Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter C3

A MODEL FOR SIMULATION OF FLOW IN SINGULAR AND INTERCONNECTED CHANNELS

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Book 7

AUTOMATED DATA PROCESSING AND COMPUTATIONS to calibrate than models of networks of multiply connected branches, wherein it is possible for the flow to travel by more than one route between various locations. If the calibration of a system of multiply connected branches is not correct, erroneous circulations may appear internally in the network rendering the model results useless. Calibration of network models is best conducted by first subdividing the network into simpler, single- or multiple-branch models keeping intact the principal natural circulation loops of the overall system. After successful calibration of these individual models, evaluation of the complete network model can be undertaken by combining the various smaller subset models. By this technique the network model calibration may be accomplished more systematically and economically.

Branch-Network Program Description

The FORTRAN IV code for the branch-network flow model is listed in Appendix IV. The model is composed of a MAIN program and eight primary subroutines, namely, OUT, PRTPLT, ARBIN, SETA, GEMXPI, OPLOT, DADIO, and DTCODE. The subroutines DADIO and DTCODE, which are referenced by the MAIN program but which are not included in the source listing in Appendix IV, are resident in the time-dependent-data, storage and retrieval system library SCHAF.DADIO.-LOADMOD. This library is cataloged on the U.S. Geological Survey computer system. The special system function, MOVE, not identified in the list but used by the MAIN program for fast, efficient array manipulation, is stored in the cataloged FORTRAN library XTENT.LIB. Other lower-level subroutines, aside from the common intrinsic FORTRAN functions, specifically required for the graphical display of computed results and directly referenced via subroutine OPLOT are available in the SYS1.DISSPLA.LIBRARY and SYS1.FLAT-BEDC system program libraries.

For reference purposes and to permit the cross-referencing of program variables and arrays with the mathematical equations, the MAIN program variables and arrays are defined in Appendix II. Commonality of variable and array names among the MAIN program and the various subroutines has been preserved to the extent practicable.

The bulk of the work of the simulation is performed in the MAIN program module of the model. The primary functions of the MAIN program are numerous:

1. to control the model input and output,
2. to initiate and terminate the simulation,
3. to allocate and appropriately initialize variables and arrays,
4. to retrieve the required boundary-value data and generate the boundary-condition equations,
5. to construct the coefficient matrices and perform the necessary matrix transformations, and
6. to generally supervise the various subprograms and the overall computation process.

The eight primary subroutines of the model perform various functions in support of the simulation conducted by the MAIN program. A matrix solution for the set of branch-transformation equations is effected by Gaussian elimination using maximum pivot strategy in the subroutine GEMXPI. The subroutine SETA computes the flow-resistance coefficient as a linear or quadratic function of water temperature, flow depth, discharge, Froude number, or Reynolds number, as designated by the user according to the prototype flow properties. The ARBIN subroutine interpolates cross-sectional area and top-width properties at a specified stage and approximates the hydraulic radius from the input stage-area-width geometry tables. The subroutine OUT prints computed results in tabular form following each iteration or time step, prints daily summaries of flow results, prints cumulative flow volumes, which it stores and subsequently retrieves from a direct-access file, and optionally punches initial condition cards (for subsequent input to follow-on executions of the model). Line-printer plots of computed results, optionally including plots of measured data, are produced by the PRTPLT subroutine. Similarly, the OPLOT subroutine prepares a daily computed and, optionally, a measured discharge or stage hydrograph for subsequent offline plotting on a Tektronix interactive cathode-ray-tube graphical terminal, a CalComp drum or flatbed electromechanical pen plotter, or an Information International, Inc., FR80 microfilm recorder. Subroutines DADIO and DTCODE, which are part of the time-dependent-data storage-and-retrieval system, perform various functions in response to the model's need for boundary-value data. The DTCODE subroutine verifies the beginning and ending dates and times for requested boundary-value data, and the DADIO subroutine effects the data retrieval from the time-dependent data base.

Program restrictions

In addition to the limitations previously mentioned that result from the mathematical formulation, from the numerical technique, or from the computed data and (or) given boundary-value data-accuracy requirements, certain restrictions are imposed by the computer program itself. Although the aforementioned limitations may necessarily preclude implementation of the model, restrictions resulting from the computer code can, in general, be overcome. These restrictions are primarily a consequence of the dimensionality of arrays as currently established in the computer program. Appendix III provides a table in which are listed those arrays that may need to be expanded to accommodate networks with unique dimensional requirements. The version of the program as listed in Appendix IV accommodates networks composed of as many as 15 branches, 15 junctions, and 5 external-boundary conditions. At most 60 sets of cross-sectional data can be input to this version. Any given branch can be subdivided into two, three, or more segments as long as the total number of sets of cross-sectional data is not exceeded. (This is a benefit derived from the array addressing technique used in the model.) For each required cross section a maximum of 20 values may be input to the program to define the stage-area-width relationship representing the geometry at that location. As many as five sets of measured time-series data can be input to the current version of the program for plotting purposes. The maximum number of measured data, per set, stored in memory for plotting purposes is 288, thus providing sufficient capacity to retain one day of continuous data recorded at 5-minute intervals. The maximum number of daily computed results held in core for plotting purposes is 288, thus accommodating results computed at intervals of five minutes or longer. As described, these limitations are not imposed as rigid constraints to be strictly adhered to; they merely represent limitations for this particular version of the model as programed. The model is programed in a manner which makes it easily possible, using the information provided in Appendix III, to change the code to accommodate specific, unique, model-application requirements. Certain other restrictions, particularly as pertain to the input of program control cards described in Appendix I, will be identified subsequently. Other obvious limitations resulting from the input format for program variables are apparent from Appendix I.

Model application

To apply the branch-network flow model to a network, it is first necessary to schematize the channel geometry in accord with the prototype conditions, model requirements, and model output expectations. Using available topographic quadrangle maps or maps of comparable quality, one must first visualize an appropriate network schematization. In the schematization process it is necessary to delineate the branches and segments so as to account for variations in the channel cross-sectional geometry, roughness, and velocity distribution, as well as tributary flows, nodal flows, and other hydraulic factors peculiar to the particular prototype under investigation. Channels with linearly varying cross-sectional properties should be schematized in a way that accounts for changes in the rate of cross-sectional variation and bottom profile changes, as well as other channel properties. Abrupt, substantial changes in the hydraulic and geometric properties of the various channels composing the prototype must be accounted for, either by subdividing such channels into multiple segments or by treating them as two or more branches. Channels of appreciable length should also be subdivided into multiple segments or branches for computational considerations. Experience with one-dimensional flow simulations indicates that branch lengths of a few kilometers up to a maximum of about 25 km may be used; this guideline appears to be appropriate for the branch-network flow model as well. However, the most ideal branch lengths are approximately 8–17 km.

Once a visual conception of the network schematization has been formulated, it is necessary to delineate the branches and identify the junction locations. The branch and segment lengths can be determined by direct field-survey techniques or by measuring along the channel thalweg as depicted on topographic maps, marine charts, or aerial-survey photographs. The chosen network schematization is conveyed to the model program by assigning numbers to the branches and junctions composing the system. The branch-network flow model is formulated in a manner that imposes only one constraint upon the numbering scheme employed. Specifically, there are no restrictions such as downstream numbering that must be adhered to in the branch and junction identification process. The only limitation on the numbering system adopted is that for a network composed of N branches and K junctions, the branches must be independently assigned successive integer values from 1 to N and junctions must be independently defined by successive integer values from 1 to K. (Branch numbers are assigned according to the order of input of the branches to the model program.) For each branch a positive flow direction must be identified (or arbitrarily selected) in order to preserve the correct algebraic signs of the computed unknowns. This is accomplished by assigning the appropriate junction numbers in the flow-direction arrays. In order to further identify the branches of the network, a name can be assigned to each branch.

After the branches to be treated in the network have been identified and all significant tributaries have been considered, cross-sectional geometry must be defined. Cross-sectional geometry, in the form of stage-area-width tables, must be supplied to the model at the beginning and end of all branches. If simulation results are needed at intermediate locations within a branch or if variations in the physical and hydraulic properties of the branch require more accurate schematization, one or more additional cross-sectional geometry tables can be input, thereby subdividing the branch into two or more segments. Each set of cross-sectional data within a branch describes the local channel geometry. Simulation output is available at all locations for which cross sections are defined; thus, as a minimum, computed results are produced at the termini of all branches within the network. The number of cross-sectional geometry tables needed to define the geometry of each branch must be designated. These tables must be input to the model in downstream order.

Cross-sectional data can be obtained by direct soundings or from existing navigation charts. After the geometry is determined, it can be manually prepared for input to the model or processed through a special computer program specifically designed to aid in the analysis and preparation of cross-sectional geometry for input to one-dimensional mathematical-numerical models. This program computes area, width, wetted perimeter, and hydraulic radius of channel cross sections at successive increments of stage from survey data consisting of point measurements of the channel-bottom elevation referenced by cross-channel stationing. After the field-recorded data are digitally encoded, compiled, and punched on computer cards or otherwise directly entered into a computer file, they are input to the cross-sectional geometry program. The output of the program consists of stage-area and stage-width tables prepared in punched-card format, as shown in table 1, which is compatible for direct inclusion in the branch-network flow model.

The required, tabular, cross-sectional data can be input to the model directly via cards or via accessing files of card-image data previously stored on an intermediate magnetic disk by the cross-sectional geometry program. Disk input of cross-sectional geometry is particularly advantageous once the schematization is verified and not subject to frequent alteration.

Other physical and hydraulic properties such as the momentum coefficient, the water temperature, and the wind speed and direction may also need to be evaluated and supplied to the model via initial-condition cards.

Implementation of the branch-network flow

TABLE 1.—Stage-area-width relationships for the Sacramento River at Sacramento, Calif.

Stage (ft)	Area (ft^2)	Width (ft)
-10.00	2,541	411
-8.00	3,364	468
-6.00	4,345	506
-4.00	5,567	528
-2.00	6,640	544
0.0	7,743	566
2.00	8,892	582
4.00	10,069	594
6.00	11,268	605
8.00	12,486	615
10.00	13,728	625
12.00	14,988	635
14.00	16,271	647
16.00	17,583	667
18.00	18,929	680
20.00	20,314	703
22.00	21,731	713
24.00	23,175	732
26.00	24,650	743
28.00	26,148	754

model also requires the preparation and input of boundary-value data if boundary conditions are not described by unique stage-discharge relationships. Boundary conditions must be defined at all external junction locations, that is, junctions having a singular connecting branch, such as 1, 2, and 4 of figure 4. As discussed in the section Initial and boundary-value data, boundary-value data can be specified in the form of stage or discharge hydrographs. The null discharge at a dead-end branch can also be used as a boundary condition. When necessary parabolic interpolation is employed with the given time series of input boundary-value data to produce values consistent with the time step being used in the simulation. A limited amount of boundary-value data—as many as 720 values per location in the current version of the model—can be manually punched on cards for input to the program. Operational use of the model, wherein larger sequences of boundary-value data are required, is most efficiently and conveniently accomplished using data stored and retrieved through the time-dependent data-processing system. The operational advantages of automatic data storage and retrieval through use of this system are obvious. Mixed modes of specifying boundary conditions can also be employed. One or more required boundary conditions can be defined by data retrieved from the data base of time-dependent data, whereas others are described by card input data or by equations. Although no specific order of input of boundary-value data-definition cards is required, if any boundary conditions are to be defined by data retrieved from the data base of time-dependent data, the first boundary-value data-definition card input must be one requesting data from disk, preferably the one specifying the boundary-value data recorded at the highest frequency. The remaining boundary-value data-definition cards can be input in any sequence. Similar considerations apply to the input of measured data.

Boundary-value data and cross-sectional geometry data input to the model must, of course, be referenced to a common datum. Other flow information in the form of inflows (or outflows) at internal junctions—also identified as nodal flows—and initial values of unknowns at all cross sections must be furnished to the model in card image form.

Having determined a computational time step, iteration and convergence criteria, and selected weighting factors for the spatial derivatives and geometric properties, one can begin model execution after the required input and job-control cards are prepared.

Program run preparation

Data input

The first step in preparing the program for execution on the computer is to punch the required input control cards according to the format given in Appendix I. A schematic diagram showing the order of input cards for a model setup is given in figure 15. Sample execution decks are illustrated subsequently (figs. 18, 35). As these figures suggest, orderly input of control cards is required. The basic sequence of data input is unchanged regardless of the particular model application.

Figure 15 shows that all branch-identity cards, initial-condition cards, and cross-sectional-geometry cards are input immediately

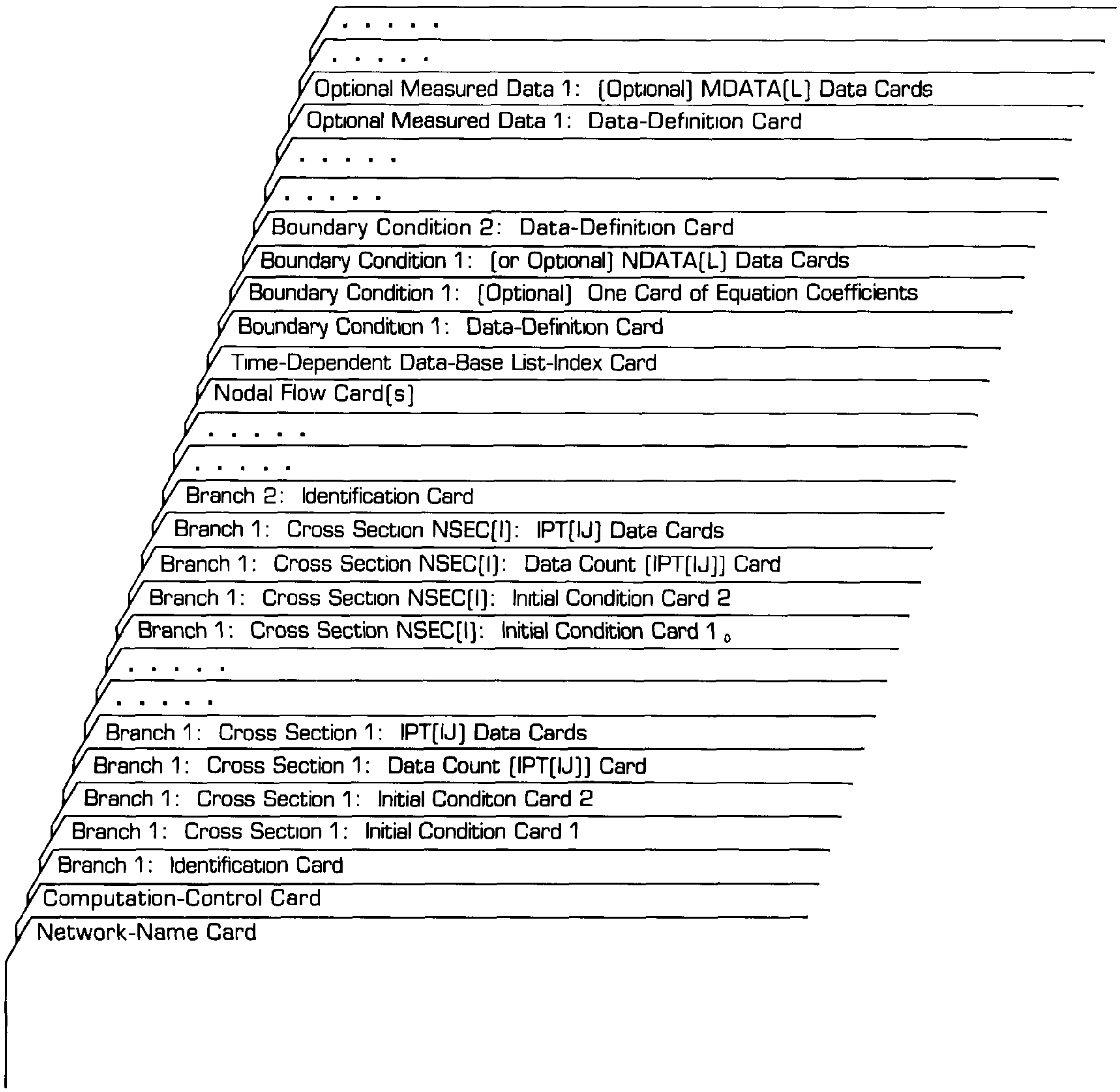


FIGURE 15.—Input-card order for the branch-network flow model.

following the network-name and computation-control cards and immediately preceding the nodal-flow card(s). The branch-identity cards, describing the branches of the network, must be input in sequences according to their designated branch numbers. This is necessary in order to retain the branch number assignments for output identification purposes. Cross-sectional-geometry cards, used to describe the channel geometry, must be input in their downstream (positive flow) order of appearance within each respective branch. (The cross section located at the flow source for the particular branch is input first; the one at the outlet, last.) All sets of cross-sectional-geometry cards defining the geometry of a branch are input following the identity card of that particular branch. Each set of cross-sectional-geometry cards is immediately preceded by two initial-condition cards that define initial values at the cross section. If cross-sectional geometry is input from a disk file, initial-condition cards are contiguous. The stage-area-width relationships defining the cross-sectional geometry are coded on individual cards that must be input in sequence beginning with the lowest stage value for the particular cross section. Each set of cards defining the relationships at a particular cross section is preceded by a card that identifies the number of such relationships (cards) input.

