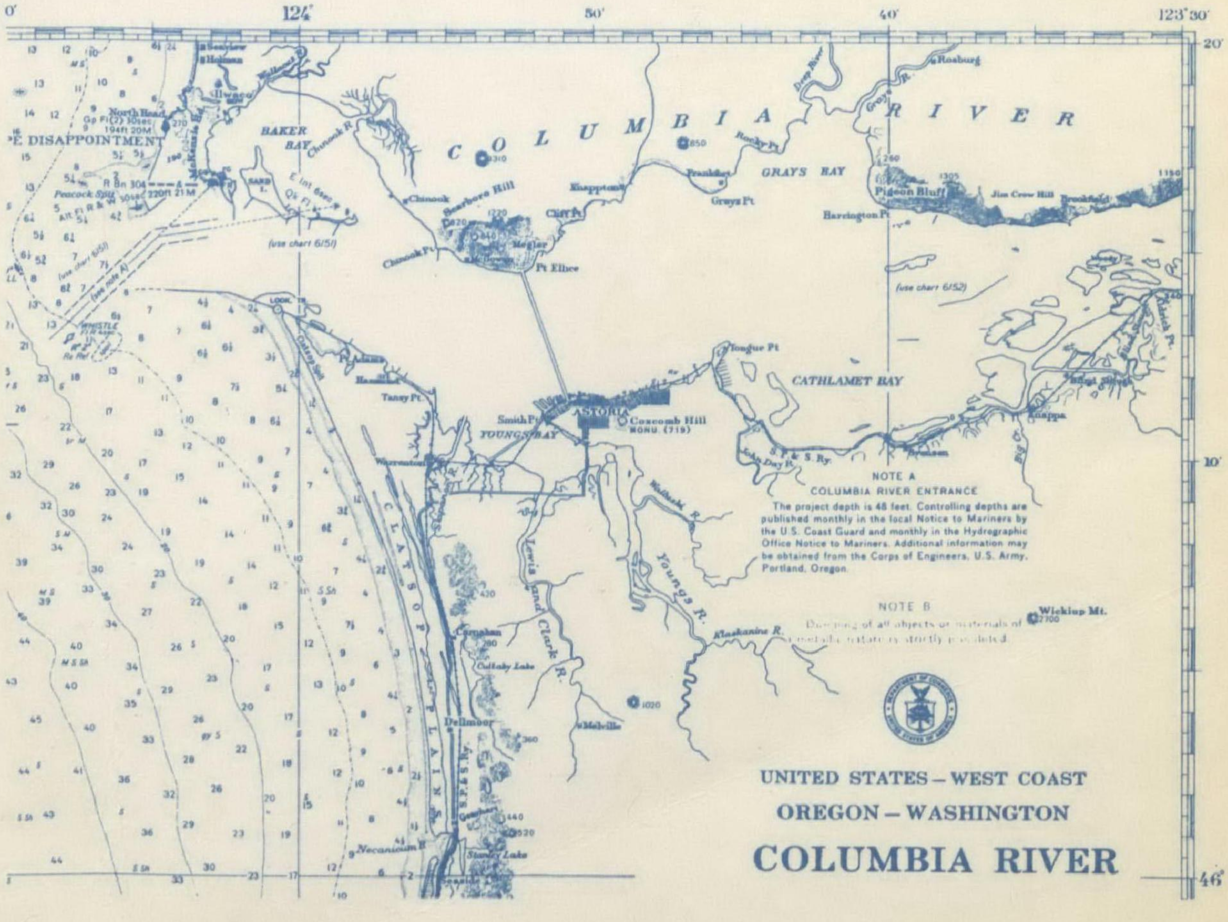
ENVIRONMENTAL PROTECTION AGENCY

NORTHWEST REGION, PACIFIC NORTHWEST WATER LABORATORY

MATHEMATICAL MODEL OF THE COLUMBIA RIVER FROM THE PACIFIC OCEAN TO BONNEVILLE DAM

PART II



CLEAN WATER

April 1971

MATHEMATICAL MODEL OF THE COLUMBIA RIVER FROM THE PACIFIC OCEAN TO BONNEVILLE DAM

PART II

Input-Output and Initial Verification Procedures

by

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INTRODUCTION

Part I of this report discussed the general model features, and presented program listings. In this part, examples of model usage are given, as well as specific examples of input-output on test cases. Preliminary verification of the model is discussed and recommendations and conclusions for future work are outlined.

