC.DICT and TAPELIB

By convention the station numbers used in EDPR models of the Fraser are SSARR numbers. However, often the initial data is in WSC format. A cross reference file TAPELIB establishes a SSARR number/WSC number cross reference for the historical databank. For a WSC file the cross reference is in the file WSC.DICT. This file must be set up by the user.

Format of WSC.DICT

1 - 2	Blank
3 - 10	WSC (integer number)
11 - 20	SSARR (integer number)

7. Tables

To complete the description of a lake station, the discharge and storage as functions of elevation must be input. Similarly for a reservoir the storage elevation curve must be input. If the EXTN routine is used the correlation curve must be input.

The format of these records is

1 - 10	station of operation	
11 - 20	card number	
21 - 30	Elevation (ft.) -------------	table pos'n 1
31 - 40	Storage (acre-ft/100)--------	" " 2
41 - 50	Flow (cfs) -----------------	" " 3
51 - 60	Time of Storage (hrs.)-------	" " 4

This file is read via logical unit 8.

8. Wave card

	Description
1 - 5	coefficient 1
6 - 10	" 2
11 - 15	" 3
16 - 20	" 4
21 - 25	" 5
26 - 30	" 6
31 - 35	" 7
36 - 40	" 8
41 - 45	" 9
46 - 50	" 10

Note: (i) Sum of coefficients must be 1

(ii) Not all need be used.