Nodal flows, defined via nodal-flow cards, must be coded on the required card(s) in sequence according to their assigned junction numbers. One nodal-flow card is sufficient to define the inflow (or outflow) at each of ten junctions. Constant nodal flow with respect to time is assumed and is maintained throughout the extent of the simulation. Sufficient nodal-flow cards must be input to account for all junctions within the particular network schematization, even though the nodal flow at all or some junctions is negligible. At a minimum one nodal-flow card is required.

Following the nodal-flow card(s), the list-index card, which signals the production of time-dependent, data-base, summary information, must be input. A blank card must be inserted in place of the list-index card when running the model using boundary-value data input exclusively via cards. Following the list-index card, boundary-value data-definition cards are input. When a boundary condition is defined by a stage-discharge equation or when boundary-value data are supplied via cards, one card – in addition to the required boundary-value, data-definition card – is input to define the equation coefficients (up to and including a cubic equation) or multiple cards are input to provide the data (one boundary-value datum per card). In either case, the card(s) must immediately follow the respective data-definition card. After all boundary-value, data-definition cards and appropriate coefficient or data cards (if any) are input, optional measured-data-definition cards follow. (Aside from boundary-value data, measured time-series data are required only for optional plotting of model-prototype comparisons.) Similarly when measured data are supplied via cards, they are input one value per card immediately following the respective data-definition card. All boundary-value and measured data must be input in proper time sequence, with no intervening gaps in time permitted.

Whereas boundary-condition locations are always identified by their junction number, measured-data locations can be specified either by junction or branch cross-sectional numbers. For a measured-data location specified by a junction number, computed flow results are always derived from the first branch connecting at that junction. For example (refer to fig. 4), measured data identified by junction number 3 would be associated with flow results computed at branch cross-sectional number I–2, as opposed to branch cross-sections II–2 or III–1. Therefore, care must be exercised in identifying measured-data locations by junction number, particularly at junctions joining more than two branches or junctions having nodal inflows or outflows. No such ambiguities exist for measured-data locations identified by branch cross-sectional numbers.

Job control

In order to facilitate use of the branch-network flow model from remote terminals connected to the Amdahl computer system operated by the U.S. Geological Survey, the model program has been compiled and loaded in an online library. To simplify the job-control requirements, a cataloged procedure, called BRANCH, which is composed of job-control statements, has been written and is available to execute the program from this library. The next step in preparing the model for execution is to set up the job-control cards necessary to invoke the cataloged procedure. Subsequent illustrations (figs. 18, 35) show the job-control statements required for two sample executions of the program using this cataloged procedure. Table 2 lists and defines the symbolic parameters in the cataloged procedure, BRANCH, which is available through the private procedure library SCHAF.PROCLIB. Appropriate symbolic parameter assignments can be determined by referring to table 2.

TABLE 2.—Symbolic parameters of the BRANCH cataloged procedure

Symbolic Parameter	Default	Description
PROG	BRANCH	Version of the branch-network-model program to be executed (BRANCH: complete version; BRANOP: version without OPLOT routine; BRANOD: version without OPLOT and DADIO routines).
ECORE	550K	Region size (K bytes) required to execute the program (BRANCH: 550K, BRANOP: 360K; BRANOD: 250K).
ETIME	1	Execution time for the program, where time is specified in minutes.
GIUNIT	3330	Unit type of the device containing the data-station reference file for the data base of time-dependent, boundary-value data.
GIVOL	(None)	Volume serial number of the device containing the data-station reference file for the data base of time-dependent, boundary-value data.
GINAME	NULLFILE	Data set name of the data-station reference file for the data base of time-dependent, boundary-value data.
DAUNIT	3330	Unit type of the device containing the data base of time-dependent, boundary-value data.
DAVOL	(None)	Volume serial number of the device containing the data base of time-dependent, boundary-value data.
DANAME	(None)	Data set name of the data base of time-dependent, boundary-value data.
XSUNIT	3330	Unit type of the device containing the cross-sectional geometry data file.
XSVOL	(None)	Volume serial number of the device containing the cross-sectional geometry data file.
XSNAME	NULLFILE	Data set name of the cross-sectional geometry data file.
FVUNIT	3330	Unit type of the device containing the cumulative flow-volume output file.
FVVOL	(None)	Volume serial number of the device containing the cumulative flow-volume output file.
FVNAME	NULLFILE	Data set name of the cumulative flow-volume output file.
FVDISP	OLD	The current disposition of the cumulative flow-volume output file; code NEW if a new flow-volume file is to be created.
TTUNIT	3330	Unit type of the device to contain the DISSPLA compressed file for Tektronix plotting.
TTVOL	(None)	Volume serial number of the device to contain the DISSPLA compressed file for Tektronix plotting.
TTNAME	NULLFILE	Data set name of the DISSPLA compressed file.
TTDISP	OLD	The current disposition of the DISSPLA compressed file; code NEW if a new file is to be created.
CCVOL	(None)	Volume serial number of the standard-labeled, magnetic tape to contain the CalComp plot file.
CCNAME	NULLFILE	Data set name of the CalComp plot file.
FRVOL	(None)	Volume serial number of the standard-labeled, magnetic tape to contain the FR80 plot file.
FRNAME	NULLFILE	Data set name of the FR80 plot file.

There are seven primary data files identified in table 2. The data-station reference and time-dependent data files[1] (identified by the symbolic parameter prefixes GI and DA, respectively) are necessary if boundary-value data are stored on a direct-access disk by the time-dependent data processing system for subsequent inclusion in the model. The cross-sectional geometry file[1] (identified by the symbolic parameter prefix XS and generated via the cross-sectional geometry program) contains stage-area-width tables for input to the model. The remaining four files identified in table 2 are intended for model output purposes. The flow-volume output file[1] (identified by the symbolic parameter prefix FV) retains cumulative flow volumes for the purpose of printing monthly summaries. The DISSPLA compressed direct-access-type file[1] (identified by the symbolic parameter prefix TT) is generated if subsequent plotting is to be accomplished on a Tektronix cathode-ray-tube graphical terminal. Likewise, the CalComp and FR80 magnetic-tape plot files[1] (identified by the symbolic parameter prefixes CC and FR, respectively) are generated if plots are to be produced using a CalComp drum or flatbed, electromechanical

[1]Details on the file structure and allocation techniques can be obtained from the authors

pen plotter or an Information International, Inc., FR80 microfilm recorder.

Program versions

The branch-network flow model is programed in modular fashion. This modular structure facilitates the exclusion of computer code at the expense of reduced model capabilities. If, for instance, the computer generation of plots via graphical terminals, electromechanical pen plotters, or microfilm recorders is not desired, the software instructions to create such plot files can be negated from the model source code of Appendix IV by replacing the OPLOT subroutine with the FORTRAN IV code listed in figure 16. (Computer generated plotting designed specifically for the line printer is unaffected by this exclusion.) Furthermore, if boundary conditions are always to be defined via equations or card-input data, the time-dependent-data storage-and-retrieval subroutine, DADIO, which provides the capability to retrieve boundary-value data automatically from a data base during the simulation, can be overridden by inserting the FORTRAN IV code listed in figure 17. In addition to the full model version, as listed in Appendix IV, two such reduced versions of the branch-network flow model have been compiled and loaded in the cataloged programs library for access via the BRANCH cataloged procedure, the symbolic parameters of which are defined in table 2. The complete version of the branch-network flow model, assigned the program name BRANCH in the library, requires 550K bytes of storage for execution. The version of the model with reduced plot capabilities, assigned the program name BRANOP, requires 360K bytes of storage. The model version with reduced plot options and no time-dependent data base link, called BRANOD, requires 250K bytes. To invoke the model version with the required capabilities one need only make the appropriate assignment of the PROG and ECORE symbolic parameters of the BRANCH cataloged procedure.

Storage and time requirements

Execution storage requirements for the three versions of the branch-network flow model are, as given in the section Program versions, 550K bytes for BRANCH, 360K bytes for BRANOP, and 250K bytes for BRANOD. The BRANCH program version listed in Appendix IV requires 400K bytes of storage for compilation when using the IBM (International Business Machines) FORTRAN IV H-level compiler and requesting a cross-reference listing of variables and labels. The time needed for compilation on the IBM 370/155 computer system is approximately 2 minutes, whereas on the Amdahl 470 V/7 computer the CPU time required for compilation is approximately 10 seconds. Execution time requirements vary greatly and are dependent upon the computational-time step, network schematization, convergence criteria, and the type of output desired, as well as other less significant factors. A month-long simulation of a river system comprising five single-segment branches required 6 minutes (approximately 12 seconds per day) of IBM 370/155 CPU time computing at a 15-minute time step and printing daily summaries of flow results. Another single-branch, single-segment model simulation took 8.3 minutes of IBM 370/155 CPU time to compute nine months at a 15-minute time step and produce flow-volume summaries. Yet another simulation of a large estuarine system composed of 25 multiple-segment branches required 28

```
      SUBROUTINE OPLOT(NSEC,XSKT,BRNAME,IJF,IJT,ISTATN,ZQCOMP,IBJNC,        OP   0
     1MBCH,MSEC,MDATA,ZQMEAS,MAXCZQ,MAXS,MAXMZQ,PRINTR)                      OP   0
      INTEGER PRINTR                                                         OP   1
      INTEGER BRNAME(10,1),ISTATN(1)                                         OP   2
      INTEGER *2NSEC(1),XSKT(1),IJF(1),IJT(1),IBJNC(1)                       OP   3
      INTEGER *2MBCH(1),MSEC(1),MDATA(1),MIYR,MIMO,MIDA,MIHR,MIMN            OP   4
      DIMENSION ZQCOMP(MAXCZQ,1), ZQMEAS(MAXMZQ,1)                           OP   5
      RETURN                                                                 OP   6
      ENTRY ZQPLOT                                                           OP   7
      RETURN                                                                 OP   8
      END                                                                    OP   9
```

FIGURE 16.—FORTRAN IV code used to negate the DISSPLA coded plot subroutine, OPLOT, from the branch-network flow model.

```
      SUBROUTINE DADIO(PRINTR,PUNCH,DSREF,TDDATA,LIST,RTCODE)
      INTEGER PRINTR,PUNCH,DSREF,TDDATA
      INTEGER STANUM
      INTEGER *2LIST,RTCODE,STRIP
      INTEGER *2TYPE,BY,BMO,BD,BH,BMN,EY,EMO,ED,EH,EMN,STAGE(1),RDPDY
      LOGICAL PRTMSG
      EXTERNAL CREATE
      RETURN
      ENTRY DATYPE(I,J,K,L,M)
      RETURN
      ENTRY DADI(STANUM,TYPE,BY,BMO,BD,BH,BMN,EY,EMO,ED,EH,EMN,STAGE,RDP
     1DY,STRIP,PRTMSG,RTCODE)
      RETURN
      ENTRY DADO(STANUM,TYPE,BY,BMO,BD,BH,BMN,EY,EMO,ED,EH,EMN,STAGE,RDP
     1DY,STRIP,PRTMSG,RTCODE)
      RETURN
      END
      SUBROUTINE DTCODE(YR,MO,DA,HR,MN,ITIME,ETIME,*)
      INTEGER ETIME,ITIME
      INTEGER *2YR,MO,DA,HR,MN,JDAYN
      INTEGER *2DPERM(12)/31,28,31,30,31,30,31,31,30,31,30,31/
      DPERM(2)=28+(4-(YR-YR/4*4))/4
      IF (YR.LT.0.OR YR.GT.99.OR.MO.LT.1.OR.MO GT 12.OR.DA.LT.1.OR.DA.GT
     1.DPERM(MO).OR.HR LT.0.OR.HR.GT.24.OR.MN.LT.0 OR.MN.GT.59) RETURN 1
      JDAYN=DA
      N=MO-1
      IF (N.EQ.0) GO TO 20
      DO 10 I=1,N
   10 JDAYN=JDAYN+DPERM(I)
   20 ITIME=YR*10000000+JDAYN*10000+HR*100+MN
      ETIME=(JDAYN-1)*1440+HR*60+MN
      RETURN
      END
      SUBROUTINE CREATE(IRETCO,IERNO,ILOGUN)
      COMMON /IHC236/ EMPTY,LOGUN
      LOGICAL EMPTY
      LOGUN=ILOGUN
      IRETCO=0
      EMPTY= TRUE.
      RETURN
      END
```

FIGURE 17.—FORTRAN IV code used to negate the time-dependent boundary-value-data storage-and-retrieval subroutine, DADIO, from the branch-network flow model.

seconds of Amdahl 470 V/7 CPU time. Flow results (computed at 15-minute intervals) were printed at every time step for all 76 cross sections and computed-versus-measured discharges were plotted on the CalComp plotter for the duration of the simulation (1.1 days). The time required to conduct a given simulation is a function of many variables, thus no simple rule for estimating execution time can be stated. Execution time is assigned to the model simulation by the ETIME symbolic parameter of the BRANCH cataloged procedure.

Diagnostic messages

In addition to standard FORTRAN IV and system-supplied diagnostic messages, error and other pertinent messages are printed by the DISSPLA plot software, by the time-dependent-data storage-and-retrieval system, as well as by the branch-network flow model itself. Diagnostic messages from the DISSPLA plot software and the time-dependent-data storage-and-retrieval system can be suppressed by setting the respective input parameters, IPLMSG and IPRMSG, to zero.

The following diagnostic messages are generated by the MAIN program and the subroutines of the branch-network flow model. Additional comments on the possible reasons for the error are given below the message:

INITIAL STAGE VALUE UNSPECIFIED IN BRANCH (I) SECTION (J)
: Initial values of stage and discharge must be supplied at all cross sections.

INITIAL STAGE XXXXX.XX OUT OF DEFINED RANGE OF CHANNEL GEOMETRY FOR BRANCH (I) SECTION (J)
: The initial value of stage is out-of-range of the stage-area-width geometry table for the specified cross section.

IMPROPER NUMBER OF CROSS-SECTIONAL DATA (2< =IPT< =20)
: More than one and 20 or fewer stage-area-width relationships must be input to define the geometry at each cross section.

DUPLICATE, OR OUT-OF-ORDER, STAGES IN CHANNEL-GEOMETRY TABLE FOR BRANCH (I) SECTION (J)
: Unique stage-area-width relationships defining the cross-sectional geometry must be input in sequential order beginning with the lowest stage value.

MATRIX NOT SQUARE
: This condition can be caused by improper schematization and (or) input parameter errors.

INVALID BOUNDARY-VALUE DATA PARAMETER(S)
: Information on a boundary-value data-definition card is invalid or inconsistent.

INVALID MEASURED DATA PARAMETER(S)
: Information on a measured data-definition card is invalid or inconsistent.

MATRIX IS SINGULAR
: The matrix has no inverse. This condition can be caused by improper boundary conditions or by schematization errors.

TOO MANY MEASURED DATA LOCATIONS (MXMD=5)
: Up to 5 sets of measured data can be input in this version of the model.

JUNCTION (J) OF BOUNDARY-VALUE DATA IMPROPERLY SPECIFIED (0<IBJNC<15)
: The junction number must be greater than 0 and less than 15.

IMPROPER NUMBER OF MEASURED DATA SPECIFIED (1< =MDATA< =288)
: Up to 288 measured data can be input at each location.

INVALID BRANCH (I) SECTION (J) SPECIFIED FOR MEASURED DATA
: The branch and cross-section numbers identifying a measured data location are errant or inconsistent with the network schematization.

JUNCTION (J) OF MEASURED DATA NOT FOUND
: The specified junction number of a measured data location is in error.

INITIAL VALUE(S) OUT OF DEFINED RANGE OF CHANNEL GEOMETRY
: One or more initial stage values are out-of-range of the respective stage-area-width geometry tables.

INITIAL OR COMPUTED STAGE RESULTS IN ZERO OR NEGATIVE AREA AND (OR) TOP WIDTH
: The initial or computed stage value is inconsistent with the stage-area-width geometry table.

COMPUTED STAGE OUT OF DEFINED RANGE OF CHANNEL GEOMETRY
: The computed stage is out-of-range of the stage-area-width geometry table.

INVALID COMPUTATION CONTROL PARAMETER(S)
: One or more input parameter values on the computation-control card are invalid.

MAXIMUM ITERATIONS EXCEEDED AT (HR:MN) ON (YR/MO/DY) Z-ZP (I,J)=XXX.XXXX Q-QP (I,J)=XXXXXX.X
: Convergence conditions were not satisfied during the specified time step. The stage and discharge printed represent the maximum difference between the last successive solutions. Computation continues using the last computed values.

EXECUTION TERMINATED DUE TO INCORRECT ATTEMPT TO UPDATE CUMULATIVE FLOW-VOLUME FILE
: The cumulative flow-volume file is allocated to contain flow volumes computed for a given calendar year and a specific network. An attempt to add data from a different network or calendar year produces the above error message.

STEP SIZE IN PLOT SCALE ALGORITHM EXCEEDS MAXIMUM LIMIT
: The magnitude of the quantity to be plotted is prohibitively large.