This report was originally undertaken as part of an effort to model the entire Columbia River, as stated in Part I. Report writing being what it is, the putting together of this document has lagged behind implementation of the model. Thus, several runs have already been made by Northwest Regional Office personnel of EPA who learned how to use the model without benefit of this writeup. They should be contacted if additional information on model flows and, in particular, real-life conditions on the Columbia are desired.

BOUNDARY AND INITIAL CONDITIONS - GENERAL

Boundary conditions for the hydraulic and quality models must be carefully specified if the models are to make realistic predictions. For the hydraulic model the boundary conditions will usually consist of a fairly simple tide wave at the ocean end and steady mainstream and tributary inflows upstream of the ocean end.

Tide and river flow data are usually available from state or federal agencies, but water quality data adequate for specification of boundary conditions may be hard to find. While automatic tide and stage recorders are inexpensive, easy to install and maintain, automatic water sampling devices and chemical monitoring equipment definitely are not. Furthermore, if a boundary water quality parameter is to be correctly estimated it should be measured throughout the water column and across a given stream--restrictions that rarely apply to stage and tidal measurements.

As a result, the usual procedure is to find a point where the parameter is constant over time and space (or nearly so, compared to other fluctuations of interest), and specify a constant boundary condition there. Otherwise, if the input load is large enough or if the source is near the boundary, one has the situation of having to specify what is to be predicted; the only solution is thus to extend the boundaries of the model to a distance where source loads will not significantly affect the boundary values.

Initial conditions are specified at each junction for both programs in order to start the solutions. In the hydraulic model the accumulation of errors due to poor guesses at initial conditions is unimportant due to the presence of strong forcing functions. The guesses are made (more simply, head and velocity are taken as zero - hence not punched), the program is run for several tidal cycles, and the output from HYDEX is examined to see whether the solution has been carried far enough to achieve convergence (see appendices).

Poor guesses at quality initial conditions are another matter. Convergence is generally slower because the amounts of quality constituents are small in relation to the tidal and river flows. Considerable amounts of time may be required, for instance, for a substance to come to equilibrium starting from zero initial and/or boundary concentrations in response to a point source load. Indeed, a clear indication of an equilibrium state may not be obvious at all. If the initial concentrations are set too high (with respect to the simulated input loads) then loss of concentration is indicated; this can only be accomplished by flushing out of the system. The latter will proceed at a rate determined by the flows present in a particular segment of the model. Conversely, a set of 'low' initial conditions can approach higher concentrations only by allowing sufficient running time for convergence.

The boundary value problem, as we have shown, is less troublesome if the model is extended to a point where the boundary conditions are easy to specify. This may mean a larger model and more computations to run it than is necessary for the area of interest. If it is desired to run only a section of the model, one can run the full model to achieve convergence, and then use the hydraulic information at the ends of the section for boundary conditions on a smaller model. Tide guages, i.e., real boundary data, could achieve the same thing in the absence of a larger model.

Instead of the mixed tide or constant flow options which the program currently allows for as hydraulic boundary conditions, it would generally be easier to input the data as equally spaced points. We have programed one version of HYDRA in which up to ten variable inputs (tributaries) can be substituted. The program is not listed here and has not been extensively tested but is available on request.

In summary, the boundary-initial value problem is fairly straightforward in the hydraulic case if constant inflow at the upper end of the model is assumed, but can be troublesome, and hard to detect and correct, in the quality program.