Input/output description

The ultimate success of any simulation effort depends in large measure on the capacity to easily manipulate both model and prototype data in order to analytically interpret model results. This aspect of modeling is not only valuable for purposes of model calibration and verification but is important in providing the facility with which to appraise, compare, and comprehend the significance of various water-management alternative plans. Because an efficient, economical, data storage-and-retrieval technique is an integral element of the branch-network flow model and because model results can be presented in diverse yet easily and quickly comprehensible formats by its numerous graphical display options, it is possible to achieve a broadly applicable, operationally usable, numerical simulation capacity.

The program-control cards and job-control statements required to execute the branch-network flow model can be set up according to the instructions given previously. A sample setup applying the model to the Sacramento-Freeport reach of the Sacramento River is illustrated in figure 18. In this example model setup, all cross-sectional geometry, boundary-value, and measured data are input via computer cards. (Figure 35 illustrates an execution deck setup with data input from disk files.) Some of the boundary-value and measured data in figure 18 are shown coded on the same card, that is, those delimited by four dashes. This is not meant to imply that–contrary to the instructions in the section Data input–more than one boundary-value or measured datum can be input per card, rather this was merely done to conserve space in the illustration. This complete deck setup will permit the user to experiment with the model. A line-printer plot of computed-versus-measured discharge and other associated printout from the simulation is shown in figure 19*A–C*.

Model input and output can be either in the International System of Units (metric) or the inch-pound system of units. The simulation is performed in the units of measure of the input data. However, the computed results can be converted for output upon request by the user.

The first page of printout (fig. 19*A*) from all simulations is a list of the control-card parameters as assigned by card or default. In addition, the boundary-value datum corrections–if any are to be applied–and the stage computation datum are printed (fig. 19*A*). The boundary-value datum corrections are input on boundary-value data-definition cards, whereas the stage computation datum is determined by the model. The stage computation datum is an arbitrary datum taken as the average of the absolute maximum and minimum stages specified on all cross-sectional-geometry tables. The simulation is performed with all stages automatically referenced to this datum for reasons of computational accuracy.

Listed on the second page of printout (fig. 19*B*) are the branch identification parameters, the cross-sectional-geometry tables, and the initial values. This information is always printed for each simulation regardless of the specific output type chosen.

The third and final page of simulation output illustrated in figure 19*C*, is the desired line-

```
//COMPUTER JOB CARD
/*PROCLIB  SCHAF.PROCLIB
//BRANCH EXEC BRANCH,PROG=BRANOD,ECORE=250K
//SYSIN DD *
SACRAMENTO R. : SACRAMENTO-FREEPORT REACH
    1 2 2    ME    33    4                                  .75
  1 2 2SACRAMENTO R   SACRAMENTO-FREEPORT REACH
       2.48    6373.0             57024 00       0.2620E-010 1283E-06- 4167E-12

 3
0.          7460.    550
2.          8602.    580
4.          9780.    595.
       2 37    4107 0

 3
0           8050     595
2           9251.    607
4          10476.    618.


 Z 1 32   11447500 FROM= 76/10/12 08 00   TO= 76/10/12 15.45      96
2 48
NOTE: AS SHOWN BY PREVIOUS CARD. PUNCH DATA OF NEXT TWO CARDS ONE VALUE PER CARD
 ---- 2.55 2.62 2.67 2.74 2 79 2.84 2.88 2.91 2.92 2.92 2.92 2.90 2 88 2.85 2.83
 2.80 2 77 2.73 2.70 2.67 2 63 2.60 2.56 2.52 2 48 2.44 2.40 2.37 2.34 2.31 2.29
 Z 2 32   11447650 FROM= 76/10/12 08:00   TO= 76/10/12 15:45      96
2 37
NOTE: AS SHOWN BY PREVIOUS CARD. PUNCH DATA OF NEXT TWO CARDS ONE VALUE PER CARD
 ---- 2.43 2 49 2.55 2 60 2.64 2 66 2.65 2.63 2.60 2 57 2.53 2 50 2.47 2.43 2 39
 2.35 2.30 2 26 2.21 2 16 2.11 2.06 2.02 1.93 1.94 1.90 1.88 1 86 1.85 1 88 1.91
 Q 1 30            FROM= 76/10/12 08 00   TO= 76/10/12 15·15      96
6360
NOTE· AS SHOWN BY PREVIOUS CARD. PUNCH DATA OF NEXT TWO CARDS ONE VALUE PER CARD
 ---- 6180 6090 6090 6120 6140 6140 6130 6140 6340 6860 7160 7340 7470 7580 7700
 7810 7940 8060 8180 8340 8530 8640 8680 8690 8690 8720 8780 8780 8690
/*
//
```

FIGURE 18.—Sample deck setup to execute the branch-network flow model of the Sacramento-Freeport reach of the Sacramento River. (See Appendix I for proper card input format of boundary-value and measured data.)

printer plot (IOTOPT=3 and IPLDEV=0) of computed-versus-measured discharge (IPLOPT=3) for the Sacramento River at Sacramento, Calif. Other options permit plotting computed-versus-measured stage (IPLOPT=4), plotting computed stage hydrographs (IPLOPT=2), or plotting computed discharge hydrographs (IPLOPT=1). These options are also available for plotting on a line printer (IPLDEV=0), a Tektronix cathode-ray-tube graphical terminal (IPLDEV=1), a CalComp drum or flatbed electromechanical pen plotter (IPLDEV=2), or an Information International, Inc., FR80 microfilm recorder (IPLDEV=3).

In addition to the generation of plots (IOTOPT=3), the model will print flow results in tabular form at every time step (IOTOPT=0), print flow results in similar tabular form at every iteration (IOTOPT=1), print only daily summaries of flow results (IOTOPT=2), or print monthly flow-volume summaries (IOTOPT=4).

The various output formats available with the branch-network flow model are illustrated in figures presented throughout this report. Table 3 is a composite list of these figures. Appropriate values of the program control variables used to produce the output illustrated in these figures are also given.

The output derived by IOTOPT option 0 and illustrated in figure 20 is the computed flow results printed in tabular form at each computa-

```
UNSTEADY FLOW COMPUTATION IN A NETWORK OF OPEN CHANNELS

         BRANCH-NETWORK MODEL (VERSION 79/04/19)
               A FOUR-POINT IMPLICIT SCHEME

                   LINEAR MATRIX SOLUTION
   BY GAUSS ELIMINATION USING MAXIMUM PIVOT STRATEGY

=======================================================

         UNITS OF INPUT (EN/ME)          =      EN
         UNITS OF OUTPUT (EN/ME)         =      ME
         BRANCHES (1<=N<=15)             =       1
         JUNCTIONS (2<=N<=15)            =       2
         BOUNDARY VALUES (1<=N<= 5)      =       2
         GEOMETRY INPUT UNIT (5/10)      =       5
         PRINTOUT OPTION (O<=N<=4)       =       3
         PLOT OPTION (O<=N<=4)           =       3
         PLOTTER DEVICE (O<=N<=3)        =       O
         PRINT MESSAGE OPTION (O/1)      =       O
         PLOT MESSAGE OPTION (O/1)       =       O
         EXTRAPOLATION OPTION (O/1)      =       O
         PUNCH INITIAL COND  (O/1)       =       O
         FRICTION TYPE (1<=N<=6)         =       4
         MAXIMUM ITERATIONS              =       5
         NUMBER OF STEPS                 =      32
         DERIVATIVE FACTOR (O<=N<=1)     =    1 00
         GEOMETRY FACTOR (O<=N<=1)       =    0 75
         TIME INCREMENT(MINUTES)         =      15
         DISCHARGE CONVERGENCE           =    20 5
         STAGE CONVERGENCE               =  0 0100
         WIND SPEED(MPH/KPH)             =     O O
         SURFACE DRAG COEFFICIENT        =  0 0026
         WATER DENSITY                   =  1 9617
         STAGE COMPUTATION DATUM         =   2 000
         BVD( 1) DATUM CORRECTION        =     O O
         BVD( 2) DATUM CORRECTION        =     O O

=======================================================
```

A

```
CHANNEL GEOMETRY FOR SACRAMENTO R     SACRAMENTO-FREEPORT REACH

BRANCH  1 FROM JUNCTION  1 TO  2   SACRAMENTO R   SACRAMENTO-FREEPORT REACH

 CROSS SECTION  1         STAGE              AREA             WIDTH
                          (FT)             (FT**2)             (FT)
                          O O              7460 O             550 O
                          2 00             8602 O             580 O
                          4 00             9780 O             595 O

 INITIAL VALUES   STAGE=  2 48  DISCHARGE=  6373 O        BETA= 1 000
 ----------------------------------------------------------------------
 LENGTH= 57024 O FT;          TEMP= 59 O DEG F,        WIND=   O O DEG

 ETA= O 262000E-01 + ( O 128300E-06)*Q + (-O 416700E-12)*Q**2
 ----------------------------------------------------------------------

 CROSS SECTION  2         STAGE              AREA             WIDTH
                          (FT)             (FT**2)             (FT)
                          O O              8050 O             595 O
                          2 00             9251 O             607 O
                          4 00            10476 O             618 O

 INITIAL VALUES   STAGE=  2 37  DISCHARGE=  4107 O        BETA= 1.000
```

B

SACRAMENTO R   SACRAMENTO-FREEPORT REACH

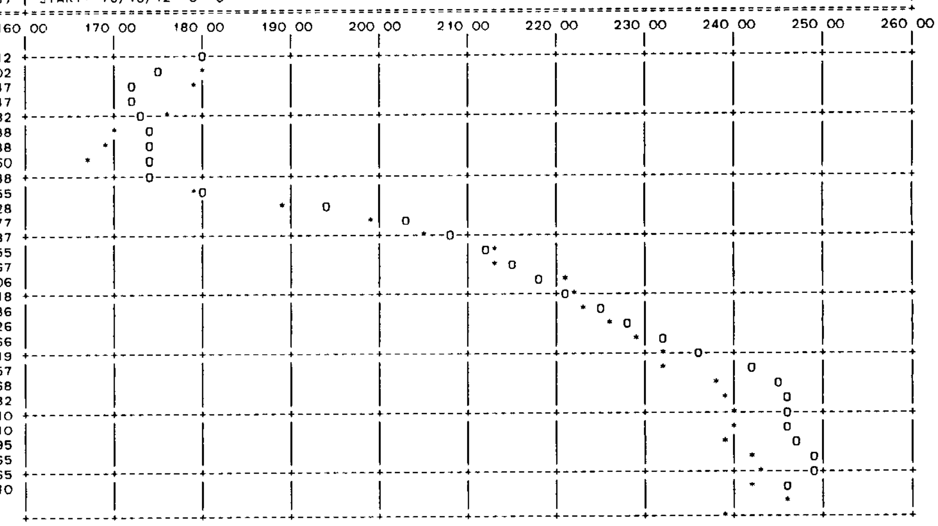
FLOW COMPUTED BY THE BRANCH-NETWORK MODEL

\# \# \# \#

SACRAMENTO R   SACRAMENTO-FREEPORT REACH   (O) MEASURED (*) COMPUTED AT BRANCH SECTION 1 1

START= 76/10/12 8 O   END= 76/10/12 15 45

TIME HR MN	DISCHARGE (M**3/S) (*)	DISCHARGE (M**3/S) (O)
8 0	180 48	180 12
8 15	180 28	175 02
8 30	179 34	172 47
8 45	172 16	172 47
9 0	175 89	173 32
9 15	169 69	173 88
9 30	169 06	173 88
9 45	167 31	173 60
10 0	174 08	173 88
10 15	178 99	179 55
10 30	188 66	194 28
10 45	198 62	202 77
11 0	205 38	207 87
11 15	212 58	211 55
11 30	212 55	214 67
11 45	220 58	218 06
12 0	221 97	221 18
12 15	223 42	224 86
12 30	225 70	228 26
12 45	228 71	231 66
13 0	232 13	236 19
13 15	232 00	241 57
13 30	237 84	244 68
13 45	239 37	245 82
14 0	239 81	246 10
14 15	239 70	246 10
14 30	239 24	246 95
14 45	242 47	248 65
15 0	242 81	248 65
15 15	242 18	246 10
15 30	245 60	
15 45	239 22	



C

FIGURE 19. – Sample output from the simulation-deck setup of figure 18, with IOTOPT option 3 and IPLOPT option 3. *A*, List of control-card parameters assigned by card or default. *B*, Branch-identification parameters, cross-sectional geometry tables, and initial values. *C*, Desired line-printer plot of computed versus measured discharge for Sacramento River at Sacramento, Calif.

FLOW RESULTS FOR SACRAMENTO R SACRAMENTO-FREEPORT REACH

DATE YR/MO/DY	TIME HR MN	STAGE (M)	VELOCITY (M/SEC)	DISCHARGE (M**3/S)	AREA (M**2)	WIDTH (M)	FALL (M)	BRANCH SECTION (ITERATIONS)	ETA	STAGE (M)	VELOCITY (M/SEC)	DISCHARGE (M**3/S)	AREA (M**2)	WIDTH (M)
76/10/12	0 15	0 99	0 30	256 6	867 5	179 6	0 17	1 (0) 1 2	0 0275	0 82	0 35	315 8	898 1	186 2
	0 30	0 98	0 30	256 5	865 1	179 5	0 18	1 (3) 1 2	0 0275	0 79	0 36	321 1	893 8	186 0
	0 45	0 96	0 30	257 4	861 8	179 4	0 18	1 (3) 1 2	0 0275	0 78	0 36	322 0	890 4	185 9
76/10/12	1 0	0 94	0 30	259 2	859 0	179 3	0 19	1 (3) 1 2	0 0275	0 75	0 37	323 7	886 4	185 8
	1 15	0 93	0 30	257 6	855 8	179 1	0 19	1 (3) 1 2	0 0275	0 73	0 37	327 5	882 5	185 7
	1 30	0 91	0 31	264 2	853 0	179 0	0 20	1 (3) 1 2	0 0275	0 71	0 37	323 3	879 0	185 6
	1 45	0 89	0 31	259 5	849 7	178 9	0 20	1 (3) 1 2	0 0275	0 69	0 38	329 2	875 1	185 5
76/10/12	2 0	0 87	0 31	261 9	846 5	178 8	0 20	1 (3) 1 2	0 0275	0 68	0 37	326 3	871 7	185 4
	2 15	0 86	0 31	262 9	843 7	178 6	0 20	1 (3) 1 2	0 0275	0 65	0 38	327 2	867 7	185 3
	2 30	0 84	0 31	264 6	841 0	178 5	0 21	1 (3) 1 2	0 0275	0 63	0 38	328 8	863 7	185 1
	2 45	0 82	0 32	264 8	837 7	178 4	0 21	1 (3) 1 2	0 0275	0 61	0 38	329 0	860 3	185 0
76/10/12	3 0	0 81	0 32	264 1	834 4	178 3	0 21	1 (3) 1 2	0 0275	0 60	0 38	328 3	856 9	184 9
	3 15	0 79	0 32	266 8	831 7	178 1	0 21	1 (3) 1 2	0 0275	0 58	0 38	325 6	853 6	184 8
	3 30	0 77	0 32	263 2	828 4	178 0	0 21	1 (3) 1 2	0 0275	0 56	0 38	327 3	850 2	184 7
	3 45	0 75	0 32	261 9	825 1	177 9	0 21	1 (2) 1 2	0 0275	0 54	0 38	325 9	846 9	184 6
76/10/12	4 0	0 74	0 32	264 4	821 8	177 7	0 21	1 (2) 1 2	0 0275	0 53	0 38	317 8	844 6	184 5
	4 15	0 72	0 32	262 2	819 1	177 6	0 21	1 (2) 1 2	0 0275	0 51	0 37	315 5	841 8	184 4
	4 30	0 71	0 32	264 4	816 4	177 5	0 20	1 (2) 1 2	0 0275	0 50	0 37	307 0	840 2	184 4
	4 45	0 69	0 32	264 2	813 6	177 4	0 19	1 (3) 1 2	0 0274	0 50	0 35	296 1	839 6	184 4
76/10/12	5 0	0 68	0 32	259 1	810 9	177 3	0 17	1 (3) 1 2	0 0274	0 50	0 34	285 7	839 6	184 4
	5 15	0 67	0 32	261 2	809 2	177 2	0 16	1 (3) 1 2	0 0274	0 51	0 32	266 5	840 7	184 4
	5 30	0 66	0 32	257 3	807 6	177 1	0 13	1 (3) 1 2	0 0273	0 52	0 29	246 7	843 5	184 5
	5 45	0 65	0 31	248 5	806 5	177 1	0 11	1 (3) 1 2	0 0272	0 54	0 27	227 2	846 9	184 6
76/10/12	6 0	0 65	0 30	239 7	806 5	177 1	0 09	1 (3) 1 2	0 0272	0 56	0 24	207 7	850 2	184 7
	6 15	0 65	0 28	228 7	807 1	177 1	0 08	1 (3) 1 2	0 0271	0 58	0 22	191 4	853 6	184 8
	6 30	0 66	0 27	222 4	808 7	177 2	0 07	1 (3) 1 2	0 0271	0 60	0 20	174 4	856 9	184 9
	6 45	0 68	0 27	217 2	810 9	177 3	0 06	1 (3) 1 2	0 0270	0 62	0 18	158 6	860 8	185 1
76/10/12	7 0	0 69	0 26	209 1	813 6	177 4	0 05	1 (3) 1 2	0 0270	0 64	0.17	150 4	864 3	185 2
	7 15	0 71	0 25	204 2	816 4	177 5	0 05	1 (3) 1 2	0 0270	0 66	0 16	140 1	868 2	185 3
	7 30	0 72	0 24	198 6	819 1	177 6	0 04	1 (3) 1 2	0 0269	0 68	0 15	129 1	872 8	185 4
	7 45	0 74	0 23	191 6	822 4	177 8	0 04	1 (3) 1 2	0 0269	0 70	0 14	122.1	876 8	185 5
76/10/12	8 0	0 76	0 22	183 7	825 7	177 9	0 04	1 (3) 1 2	0 0269	0 72	0 14	119 5	880.2	185.6
	8 15	0 78	0 22	185 5	829 5	178 1	0 04	1 (3) 1 2	0 0269	0 74	0 13	110.5	884 2	185 7
	8 30	0 80	0 22	179 6	833 3	178 2	0 04	1 (2) 1 2	0 0269	0 76	0 13	115.4	887 0	185 8
	8 45	0 82	0 21	175 6	836 1	178 3	0 04	1 (2) 1 2	0 0269	0 78	0 13	116 6	890 4	185 9
76/10/12	9 0	0 84	0 21	179 7	839 9	178 5	0 05	1 (2) 1 2	0 0269	0 79	0 13	115 3	893 3	186 0
	9 15	0 85	0 21	173 8	842 6	178 6	0 05	1 (2) 1 2	0 0269	0 80	0 14	125 5	895.5	186 1
	9 30	0 87	0 21	173 3	845 4	178 7	0 06	1 (2) 1 2	0 0269	0 81	0 15	135 7	896 7	186 1
	9 45	0 88	0 20	173 3	847 6	178 8	0 07	1 (3) 1 2	0 0269	0 81	0 17	151 8	896 7	186 1
76/10/12	10 0	0 89	0 21	174 9	849 2	178 9	0 09	1 (3) 1 2	0 0270	0 80	0 20	174 9	895 0	186 1
	10 15	0 89	0 22	184 3	849 7	178 9	0 10	1 (3) 1 2	0 0270	0 79	0 21	189 7	893 8	186 0
	10 30	0 89	0 22	188 8	849 7	178 9	0 11	1 (3) 1 2	0 0271	0 78	0 24	210 3	891 6	186 0
	10 45	0 89	0 24	203 4	849 7	178 9	0 12	1 (3) 1 2	0 0271	0 77	0 25	219 5	889 9	185 9
76/10/12	11 0	0 89	0 24	205 0	848 6	178 9	0 12	1 (3) 1 2	0 0272	0 76	0 27	237 2	887 6	185 8
	11 15	0 88	0 25	215 2	847 6	178 8	0 13	1 (3) 1 2	0 0272	0 75	0 27	242 0	885 9	185 8
	11 30	0 87	0 25	215 2	845 9	178 7	0 13	1 (3) 1 2	0 0272	0 74	0 29	252 8	883 6	185 7
	11 45	0 86	0 26	223 3	844 8	178 7	0 14	1 (3) 1 2	0 0273	0 73	0 29	255 5	881 3	185 7
76/10/12	12 0	0 85	0 27	224 7	843 2	178 6	0 14	1 (3) 1 2	0 0273	0 71	0 30	262 2	879 0	185 6

	DISCHARGE (upstream)			DISCHARGE (downstream)	
MINIMUM	MEAN	MAXIMUM	MINIMUM	MEAN	MAXIMUM
173 3	228 6	266 8	110 5	238 6	329 2

FIGURE 20.—Computed flow results at each time step printed in tabular form, produced using IOTOPT option 0.

TABLE 3.—Composite list of output examples and appropriate values of the output-control variables

Output option-control variables			Number of figure illustrating output
IOTOPT	IPLOPT	IPLDEV	
0	-----	-----	20.
1	-----	-----	(1)
2	-----	-----	29.
3	3	0	19C.
3	1	[2]1, 2, or 3	27, 32.
3	2	[2]1, 2, or 3	(3)
3	3	[2]1, 2, or 3	25.
3	4	[2]1, 2, or 3	31, 36.
4	-----	-----	21.

[1] Not illustrated, but similar in format to figure 20

[2] For this output option, printed output as produced for IOTOPT=0 is also generated This output option is not available in the BRANOP model-program version

[3] Not illustrated, but similar in format to figure 32

tion time interval, which is 15 minutes in this simulation for the Sacramento River. Each line of printout gives the computed flow at the upstream and downstream ends of the segment at each successive time interval. The flow results printed on the left side of the page are for the upstream cross section, which in this simulation, is located at the gage site in the city of Sacramento whereas those printed on the right side are for the downstream cross section located near Freeport, Calif. Also identified on the printout is the fall computed through the segment and the η value used to compute the flow. The number enclosed in parentheses in the center of the listing is the number of iterations required during the time step to satisfy the convergence criteria. The number of iterations at the initial time step is always zero since these quantities are specified as initial values. Flow

OCTOBER 1977 DISCHARGE AT STATION 11447650

DAY	VOLUME(S) IN MILLIONS OF CUBIC FEET				
1	209 (0700)	-10 (0945)	186 (1715)	-46 (2115)	71
2	240 (0800)	-9 (1030)	168 (1745)	-45 (2145)	51
3	271 (0845)	-12 (1130)	146 (1830)	-41 (2230)	28
4	289 (0930)	-19 (1245)	141 (1930)	-41 (2315)	7
5	319 (1030)	-9 (1330)	170 (2100)	-23 (2400)	0
6	316 (1130)	-18 (1445)	170 (2215)	-16	
7	-13 (0130)	286 (1200)	-38 (1600)	168 (2315)	-4
8	-33 (0300)	258 (1230)	-42 (1645)	185	
9	0 (0015)	-41 (0400)	244 (1300)	-47 (1715)	193
10	9 (0100)	-41 (0445)	237 (1330)	-49 (1745)	191
11	32 (0200)	-39 (0545)	226 (1400)	-49 (1815)	178
12	62 (0245)	-40 (0645)	206 (1430)	-59 (1845)	162
13	94 (0345)	-41 (0730)	191 (1445)	-68 (1915)	140
14	127 (0430)	-38 (0815)	176 (1530)	-77 (2000)	119
15	160 (0530)	-35 (0915)	162 (1600)	-79 (2045)	93
16	195 (0645)	-29 (1015)	154 (1645)	-81 (2130)	64
17	240 (0745)	-31 (1115)	145 (1730)	-81 (2230)	35
18	267 (0830)	-38 (1230)	148 (1845)	-68 (2315)	6
19	291 (0930)	-44 (1345)	160 (2030)	-42	
20	-1 (0015)	315 (1045)	-33 (1430)	191 (2200)	-24
21	-19 (0145)	270 (1130)	-46 (1545)	198 (2330)	-4
22	-35 (0300)	245 (1215)	-50 (1630)	215	
23	3 (0030)	-37 (0415)	223 (1245)	-54 (1700)	208
24	23 (0130)	-34 (0515)	207 (1315)	-58 (1745)	195
25	51 (0230)	-30 (0600)	190 (1345)	-65 (1815)	182
26	78 (0315)	-35 (0700)	176 (1415)	-72 (1845)	165
27	113 (0415)	-24 (0730)	190 (1500)	-49 (1900)	162
28	142 (0500)	-20 (0815)	177 (1530)	-51 (1930)	144
29	175 (0600)	-13 (0845)	179 (1600)	-41 (1945)	128
30	203 (0700)	-9 (0930)	164 (1630)	-46 (2015)	102
31	228 (0800)	-7 (1015)	161 (1730)	-33 (2045)	85

FIGURE 21 —Sample printout of monthly accumulated flow-volume summary produced using IOTOPT option 4.

results can be printed in similar tabular form at every iteration by assigning IOTOPT a value of 1; however, large volumes of printout should be expected from this option. If information such as the minimum, mean, and maximum discharges for the day is needed, it can be derived for each cross section by specifying IOTOPT option 2. The times of occurrence of the minimum and maximum discharges, as well as the concurrent stage, average cross-sectional velocity, and cross-sectional area, are also printed.

In appraising the flow conditions in tide-affected systems one may often be interested in the volume interchange of the network. Volumes of discharges for downstream and upstream flows at specific locations in a network can be obtained by IOTOPT option 4 as is illustrated in figure 21. This option allows for the accumulation of computed flow volumes at all gaging-station locations in the network. The flow discharge in one direction is accumulated by the model until the flow reverses. The discharge for this reversed flow is then accumulated until the next change-of-flow direction. Thus, both upstream and downstream flow volumes are tabulated, and the approximate time of the flow reversal is identified in the monthly flow-volume summaries. Accumulated flow volumes are stored in a direct-access file and are printed in tabular form, as illustrated by figure 21, at the conclusion of each simulation. Knowledge of the flow interchange of the riverine or estuarine system, such as is available via this output option, can be useful in appraising the flushing capacity or mixing capability of the system.

During simulations in which plots are produced for devices other than the line printer, computed results are also printed in tabular form at every time step according to IOTOPT option 0. Actual plot production (other than by the line printer) is accomplished in auxiliary, offline operations from intermediate computer files generated by the model. The CalComp and

FR80 plot files are generated on magnetic tape, whereas Tektronix plot files are stored on a temporary disk file. If a CalComp plot is desired, a plot request form must be submitted to the Production Control Unit of the Computer Center Division in order to have the plot tape processed on the Reston, Va., CalComp plotter.[2] In order to plot FR80 files, follow the installation guidelines where the actual plotting is to be performed. In the case where plotting is to be performed on a Tektronix cathode-ray-tube graphical terminal, the model creates a compressed direct-access-type file for access by the DISSPLA Post Processor program. The required time-sharing option (TSO) commands for allocation of files and execution of the DISSPLA Post Processor routine to access the compressed file and output to a Tektronix graphics terminal of the 4010 series appear in figure 22. After the required TSO commands are entered the DISSPLA Post Processor will pause for input of appropriate control directives, whereupon the terminal RETURN key must be depressed to initiate plotting. Likewise, the terminal pauses at the end of each plot; the next plot can be requested by again depressing the RETURN key.

Any general operational simulation capacity must fulfill a diversity of requirements. For instance one model user might be interested in a graph showing the time-sequential variation of the discharge or water-surface elevation at a particular cross section. On the other hand, a tabular summary of the volume of flow through a particular cross section may be desired by another user. Yet another requirement might be a comparative plot of the before-and-after conditions illustrating the hydrodynamic changes resulting from some alteration of the channel or network configuration. Whatever the particular requirement, branch-network flow model results are made readily available in a variety of formats via several output devices, as identified in the section Input/output description. In particular, the conversational, remote-job-entry facility of the aforementioned interactive display terminal offers unique capabilities to model users. By using the terminal keyboard a model user can enter control parameters for a model execution, initiate the simulation on the host computer, and have alphanumeric or graphical results returned via the display screen – all in a single remote-terminal session. The model-computed discharges at the boundary-value data collection sites for this simulation of the Sacramento River are graphically displayed on the Tektronix terminal, as illustrated in figure 23. Time-dependent water-surface elevations at Sacramento and near Freeport, Calif., processed and stored using the time-dependent data-processing system, provide the boundary-value data necessary to actuate the model simulation. This interactive capability significantly hastens the model calibration and verification operations.

```
ATTR TERM RECFM(F) LRECL(137) BLKSIZE(137)
ALLØC FI(FT05F001) DA(*) USING(TERM)
ALLØC FI(FT06F001) DA(*) USING(TERM)
TERM LINESIZE(136) INPUT(***)
ALLØC FI(CØMPIN) DA(your plot file name)
CALL 'SYS1.DISSPLA.STEPLIB(TEKPØP)'
```

FIGURE 22.—TSO allocation and execution commands for Tektronix plotting by use of the DISSPLA Post Processor.

Branch-Network Model Applications

The branch-network flow model is presently being utilized to simulate the time-varying flows in several coastal and upland river systems. These implementations of the model represent a broad sampling of the hydrologic field conditions one might typically expect to accommodate when contemplating model use. Other implementations of the model – including singular and simply or multiply connected channels – are in process, are being actively planned, or are under consideration.

In order to demonstrate the general applicability of the model, five specific implementa-

[2] This may be accomplished, by registered users of the U S. Geological Survey computer system, by telephoning the Automatic Data Processing Unit, Water Resources Divison (telephone (non-FTS) 703-860-7131 or (FTS) 928-7131), or the Production Control Unit, Computer Center Division (telephone (non-FTS) 703-860-7171 or (FTS) 928-7171), and providing the necessary plot instructions The finished plots will be mailed to the address specified by the requestor

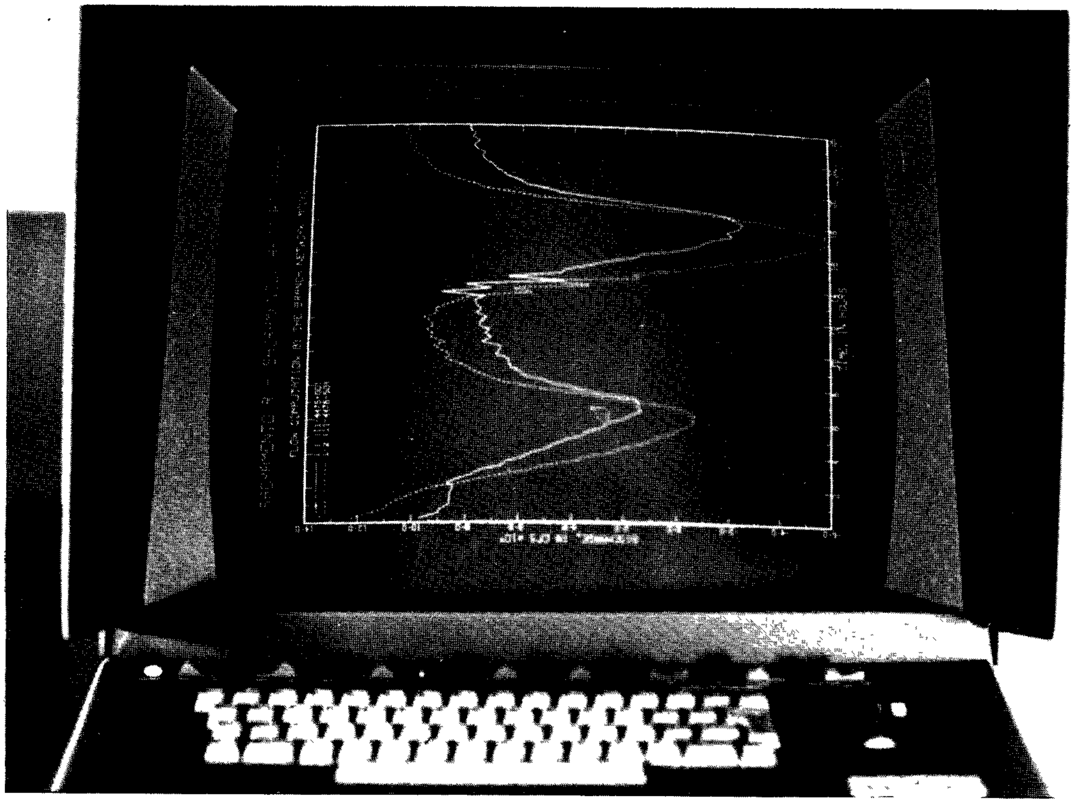


FIGURE 23.—Closeup view of Tektronix cathode-ray-tube display unit.

tions are presented and discussed briefly herein. These particular applications were selected to illustrate not only the means for model implementation but also to portray the adaptability of the model to a wide range of hydrologic conditions and field situations. The implementations depict such diverse field situations as hydropower-plant regulated flows in a singular upland-river reach, tide-induced flows in both riverine and estuarine reaches, and meteorologically generated seiches and wind tides in a multiply connected network of channels joining two large lakes. These example model implementations are in various phases of calibration and verification and are presented merely as illustrations of the model's capabilities. In presenting the findings of these illustrative applications, only those details pertinent to an understanding of the overall implementation process are introduced and discussed.

It is important to recognize that the diversity of applications illustrated is not due solely to the development and subsequent existence of the branch-network flow model. Rather, what is presented in these applications is a product of a systematic, broadly applicable, and operationally usable means for conducting numerical simulation modeling. In order to achieve this capacity for modeling, the branch-network flow model is integrally linked with an efficient, versatile, and highly economical data storage-and-retrieval technique having access to a data base of time-dependent boundary values. Thus, the storage-and-retrieval technique incorporates an automatic mechanism within the model by which to selectively acquire and manipulate the large volumes of boundary-value data typically required for operational simulation modeling. Furthermore, the model is supported by a computer software system whose function is to process field-recorded channel geometry and to produce stage-area-width tables which depict the channel geometry. Yet another distinct feature of the branch-network flow model is its inherent graphics capability, which not only significantly hastens the model calibration and verification operations but also provides a unique, rapid, economical mechanism for evaluating solution alternatives to water-management problems.