HYDRAULIC PROGRAM

Test Situation

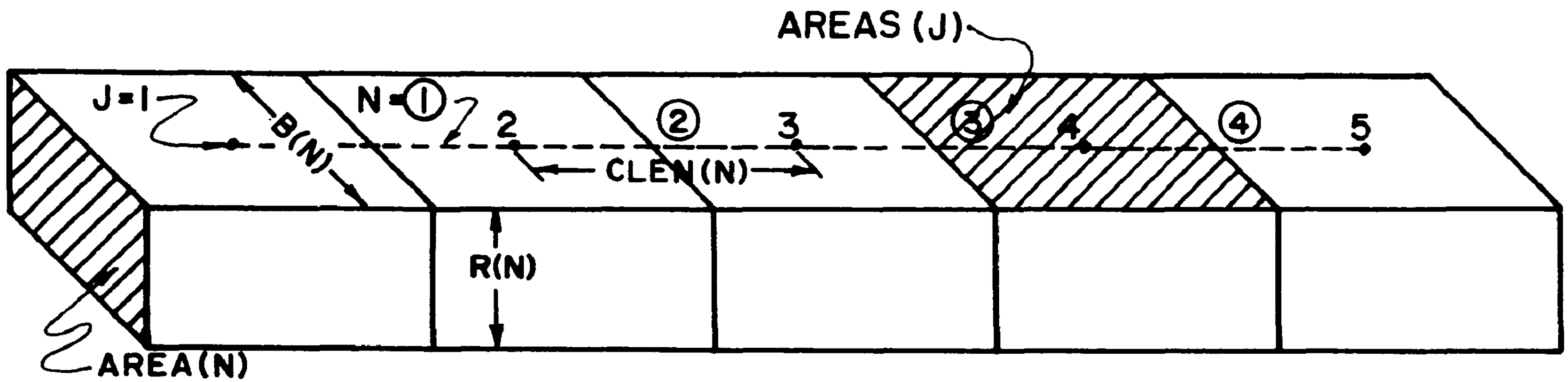
A many-junctioned and channeled model can produce lots of computer output, and to keep down the weight of this publication most of our examples are shown for a test system, which is essentially a rectangular channel with five junctions and four channels. The channel-junction numbering identification and dimensions are shown in Figure 1. General format specifications are given in Table 1. Card input format for a test run is shown in Table 2. The output generated by these cards is shown in Appendix 1.

Boundary and Initial Conditions

The boundary conditions for the hydraulic program are specified as a function of time at the ocean end of the model and as constants at the upper end. In the test system examples, a wave with a range of two feet and period of 12 hours is input at the ocean end, junction 1.

The Fourier series expression for head, y, at time t is then:

$$y(1) = 2 \sin \left(\frac{2\Pi}{12} t\right)$$



CHANNEL DIMENSIONS

FIXED

B(N) = 1,000 FT. = WIDTH

CLEN(N) = 5,000 FT. = LENGTH

VARIABLE

AREA (N) = 10,000 $FT.^2$ = CROSS-SECTIONAL AREA (INITIAL)

R(N) = 10 FT = AREA(N)/B(N) ≃ HYDRAULIC RADIUS

JUNCTION DIMENSIONS

AREAS(J) = 5×10^6 $FT.^2$ = SURFACE AREA (FIXED)

FIGURE 1. TEST CHANNEL DIMENSIONS

The program will accept two harmonics as:

$$y = a_o + a_i \sin(\omega t + \phi_i) + a_2 \sin(2\omega t + \phi_2)$$

where,

a_o = A datum level or constant stage elevation with reference to the datum.

a_i = Amplitude of i^{th} harmonic.

ω = A speed number or frequency.

ϕ_i = Phase angle of i^{th} harmonic.

t = Time.

If a more complicated wave form is required for input, i.e., one requiring more than two harmonics, or if it is desired to utilize known tidal coefficients, then program modifications can easily be made.

If there are two junctions at the ocean with the same input wave then YT(2) = YT(1) and Y(2) = Y(1) can be employed and the loops changed from J=2, NJ to J=3, NJ. (See sequence numbers 160-161, 189-190 in program HYDRA, Part I)

No tributary or mainstream inflow will be allowed. This is the condition that would exist in an embayment with no runoff entering the system. For initial conditions, heads and velocities will be set to zero and the Manning coefficient will be set to 0.02 for all channels.

Control of Time

For all cases, a time step of two minutes (DELT=120 seconds) is used and the simulation run for a period of 18 hours. Then,

$$NCYC = \frac{18 \text{ hrs} \times 60 \text{ min hr}^{-1}}{2 \text{ min cycle}^{-1}} = 540 \text{ hydraulic cycles.}$$

HYDEX is called and an averaging period of 30 minutes used. Then $NODYN = \frac{1800 \text{ sec } (30 \text{ min})^{-1}}{120 \text{ sec cycle}^{-1}} = 15 \left(\frac{\text{cycles}}{1/2 \text{ hr}}\right)$. Referring to sequence numbers 34 and 35 in HYDEX, it will be seen that NSTOP = 540 and $NSTART = 540 - \frac{3600 \times 12}{120} = 180$, so the total averaging period consists of 360 dynamic cycles or 12 hours.