Sacramento-Freeport reach of the Sacramento River

Data from the tide-affected reach of the Sacramento River extending downstream from the city of Sacramento to a location near the town of Freeport, Calif., have been collected and used for model research and development purposes for many years. Data from this 17.4-km reach of the Sacramento River have been used extensively throughout this report for simulations illustrating the computational behavior of the branch-network flow model. The modeled reach, as illustrated in figure 24, has recently been extended downstream to the town of Hood, Calif. The unsteady flow is caused by tide-induced translatory waves propagating upstream through San Francisco Bay from the Pacific Ocean. During periods of high upland discharge, which generally occur during the winter and spring months, tide effects are negligible if not completely absent from the reach, and steady flow prevails. During periods of extreme low upland river runoff, tide-induced reversals in the flow direction have been detected as far upstream as the city of Sacramento. However, during these low-flow periods, no salt-water intrusion has been detected in the reach, and the flow remains well mixed vertically. Because of this extensive range of flow conditions, the Sacramento-Freeport reach provides an excellent source of prototype data for evaluating experimental modeling techniques and for conducting model-sensitivity analyses.

As the Sacramento River traverses the lowlands of the Central Valley of California it is almost entirely confined within levees, exhibiting only a slight expansion in cross-sectional area throughout the reach. Inflow and diversions are negligible within the Sacramento–Freeport reach. A comprehensive field survey was conducted in order to establish the overall channel properties of the reach being modeled. After the field data were digitally encoded, compiled, and punched on computer cards, they were input to the cross-sectional geometry program, which subsequently produced the stage-area-width tabulations of channel geometry in the format shown in table 1.

The boundary-value data used for simulation of the flow in the Sacramento River consist of water-surface elevations digitally recorded at the upstream and downstream ends of the modeled reach. Such boundary-value data are continuously recorded at the city of Sacramento, near the town of Freeport, and at Hood, Calif., at stations numbered 11–4475.00, 11–4476.50, and 11–4476.52, respectively, in figure 24. For the reach being simulated in this example application, boundary-value data recorded at the city of Sacramento and near the town of Freeport are used. The digitally recorded water-surface elevations are prepared for input to the model through use of the time-dependent data-processing system.

After the model was set up and an initial batch of required boundary-value data were processed and filed, a flow-resistance coefficient (η) had to be determined before the actual simulations could commence. In the branch-network flow model η can be expressed as a constant or as a polynomial function of the water temperature, the flow depth, the discharge, the Reynolds number, or the Froude number. The determination of a functional relationship and the definition of its appropriate coefficients are derived during the model-calibration process by the model user. In general, if a functional relationship is to be used, then definition of suitable coefficient values requires prototype data representing a range of flow and other hydrologic conditions sufficient to permit accurate determination of this relationship.

For calibration of the Sacramento–Freeport model, a constant η was used initially; it produced reasonable results. However, as the flow computation was extended to longer periods of time and to a wider range of flow and other hydrologic conditions, it was found necessary to use a variable η to produce satisfactory results. Consequently, η has been expressed in terms of a quadratic function of the discharge, with the result that the model now produces more accurate results for a wider range of flow regimes.

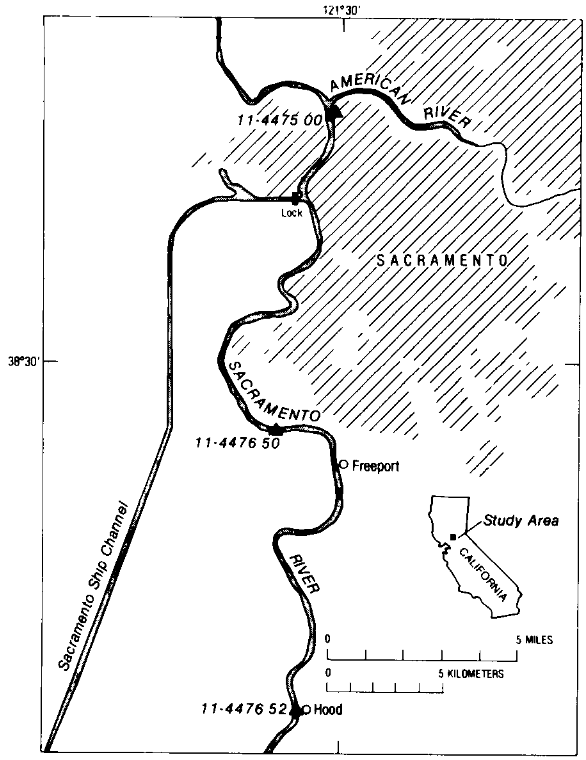


FIGURE 24.—Sacramento River reach near Sacramento, Calif.

The functional relationship determined to be applicable to the schematization of the Sacramento-Freeport reach (Oltmann, 1979) is $\eta = 2.620 \times 10^{-2} + 1.283 \times 10^{-7} Q - 4.167 \times 10^{-13} Q^2$.

Several sets of measured discharges and recorded stages ranging from extremely low to extremely high flows have been used to calibrate the model. One such sample simulation for calibration purposes is illustrated in figure 25. Stages concurrently recorded at the Sacramento and Freeport gages on October 12, 1976, were used as boundary values for this model simulation. This comparative plot of computed versus measured discharges for the Sacramento River at the city of Sacramento was computer produced during the flow simulation and subsequently digitally plotted in an offline operation. Through the use of a range of such sets of discharge data and concurrently recorded stages, the flow-resistance coefficient used in the model has been adjusted, and the flow computations have gradually improved. Thus, the model itself has been used to deduce a functionally dependent resistance coefficient that suits the model schematization employed.

Columbia River reach at Rocky Reach Dam near Wenatchee, Wash.

The branch-network flow model has been used to compute the flow of the Columbia River immediately downstream from Rocky Reach Dam near Wenatchee, Wash. This relatively short reach (3.1 km) is treated as a single-segment branch in the model schematization. Flow in the reach is highly unsteady owing to regulation created by the combined operation of turbines and gates at the dam for the purpose of optimal hydroelectric power generation.

Channel geometry data for the model were abstracted from detailed field surveys, processed by the cross-sectional geometry program, and prepared for input to the model. The branch-network flow model treats the reach as a single segment; therefore, stage-area-width tables were produced that define the upstream and downstream cross sections at the boundary-value data locations.

Water-surface elevations are used as boundary conditions for the model application. These data are collected on a continuous basis at the field-station locations (stations numbered 12–4537.00 and 12–4537.01) identified in figure 26 near river miles 471 and 473, respectively. The close proximity of the boundary-value stations underscores the importance of precise synchronized recording of the water-surface elevations. The boundary-value data are extracted from the time-dependent data base during the simulation as required to define the boundary conditions.

The highly unsteady nature of the flow is illustrated in the model-generated plot of computed discharges in figure 27. As this figure illustrates, the unsteady discharge can vary as much as 2,000 m^3/s in less than 2 hours elapsed time. In fact, the discharge has been observed to vary as much as 1,000 m^3/s in less than 0.5 hour. This application amply demonstrates the ability of the branch-network flow model to simulate highly varying flow conditions, as may be encountered in regulated upland rivers.

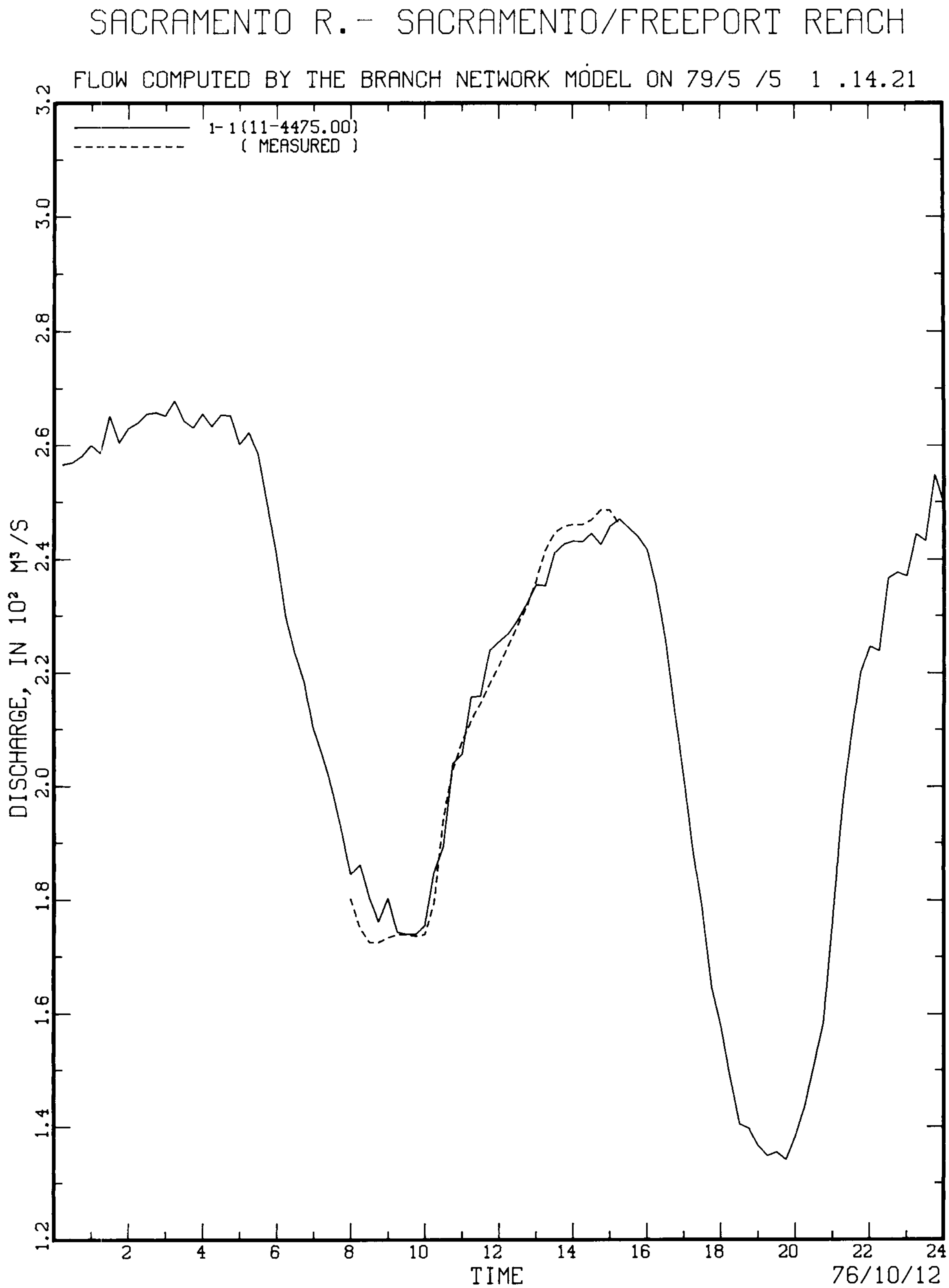


FIGURE 25.—Model-generated plot of computed-versus-measured discharges for the Sacramento River, produced using IOTOPT option 3, IPLOPT option 3, and IPLDEV option 2.

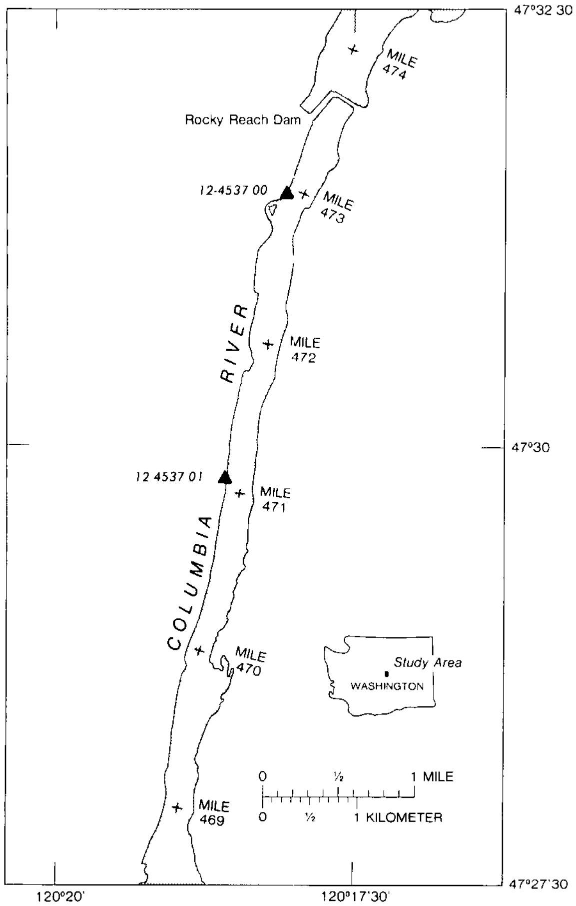


FIGURE 26.—Columbia River reach near Rocky Reach Dam in the State of Washington.

Kootenai River reach near Porthill, Idaho

The branch-network flow model has been used to simulate the flows in a 54.75-km reach of the Kootenai River near Porthill, Idaho. The reach being modeled is delineated by the gaging stations located at Klockman Ranch and at the town of Porthill, Idaho (stations numbered 12–3140.00 and 12–3220.00, respectively), as illustrated in figure 28. Water-surface elevations were also previously recorded at Copeland, Idaho (station number 12–3185.00), which is located near midreach. As figure 28 illustrates, the Kootenai River is characterized by a rather sinuous, meandering path of travel. The river flows in a northerly direction through a more-or-less diked channel traversing a rather narrow mountain-valley flood plain before crossing the international boundary and discharging into Kootenay Lake in Canada. Depending on the regulated level of this lake, varying backwater effects occur at the Porthill gaging location. The reach is also subject to regulated flows propagating downstream from nearby Libby Dam in Montana. It is the combination of these regulated flows and backwater effects that necessitates the use of an unsteady-flow model in order to produce accurate flow information at the Porthill international-boundary gaging station.

The reach between the Klockman Ranch gage (station number 12–3140.00) and the Porthill gage (station number 12–3220.00) is subdivided into five branches for purposes of model implementation. Four internal junctions are located at the Trout Creek tributary, at the Copeland gage, at the Parker Creek tributary, and at the Smith Creek tributary (fig. 28). These junctions are located in order to account for the tributary inflow. Tributary discharges are treated as nodal inflows occurring at the junction locations.

From survey data collected at 15 cross sections between the boundary-value-data gaging stations, a set of geometry tables for the branch-network flow model was constructed for purposes of conducting the simulations. The cross-sectional data were analyzed, and tables were prepared for use in the model via the cross-sectional geometry program.

Simulations are conducted using simultaneous, digitally recorded, water-surface elevations from the Klockman Ranch and Porthill gage locations as boundary-value data for establishing the required boundary conditions in the model. These data are routinely translated, processed, and filed in the time-dependent data base for direct inclusion in the flow model.

Water-surface elevations previously recorded at the Copeland gage location at midreach, as well as several approximately steady-flow discharge measurements, were used to conduct the preliminary flow-model calibration. Initial calibration of the model using a total of eight such discharge measurements resulted in a maximum error of 10 percent in the computed momentary discharge. The eight discharge measurements represented a range of flow conditions from a low of 250 to a maximum of 800 m^3/s. Additional calibration and verification of

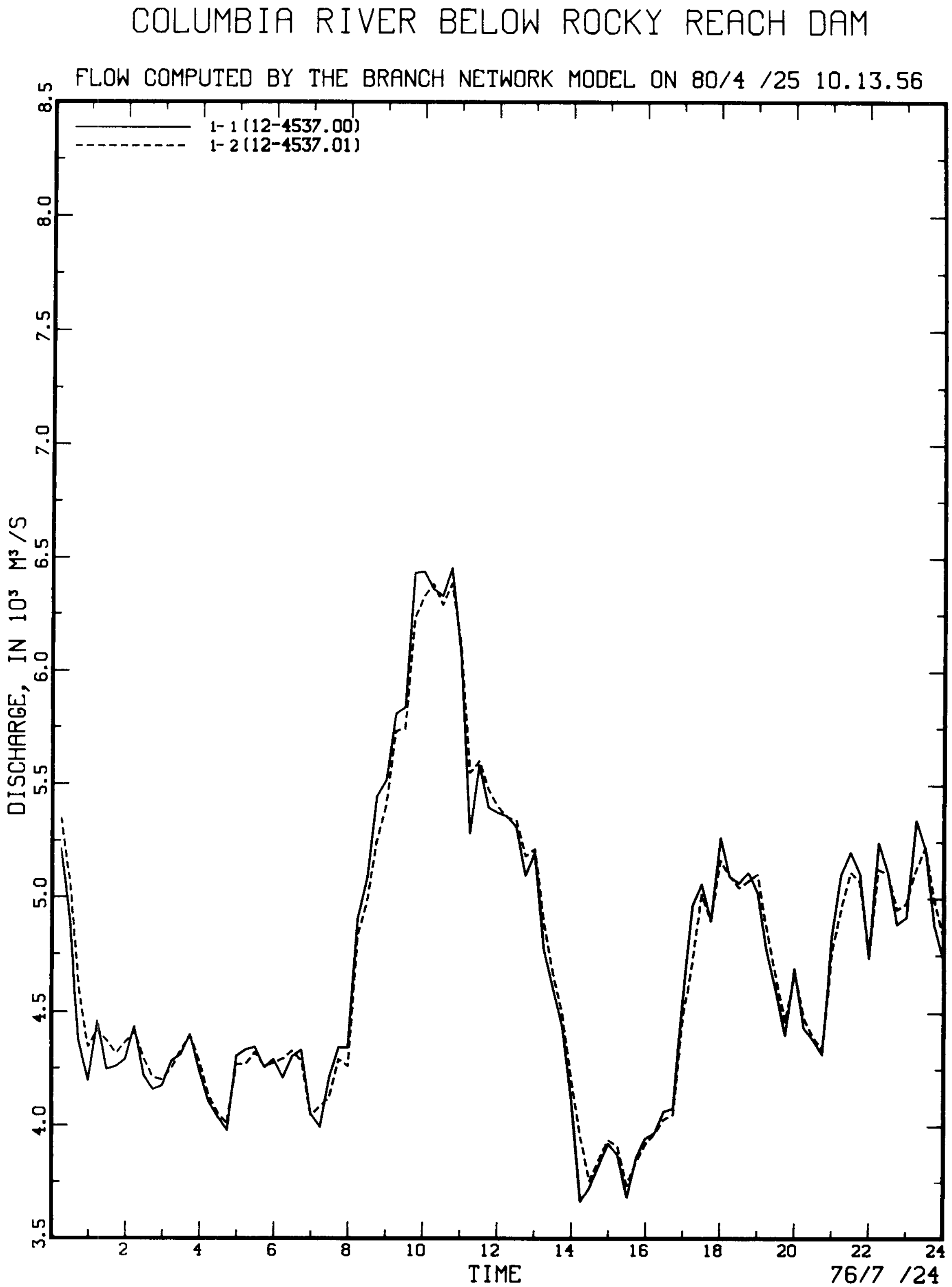


FIGURE 27. — Model-generated plot of computed discharges for the Columbia River, produced using IOTOPT option 3, IPLOPT option 1, and IPLDEV option 2.