Control of Output

The input data is listed (INPSUP=0), printout begins with the first cycle (IPRT = 1) and the binary record is written starting at hydraulic cycle 180 (IWRTE = 180). Output is made at all junctions, hence NOPRT = 5 and JPRT = 1, 2, 3, 4, and 5. A 'restart' deck is written after cycle 540. If it is found that convergence has not been achieved, this data may be used as initial conditions and the program run again or extended.

For each example, the running time was about 24 seconds and there were 493 lines of printed output.

Flow and Velocity Sign Convention

The sign convention for direction of flow from channels to junctions is negative into the junction, and positive out of it.

This is carried in the "system status" printouts, and in the input when it is necessary to use QIN to show tributary inflow (negative QIN) or non-system outflow (positive QIN).

When a flow or velocity is printed for association only with a channel, such as in the "channel data" or the channel summary in HYDEX, a positive flow/velocity means a flow from junction number NJUNC (x,1) to junction number NJUNC (x,2). Since, on input of channel data, the NJUNC (x,1) appears on the card to the left of NJUNC (x,2), it may help to consider that positive flow is from "left" to "right" (but only for this simple example!).

Compatability Checks

Junction numbers are listed on channel cards to designate the junctions which are at the end of the channel. Channels are listed on the junction cards to designate which channels enter the junction. If an error in coding from the schematization results in an inconsistency, an error message is printed, and the program terminates. Appendix 4 is such a case. The channel data show channel 1 ends at junction 1 and 3, but the junction 3 data show only channel 4 as connecting to it.

Examples of Output

Output for Appendix 1 is shown on pages 68 to 79. Junction, channel and tidal input data are printed on pages 68 and 69 . It can be seen that initial heads and speeds are set to zero. Output for every thirtieth cycle is given on pages 70 to 72. Intermediate output is not shown; cycle 511 and the final cycle output is shown on pages 73 and 74. Output from subroutine HYDEX is shown on pages 77 to 79..

In Appendix 2 (pp 80 to 91) conditions are the same as in Appendix 1 except that the Manning coefficient is increased to 0.03. Differences in head, velocity and flow compared with Appendix 1 begin appearing at cycle 31 (page 83) and are most apparent in the HYDEX output (pp 89 to 91). In both examples it can be seen that there is a slight net flow (pp 77 and 89) in each channel. Flow is seaward (-) in Appendix 1, and landward (+) in Appendix 2, a consequence of the roughness coefficient, the duration of the run, and the averaging period (1/2 hour).

As a third example, 100 cfs is input at the upstream junction (QIN 5 = -100), other conditions being the same as Appendix 1 in order to show the influence of inflow on the solution. Output is shown on pages 92 to 103. As can be seen on page 101 the net flow is approximately 100 cfs seaward. Comparison with Appendix 1 shows a slight difference in the channel cross-sectional areas; there is a general increase seaward and decrease landward in velocities and flows as would be expected because of the river input.

Subroutine HYDEX provides a means of determining whether convergence has been achieved and indicates the magnitude of water accumulation or loss (if any). Two additional cases of this are illustrated in Appendix 5 (pp 105 to 109) and 6 (pp 110 to 114), for which only the HYDEX output is shown. The only difference in input conditions is that all channel lengths for example 5 are 2500 feet and for example 6 are 5000 feet. A flow of 1000 cfs is input at junction 5. In each case only the junction and channel restart decks at the end of 540 cycles are listed from program HYDRA, while print-out from HYDEX is shown that for the 'short-channel' example net flows in each channel are very close to the river input of 1000 cfs while for the 'long-channel' example (p112) there is a more serious discrepancy. Differences are also apparent in the cross-sectional area data, tidal ranges (pp108 and 113), and the flows in the first two channels (pp 109 and 114).