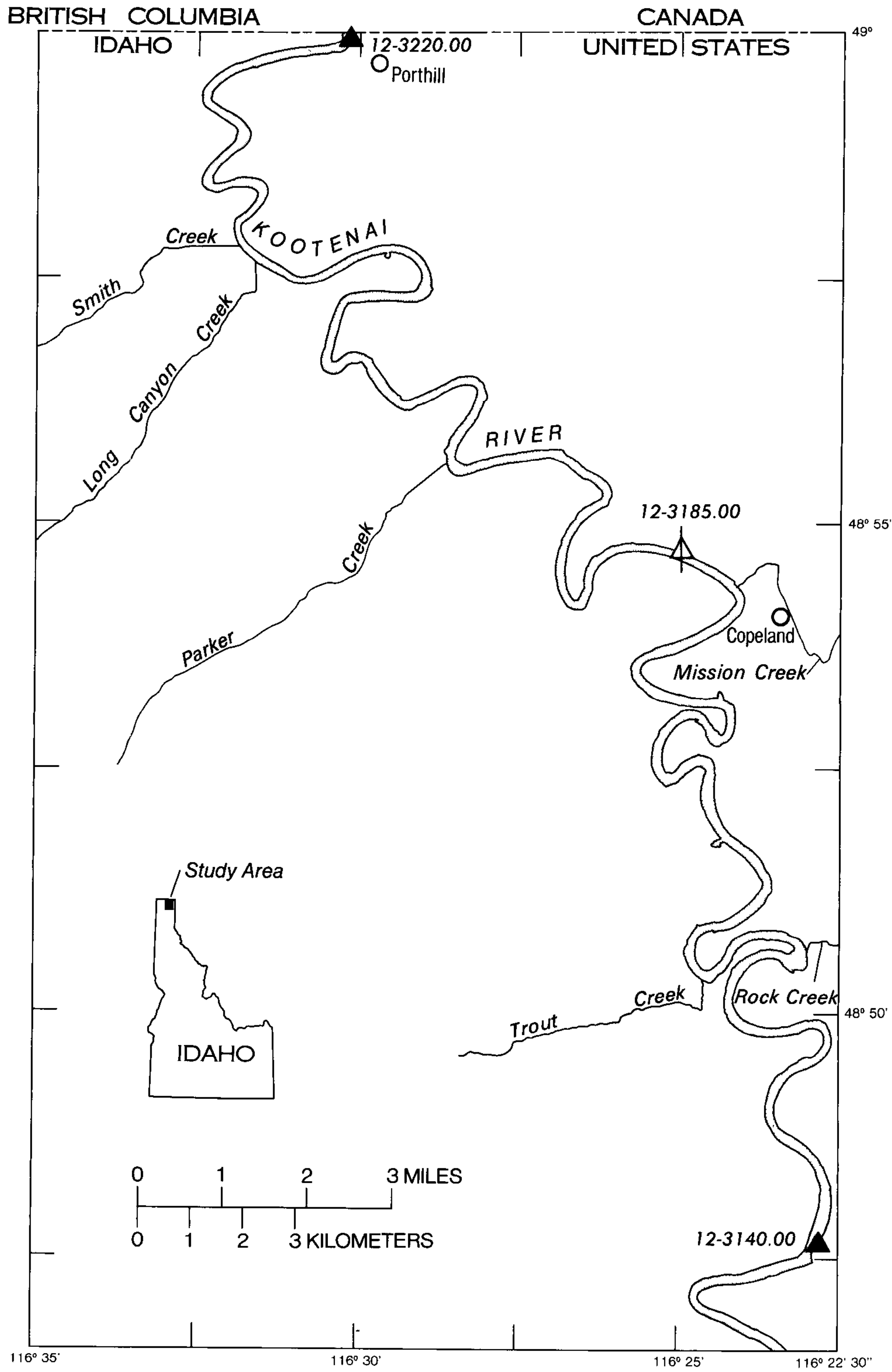


FIGURE 28. — Kootenai River reach near Porthill, Idaho.

the Kootenai River flow model are being conducted.

Figure 29 illustrates another output format available from the branch-network flow model. This output is a tabular summary, on a daily basis, of the computed flows for the Kootenai River. The minimum, mean, and maximum discharges computed at each junction (cross-section) location are identified on successive lines of printout. The daily results printed for August 31, 1978, are indicated as representing a partial day of record. They are in fact, the initial values used to actuate the flow-model simulation. Looking at the computed flow results for a complete day, for example September 2, 1978, one can see that the minimum discharge for the day at each cross section occurred at or near the last computational time for the day (2400 hours). The times of the maximum discharge for the day are similarly identified for each cross section; these occurred between 0515 and 0730 hours at all locations. Note that cross section one of branch one is at the Klockman Ranch gage location and cross section two of branch five is at the Porthill gage location.

By virtue of the schematization, the internal cross sections at common junction locations are, of course, duplicates of one another. Thus, as can be seen from the results illustrated in figure 29, the computed flows at these common junction locations are—as well they should be—nearly identical. A slight difference may be detected and can be attributed to the tributary inflow and

FLOW RESULTS FOR KOOTENAI RIVER BETWEEN KLOCKMANN RANCH AND PORTHILL

DATE (YR/MO/DY)	MINIMUM TIME (HR MN)	MINIMUM STAGE (M)	MINIMUM VELOCITY (M/S)	MINIMUM DISCHARGE (M**3/S)	MINIMUM AREA (M**2)	BRANCH	SECTION	MEAN DISCHARGE (M**3/S)	MAXIMUM TIME (HR MN)	MAXIMUM STAGE (M)	MAXIMUM VELOCITY (M/S)	MAXIMUM DISCHARGE (M**3/S)	MAXIMUM AREA (M**2)
*78/ 8/31	24 0	13 79	0 16	201 2	1224 4	1	1	201 2	24 0	13 79	0 16	201 2	1224 4
	24· 0	13 75	0 17	206 8	1231 7	1	2	206 8	24 0	13 75	0 17	206 8	1231 7
	24 0	13 75	0 17	206 8	1231 7	2	1	206 8	24. 0	13 75	0.17	206 8	1231 7
	24 0	13 68	0 21	220 7	1060 4	2	2	220 7	24 0	13 68	0 21	220 7	1060.4
	24 0	13 68	0 21	220 7	1060 4	3	1	220 7	24 0	13 68	0 21	220 7	1060 4
	24 0	13 63	0 19	228 9	1190 7	3	2	228 9	24 0	13 63	0 19	228.9	1190 7
	24 0	13 63	0 19	228 9	1190 7	4	1	228 9	24 0	13 63	0 19	228 9	1190 7
	24 0	13 59	0 21	234 4	1112 0	4	2	234 4	24 0	13 59	0 21	234 4	1112 0
	24 0	13 59	0 21	234 4	1112 0	5	1	234 4	24 0	13 59	0 21	234 4	1112 0
	24 0	13 55	0 19	238 6	1268 6	5	2	238 6	24 0	13 55	0 19	238 6	1268 6
78/ 9/ 1	0 15	13 79	0 17	207 5	1224 4	1	1	334 6	9 0	14 19	0 32	405 0	1280 3
	0 15	13 75	0 17	209 3	1231 4	1	2	327 9	9 45	14 10	0 31	393 5	1288 9
	0 15	13 75	0 17	210 3	1231 4	2	1	329 0	9.45	14 10	0 31	394.5	1288.9
	0 30	13 68	0 20	216 6	1059 6	2	2	321 8	10 45	13 93	0 35	383 0	1096 3
	0 30	13 68	0 21	217 7	1059 6	3	1	322 9	10 45	13 93	0 35	384 1	1096 3
	0 45	13 62	0 19	222 9	1189 1	3	2	319 1	12 0	13 81	0 31	379.2	1217 0
	0 45	13 62	0 19	222 9	1189 1	4	1	319 1	12 0	13 81	0.31	379 2	1217.0
	1 0	13 57	0 20	226 8	1109 8	4	2	316 9	11 45	13 70	0.33	376 3	1129 5
	1 0	13 57	0 20	226 8	1109 8	5	1	316 9	11 45	13 70	0 33	376 3	1129 5
	1 45	13 53	0 18	230 0	1265 8	5	2	315 5	11·30	13 61	0 29	373 8	1278 1
78/ 9/ 2	23 45	13 77	0 13	163 0	1221 9	1	1	290 6	5·15	14 29	0 32	409 3	1295.4
	24 0	13 75	0 14	167 7	1231 0	1	2	297 4	5 45	14 19	0.31	401 4	1304 8
	24 0	13 75	0 14	168 7	1231 0	2	1	298 5	5 45	14 19	0 31	402 4	1304 8
	24 0	13 70	0 16	174 3	1063 1	2	2	305 5	6 45	14 02	0 36	394 9	1109 2
	24 0	13 70	0 17	175 5	1063 1	3	1	306 6	6 45	14 02	0 36	396.0	1109 2
	24 0	13 67	0 15	178 8	1196 1	3	2	309 8	7 30	13 89	0 32	392 1	1229 0
	24 0	13 67	0 15	178 8	1196 1	4	1	309 8	7 30	13 89	0 32	392 1	1229.0
	24 0	13 64	0 16	180 3	1120 5	4	2	311 3	7·30	13 78	0 34	390.1	1142.2
	24 0	13 64	0 16	180 3	1120 5	5	1	311 3	7 30	13 78	0 34	390 1	1142 2
	24 0	13 62	0 14	180 7	1279 5	5	2	311 8	7 15	13 69	0 30	388.3	1289 9
78/ 9/ 3	18 15	13 75	0 12	144 8	1218 4	1	1	159 2	13 45	13 76	0 14	172.6	1221 0
	18 45	13 73	0 12	148 4	1228 0	1	2	159 8	14 0	13 74	0 14	168 2	1230 0
	18 45	13 73	0 12	149 5	1228 0	2	1	160 9	14 0	13 74	0 14	169 2	1230 0
	19 0	13 69	0 14	152 9	1061 6	2	2	161 5	0 15	13 70	0 16	173 0	1062 9
	19 0	13 69	0 15	154 0	1061 6	3	1	162 6	0 15	13 70	0 16	174.2	1062 9
	21 15	13 66	0 13	156 9	1194 4	3	2	163 0	0 15	13 67	0 15	176 8	1196 0
	21 15	13 66	0 13	156 9	1194 4	4	1	163 0	0·15	13 67	0 15	176 8	1196 0
	12 15	13 64	0 14	157 2	1119 5	4	2	163 2	0 15	13 64	0 16	177 9	1120 4
	12 15	13 64	0 14	157 2	1119 5	5	1	163 2	0 15	13 64	0 16	177 9	1120 4
	12 0	13 62	0 12	154 8	1279 0	5	2	163 3	0 15	13 62	0 14	178 2	1279 5
78/ 9/ 4	14 30	13 72	0 12	140 2	1214 1	1	1	153 1	4 30	13 75	0 14	165 4	1219 3
	18 30	13 70	0 12	141 0	1223 9	1	2	153 0	6 45	13.73	0 13	162 6	1228 2
	18 30	13 70	0 12	142 0	1223 9	2	1	154 0	6 45	13 73	0 13	163 6	1228 2
	17 15	13 67	0 13	141 4	1058 5	2	2	153 9	7 0	13 69	0 15	161 9	1061 1
	17 15	13 67	0 13	142 5	1058 5	3	1	155 0	7 0	13 69	0.15	163 1	1061.1
	17 15	13 65	0 12	142 6	1192 8	3	2	155 0	7 45	13 66	0 14	163 0	1194 3
	17 15	13 65	0 12	142 6	1192 8	4	1	155 0	7 45	13 66	0.14	163 0	1194 3
	16 30	13 63	0 13	141 4	1118 1	4	2	155 0	7 45	13 63	0 15	164 4	1118 9
	16 30	13 63	0 13	141 4	1118 1	5	1	155 0	7 45	13 63	0 15	164.4	1118 9
	16 15	13 61	0 11	140 5	1278 1	5	2	155 0	7 45	13 61	0 13	164 7	1278 1

* IDENTIFIES A PARTIAL DAY OF RECORD

FIGURE 29.—Sample output of the daily summary of computed flow for the Kootenai River, produced using IOTOPT option 2.

(or) the specified computational convergence criteria.

Connecticut River reach near Hartford, Conn.

The Connecticut River, the largest river in New England, bisects the State of Connecticut as it flows southward to Long Island Sound. The river is tide affected from its mouth on Long Island Sound northward almost to the Connecticut-Massachusetts State line. The extent of tidal influence is greatly controlled by the amount of fresh-water inflow and, therefore, varies considerably from season to season. Although the river near Hartford, Conn., is frequently influenced by tidal effects, the direction of flow is always downstream. Flow reversals, however, often occur between Middletown and Hartford, even though much of the tide effect is suppressed by fresh-water inflow during periods of high upland runoff. Thus, within the 41.2-km reach being modeled between the Bulkeley Bridge gage at Hartford and the CANEL Pier gage, which is 9.9 river kilometers downstream of Middletown (stations numbered 01–1900.70 and 01–1930.50, respectively, in fig. 30), the flow conditions vary from steady to unsteady flow.

In order to conduct the simulations, boundary conditions are specified via water-surface elevation data continuously recorded at the Bulkeley Bridge and CANEL Pier gage locations. These continuously recorded, water-surface elevations are processed and prepared for input to the model through the time-dependent data-processing system.

For simulation purposes the modeled reach of the Connecticut River is treated as two branches each consisting of four unequal segments, therefore requiring five stage-area-width tables per branch to delineate the respective segments. The internal junction is located at approximately the midpoint of the overall reach, 21.4 km downstream of the Bulkeley Bridge gage near Cromwell, Conn. Cross-sectional data, obtained by depth soundings, from topographic maps, or from marine charts, were used to defined the average cross-sectional properties of the channel at the segment ends. The cross-sectional geometry program reduced the profile data to the required stage-area-width tables for direct input to the branch-network flow model.

Data for calibration and verification of the model consist of several discharge measurements made over at least a tidal cycle. Water-surface elevations were also observed during the periods of these discharge measurements at several sites along the reach selected in order to assist in the overall model calibration.

Figure 31 shows computed versus measured water-surface elevations for the Connecticut River at the Bodkin Rock gage location (field station number 01–1930.00), identified in the figure as branch cross-sectional number 2–4, which is 6.2 river kilometers upstream of the CANEL Pier gage. As can be seen from the figure, the agreement appears satisfactory exhibiting mainly a slight difference in phasing. The maximum discrepancy between measured and computed stages is approximately 2.1 cm, occurring at 1230 hours.

Figure 32*A*, *B* illustrates plots of discharge hydrographs available via the branch-network flow model. Each curve in these plots depicts the computed discharge at a specific cross section, in other words, at the ends of each segment. The results computed at all nine cross-sectional locations are illustrated in these figures. The curves are identified by branch cross-sectional numbers. Discharge hydrographs for branch 1 are plotted in figure 32*A*, whereas hydrographs plotted in figure 32*B* are for branch 2. Of course, at the common internal junction location near Cromwell, Conn., the computed results identified by branch cross-sectional numbers 1–5 and 2–1 are identical by virtue of the model schematization. From these plots one can perceive the attenuating effect on the discharge of the tide wave as it propagates upstream to the Bulkeley Bridge gage site.

Detroit River between Lake St. Clair and Lake Erie

The Detroit River is a navigable international waterway. More specifically it comprises a series of interconnected channels joining Lake St. Clair with Lake Erie, as shown in figure 33.

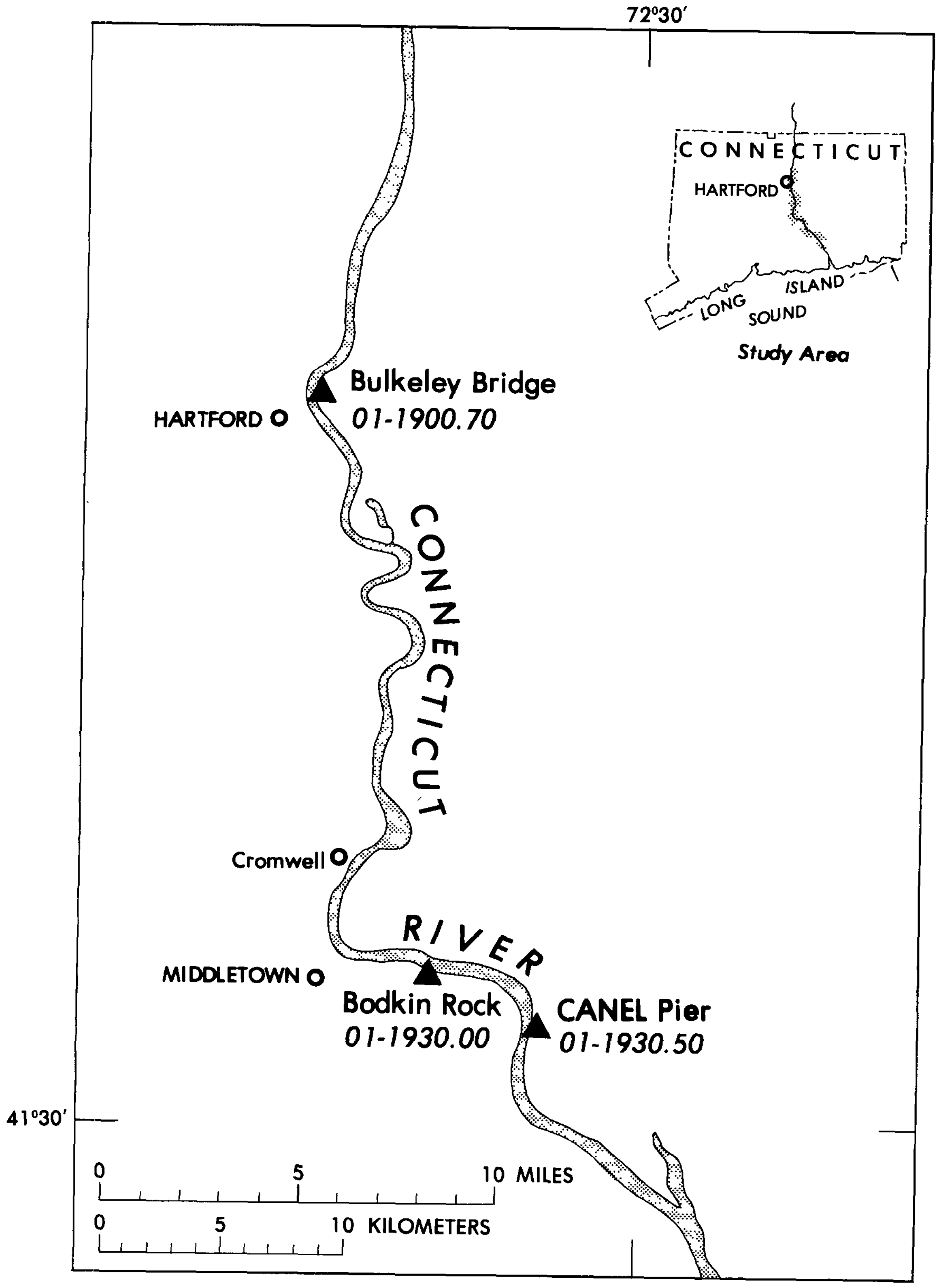


FIGURE 30. — Connecticut River reach near Hartford, Conn.

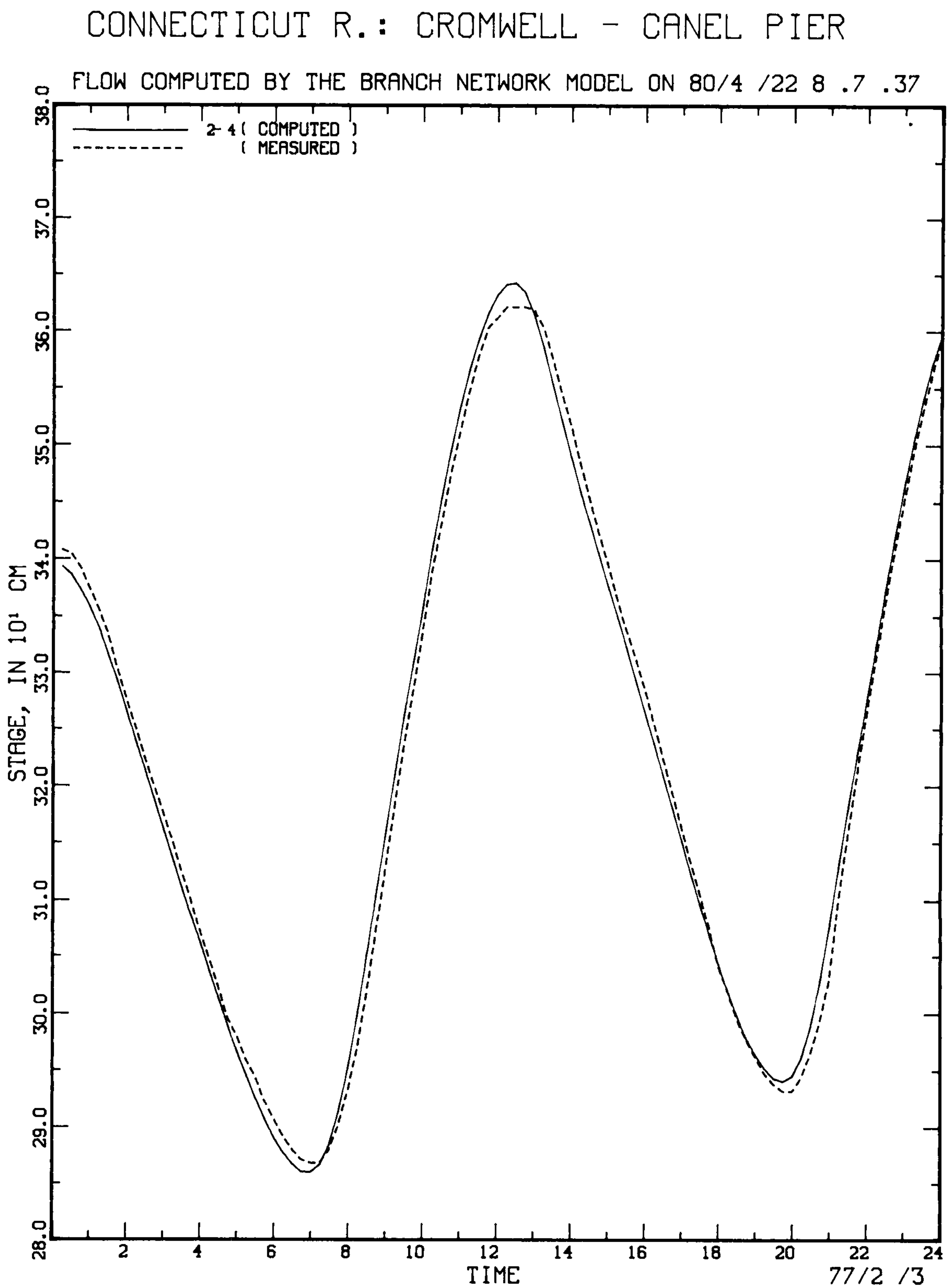


FIGURE 31.—Model-generated plot of computed-versus-measured water-surface elevations for the Connecticut River, produced using IOTOPT option 3, IPLOPT option 4, and IPLDEV option 2.

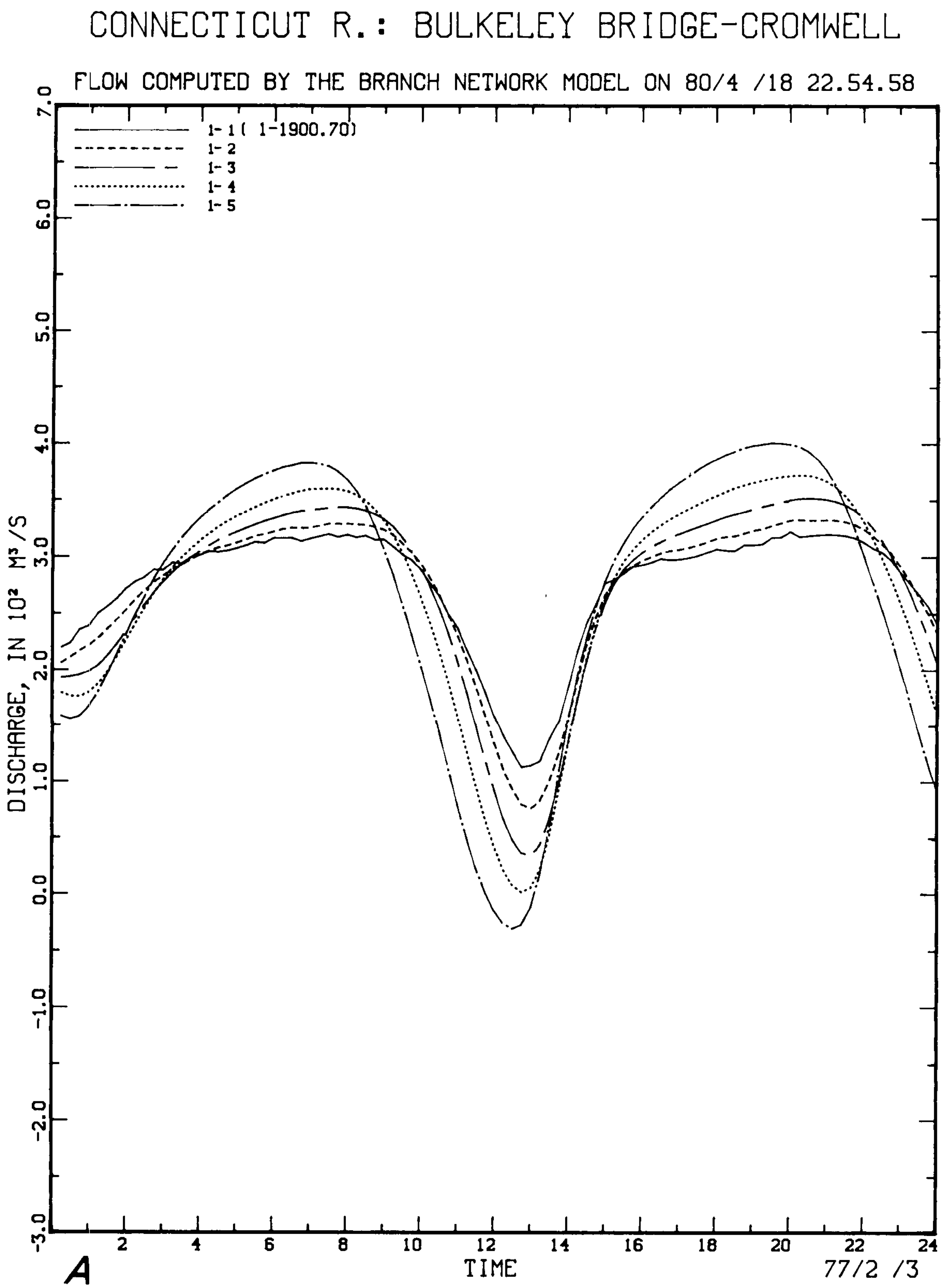


FIGURE 32.—Model-generated hydrographs of computed discharges for the Connecticut River, produced using IOTOPT option 3, IPLOPT option 1, and IPLDEV option 2. *A*, Branch 1. *B*, Branch 2.

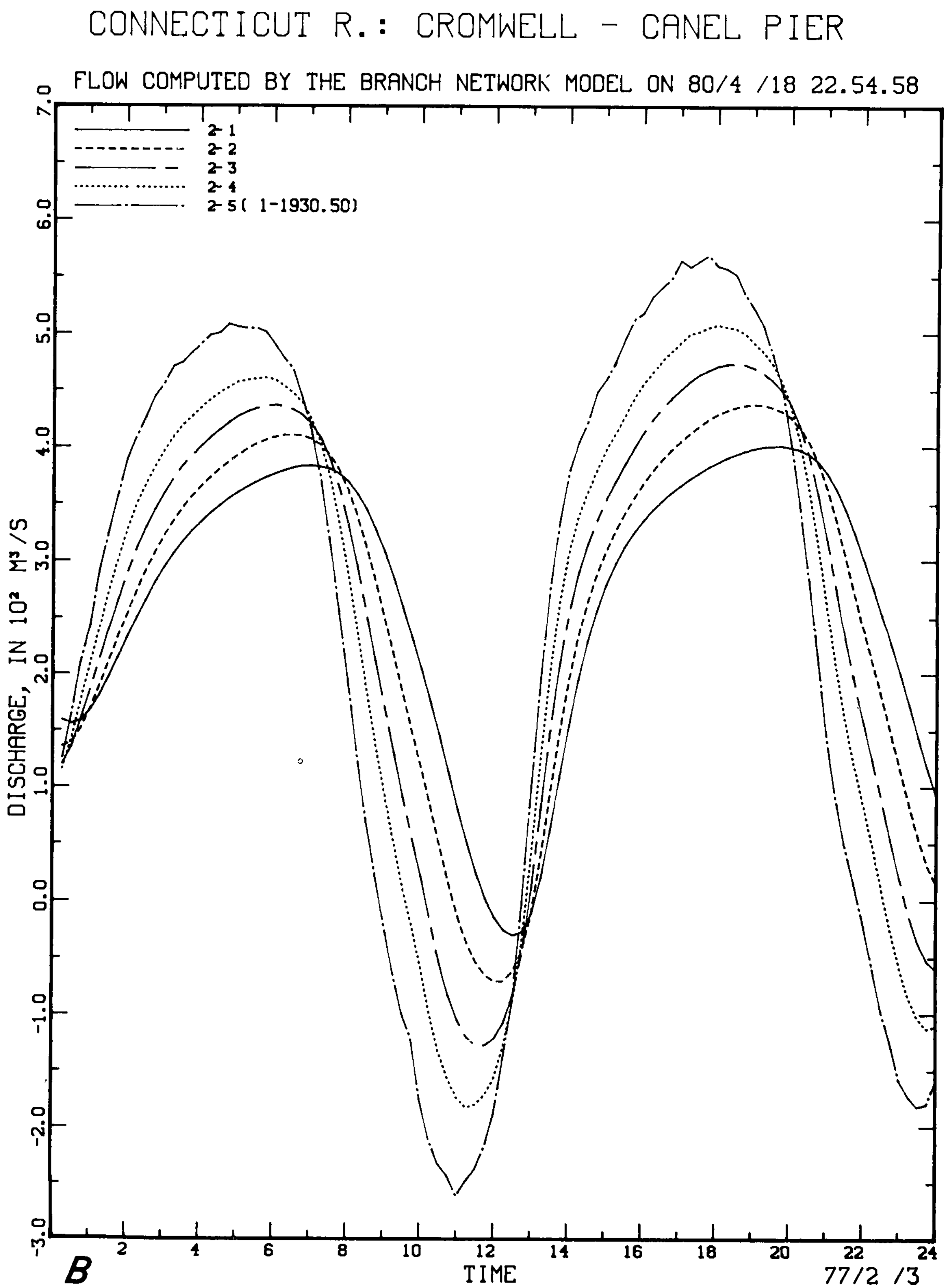


FIGURE 32.—Continued.

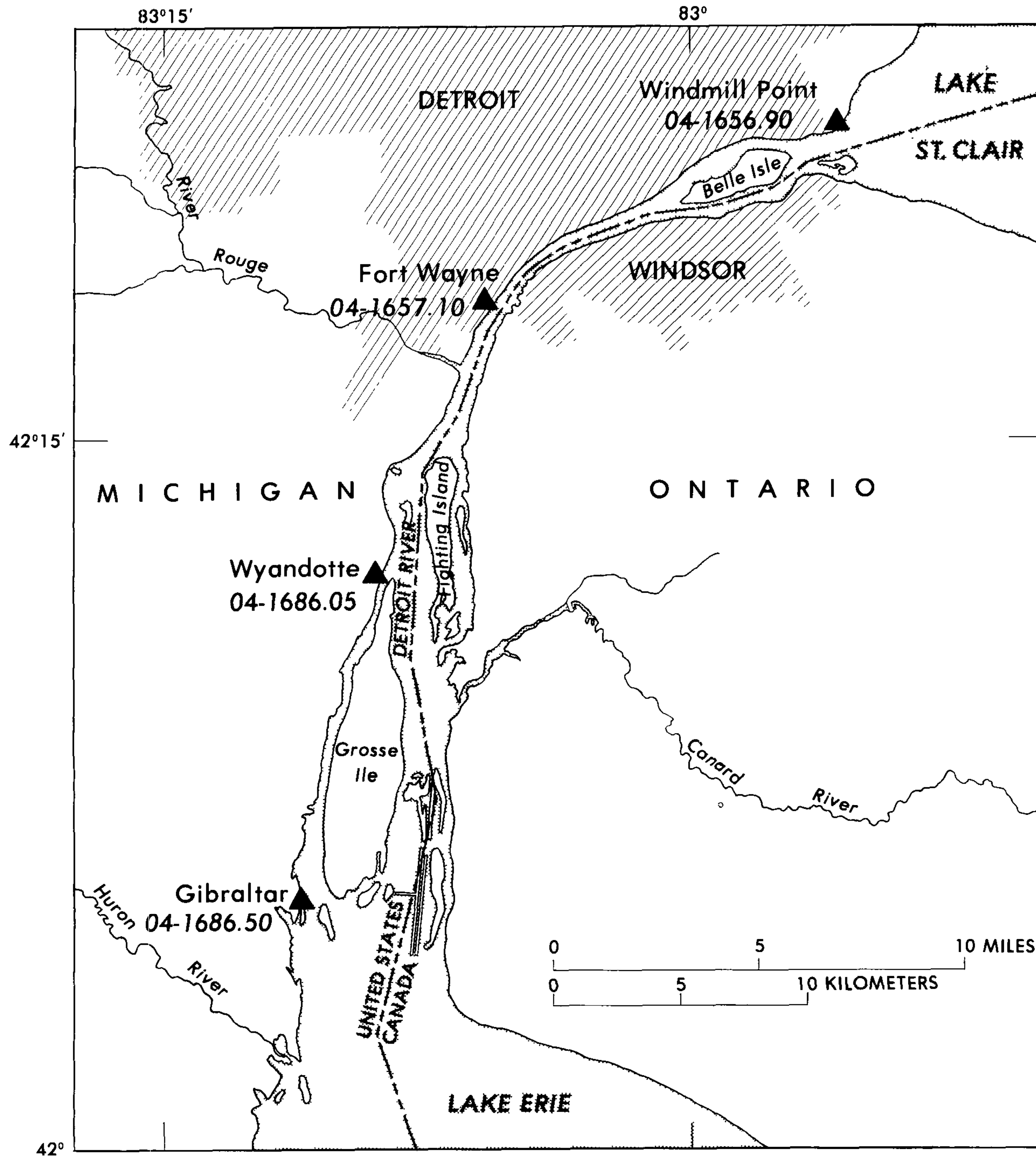


FIGURE 33.—Detroit River near Detroit, Mich.

Significant fluctuations in its flow result from wind tides and meteorologically induced seiches occurring in both Lakes St. Clair and Erie. During severe wind conditions the elevation of the water surface of Lake Erie at the mouth of the Detroit River has been observed to fluctuate as much as 2.5 m over a period of less than one day. Similar, but less pronounced, fluctuations of the water-surface elevation have been observed in Lake St. Clair at the headwaters of the river.

Significant, also, is the fact that the flow of the Detroit River is affected not only by the wind setup and seiching occurring in the adjoining lakes but that the flow can be appreciably affected, because of the river's length, breadth, and orientation, by wind shear acting on its surface.

The flow in the Detroit River and particularly fluctuations in the flow are of interest to those concerned with navigation, water supply, water quality, and industry. Knowledge of the flow is of international importance as well. Thus, the interconnecting channels of the Detroit River have been schematized, and the branch-network flow model is being used to simulate flows at selected locations. Boundary conditions for these simulations consist of stage hydrographs for Lake St. Clair (recorded at the Windmill Point gage location) and Lake Erie (recorded at the Gibraltar gage location).

The Detroit River application is truly a network simulation in the sense that the model schematization specifically accounts for the presence of one minor and three major islands within the river. The major islands of Belle Isle, Fighting Island, and Grosse Ile separate the Detroit River into various channels – and therefore, multiple flow paths – as can be seen in figure 33. A minor island at the headwaters of the river at Lake St. Clair is also accounted for in model schematization. The model schematization of the Detroit River is indicated in figure 34. As this figure indicates the full length of the river extending from a water-level gage at Windmill Point, Mich., to another near Gibraltar, Mich. (stations numbered 04–1656.90 and 04–1686.50, respectively) is being modeled. The overall length of the principal reach is 38.9 km. Water-surface elevations are also monitored and digitally recorded at intermediate locations at Fort Wayne, Mich., and Wyandotte, Mich. (stations numbered 04–1657.10 and 04–1686.05, respectively). These water-surface elevations constitute the boundary-value data, as well as data for model calibration and (or) verification.

As figure 34 illustrates, the Detroit River is treated as a network of 12 single-segment branches. Cross-sectional geometry data depicting the various channels were derived from hydrographic charts. Stage-area-width tables were prepared which describe the cross section at the beginning and end of each branch identified by a Roman numeral in figure 34. The 11 junctions of the model are identified by the numbered squares in figure 34. External boundary conditions are required at junctions 1, 2, 10, and 11. Recorded water-surface elevations at Windmill Point are used to define the boundary conditions at junctions 1 and 2. Recorded water-surface elevations at the Gibraltar gage location are used to define the boundary conditions at junctions 10 and 11. The required boundary conditions at internal junctions are established automatically by the model program.

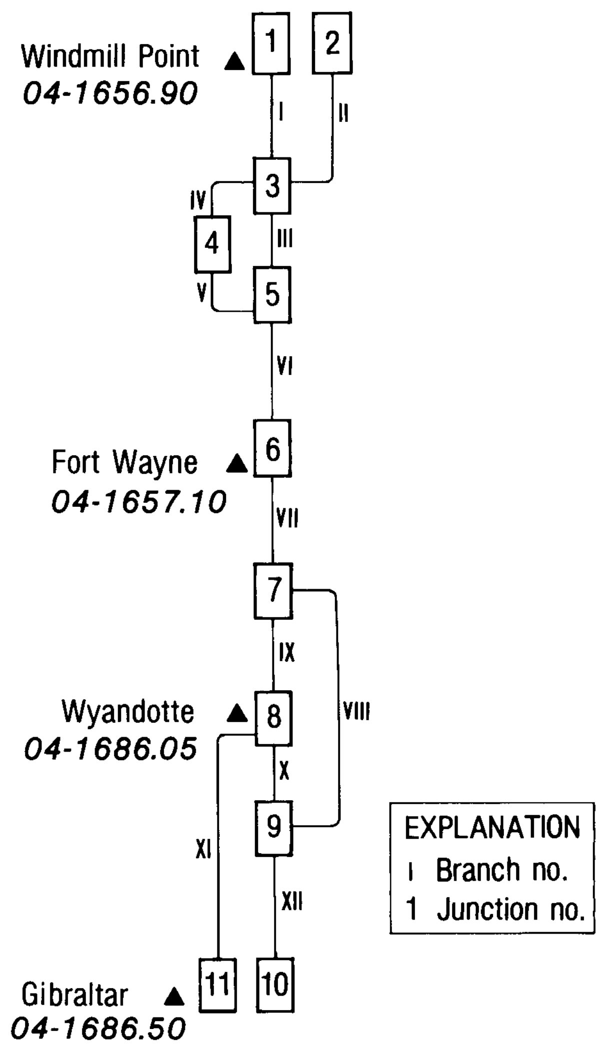


FIGURE 34. – Schematization of the Detroit River for the branch-network flow model.

```
//COMPUTER JOB CARD
/*PROCLIB  SCHAF PROCLIB
//BRANCH EXEC BRANCH,PROG=BRANOP,ECORE=360K,
// XSNAME='SCHAF BRANCH DETROIT GEOMETRY',
// GINAME='BALTZ GPHINDX1 DETROIT',
// DANAME='SCHAF TIMEDPDT DACCDATA'
//SYSIN DD *
DETROIT RIVER BETWEEN LAKE ST CLAIR AND LAKE ERIE
  1211 4     ME10  34 1 11       15 60500 0
 1 3 2DETROIT R    WINDMILL POINT - BELLE ISLE
      4 46 151531 00             5500 00     59 000 2235E-010 0        0 0
    135 00     1 0000
      4 34 151162 00

 2 3 2DETROIT R    PEACH ISLAND - BELLE ISLE
      4 46  50766 00             5500 00     59 000 2385E-010 0        0 0
    106 00     1 0000
      4 34  50618 00

 3 5 2DETROIT R    FLEMING CHANNEL
      4 34 142830 00            19500 00     59 000 2235E-010 0        0 0
    137 00     1 0000
      4 08 142239 00

 3 4 2DETROIT R    NORTH BELLE ISLE CHANNEL
      4 34  58949 00            10500 00     59 000 2485E-010 0        0 0
    108 00     1 0000
      4 20  58635 00

 4 5 2DETROIT R    SOUTH BELLE ISLE CHANNEL
      4 20  58635 00            10500 00     59 000 2485E-010 0        0 0
    157 00     1 0000
      4 08  58353 00

 5 6 2DETROIT R    BELLE ISLE - FORT WAYNE
      4 08 200592 00            25000 00     59 000 2235E-010 0        0 0
    147 00     1 0000
      3 81 200404 00

 6 7 2DETROIT R    FORT WAYNE - FIGHTING IS
      3 81 200404 00            19000 00     59 000.2235E-010 0        0 0
    170 00     1 0000
      3 59 200654 00

 7 9 2DETROIT R    EAST FIGHTING IS  CHANNEL
      3 59  45602 00            35500 00     59 000 2585E-010 0        0 0
    149 00     1 0000
      3 16  46271 00

 7 8 2DETROIT R    FIGHTING ISLAND CHANNEL
      3 59 155052 00            18500 00     59 000 2285E-010 0        0 0
    147 00     1 0000
      3 32 155845 00

 8 9 2DETROIT R    WYANDOTTE - GROSSE ILE
      3 32 102613 00            16500 00     59 000 2285E-010 0        0 0
    147 00     1 0000
      3 16 103066 00

 811 2DETROIT R    TRENTON CHANNEL
      3 32  53232 00            41500 00     59 000 2335E-010 0        0 0
    162 00     1 0000
      2 19  54287 00

 910 2DETROIT R    EAST GROSSE ILE CHANNEL
      3 16 149339 00            23500 00     59 000 2785E-010 0        0 0
    148 00     1 0000
      2 19 151521 00


3330                LIST_INDEX BEFORE= 0AFTER= 0
 Z 1      4165690       78/ 7/25 00 15      78/ 7/25 24 00     288  -70 0
 Z 2    5 4165690       78/ 7/25 00 15      78/ 7/25 24 00          -70 0
 Z10    5 4168650       78/ 7/25 00 15      78/ 7/25 24 00     288  -70 0
 Z11      4168650       78/ 7/25 00 15      78/ 7/25 24 00     288  -70 0
 Z 8      4168605       78/ 7/25 00 15      78/ 7/25 24 00      96  -70 0
/*
//
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FIGURE 35.—Sample deck setup to execute the branch-network flow model of the Detroit River.

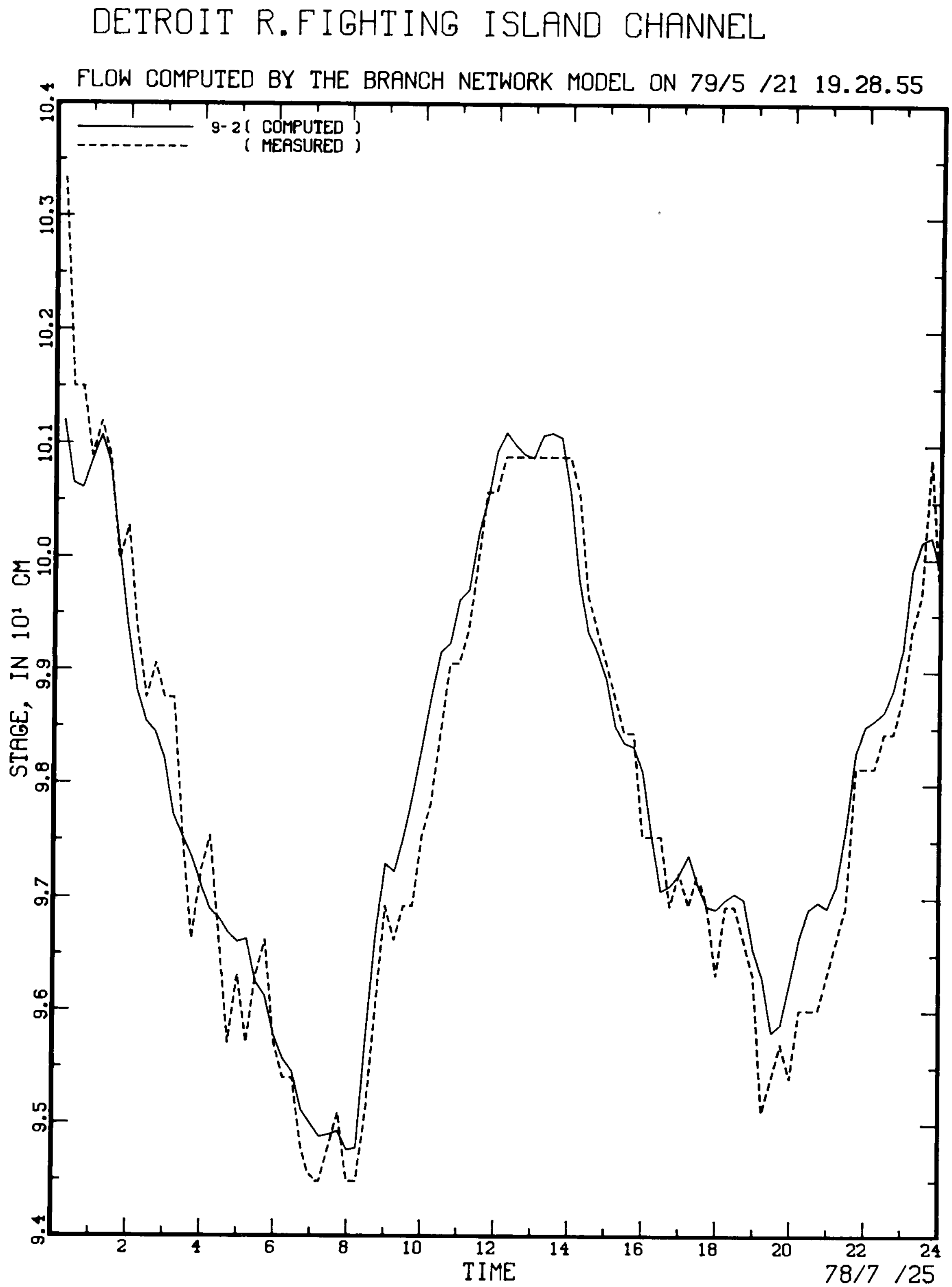

FIGURE 36. — Model-generated plot of computed-versus-measured water-surface elevations for the Detroit River, produced using IOTOPT option 3, IPLOPT option 4, and IPLDEV option 2.

A sample card deck setup to execute the branch-network flow model of the Detroit River is shown in figure 35. This figure is included to illustrate the relative ease and operational simplicity with which a complete flow simulation model may be initiated by the model user. In this particular execution setup, cross-sectional geometry, as well as boundary-value data, are retrieved from computer files. Cross-sectional geometry tables are retrieved from a computer file established by the cross-sectional geometry program, whereas boundary-value data are retrieved from a data base of time-dependent data. The initial conditions for the simulation depicted in figure 35 were computed and subsequently punched from a previous simulation. The model is set up to execute on a 15-minute time step using a value of 0.6 for θ and χ as defined in the section Finite-difference formulation.

The sample deck setup illustrated in figure 35 is intended to produce a line-printer plot of computed versus measured water-surface elevations. The model-generated graph, plotted via a Tektronix interactive terminal and illustrated in figure 36, was derived from a similar deck setup. This output represents a plot of the computed versus measured water-surface elevations at the Wyandotte gage location (fig. 33). In general, the agreement between computed and measured stages appears to be satisfactory; however, additional calibration and verification of this particular model are required. More conclusive tests of the model must await collection of synoptic sets of measured discharges, wind-vector data, and, of course, boundary-value water-level data for various flow and meteorological conditions. Computed discharges were within 3.5 percent of the measured discharges for one such set of synoptic data collected near the Fort Wayne gage location. Consequently, the Detroit River schematization appears to be appropriate for the flow model implementation and simulation; however, additional flow simulations are necessary to verify this assumption.

Summary

The branch-network flow model has been successfully used to simulate flow in singular reaches and in networks of interconnected open channels. The results of several applications illustrate the flexibility and accuracy of the flow model in simulating a wide range of flow conditions. The various model implementations were efficiently carried out using a computer program for analyzing channel cross-sectional geometry, a computerized system for editing, transcribing, storing, and retrieving time-dependent boundary-value data, and specific model-generated graphical outputs for evaluating computed results. These capabilities, which significantly hasten the model calibration and verification operations, also constitute an operational system for implementing and using the branch-network flow model.

The branch-network flow equations include wind shear on the water surface as a forcing function and are formulated to account for nonuniform velocity distributions through the momentum or Boussinesq coefficient. The four-point, finite-difference technique, with weighting factors for function values and their spatial derivatives in the flow equations, provides a high degree of flexibility in simulating diverse flow conditions in channels of variable cross-sectional properties. A unique branch-transformation technique is utilized in the model, resulting in a significant savings in computational time and computer storage. The implicit solution technique employed permits computations at large time steps. The subdivision of branches into segments of equal or unequal lengths is possible, thereby providing for the computation of water-surface elevations and flow discharges at any desired location.

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Baltzer, R. A., and Shen, John, 1961, Computation of flows in tidal reaches by finite-difference technique: Proceedings of the First National Coastal and Shallow-Water Research Conference, The National Science Foundation and The Office of Naval Research, Tallahassee, Fla., p. 258–264.