QUALITY PROGRAM

Boundary and Initial Conditions

If the boundary conditions for BOD, for instance, are known to be 0 or some constant value, regardless of the fluctuations in head or velocity, or are specified, then the problems of convergence in the water quality program concern initial conditions specified within the boundaries. If "too much" constituent is initially specified, then so much computer time will be expended in removing the excess; likewise, if "too little" is specified, then a certain amount of time will be expended in reaching steady-state by addition from the sources.

Experience in applying the convergence factor, FACTR (I,K), to one or more groups, NGROUP (I), consisting of the junctions numbered NJSTRT up to and including NJSTOP for any constituent, K, can diminish the time required for convergence. If, after a certain amount of time it is found that concentrations have not achieved steady-state, the FACTR can be applied as some value $\lesssim 1$ depending on the constituent state at the time. The program then can be restarted from the restart deck or from scratch.

Boundary conditions consist of those from tributaries or waste flows at a given junction and those at the ocean (lower) end of the model. Constituent mass is added to the system by either of two separate mechanisms: the first of these is a discharge, where the water of concentration CSPEC and flow rate QINWQ is assumed to come from outside the system. Situations like these are tributary inflow (where the flow of water is significant and has been allowed for in HYDRA), or a sewage plant effluent (where the flow of water may not be significant, but where the constituent is). The second mechanism is a diversion return, where the water is to come out of and then be returned to the system. Constituent is added to the system during the diversion by specifying a mass-concentration (CONST, mg/l-cubic foot/delta-t) independent of flow in the diversion. Constituent originally in the water as it was diverted is transported by the diversion, but if not all water removed is returned (RETRNF≠1), some constituent is lost to the system also. Only one of the two mechanisms should be used at any particular junction.

The final quality boundary condition to be considered is at the ocean or lower end. The simplest case occurs if the concentration is some constant value. If it varies with tide stage, then enough (NSPEC) varying concentration values must be input to cover a tidal cycle. If the lower end is not large enough to be considered an infinite source or sink or if a concentration is significantly different from the specified boundary value (CIN) when the substance reaches a boundary, then the resulting gradient will be forced to conform to the boundary value.

In the specific case of the temperature initial and boundary conditions, special problems arise. One must assume that a realistic set of conditions, preferably real data, is on hand at the outset. If meteorological data are used, several trends of different duration (days) may exist and there is no real approach to steady-state, so that it may be difficult to detect subtle errors. If no large gradients exist (e.g., in the absence of a large heat input at a junction) the dispersion errors can be shown negligible by making all initial and boundary conditions constant, removing the meteorological input and noting the accumulation of values different from those initialized when the dispersion coefficient is set to zero.

Decay and Reoxygenation Coefficients

Decay and reoxygenation rates are usually given in units of day^{-1}. (If base 10 is employed the usual convention is to use small k, i.e., k_1 and k_2 for the first order decay and reoxygenation rates, respectively. Base e goes with a capital: K_1, K_2.) In order to input these rates into the program, conversion to the time unit employed (sec^{-1}) must be made. No provision is made to vary k_2 with velocity or k_1 with flow or temperature here although these options could be incorporated.

For the decay rate for BOD, or any substance, the dimensionless quantity

$$k_{1c} = 10^{-k_1 \Delta t} \text{ (or } K_{1c} = e^{-K_{1c} \Delta t}\text{, if base e is employed)}$$

is input, where

k_1 = Decay rate converted to sec^{-1}

Δt = Quality time step in seconds

K_{1C} = Quantity input ($k_{1computer}$) as DECAY(K), F10.0,
(See sequence number 74; (K) here refers to the K^{th} constituent.)

A different procedure is used for the reoxygenation coefficient and

$K_{2j} = K_2$, or $k_{2j} = k_2$

is input, where K_2 is the reoxygenation coefficient in sec^{-1}, and K_{2C} is the quantity input as REOXK(K), F10.0, with dimensions of sec^{-1}.

For example, with a quality time step of 30 minutes (Δt = 1800 seconds), and K_1 = 0.1 day^{-1}, K_{1C} would be input as 0.997919; for K_2 = 0.1 day^{-1}, K_{2C} would be input as 0.00000115. The program assumes both rates to be uniform throughout the estuary. As always, be wary of which base is being employed and be consistent, i.e., don't use base e for K_1 while using base 10 for k_2. Future versions of the model will allow for automatic computation of these coefficients.

Inputting the Meteorological Data

It has been stated that the temperature independent terms were assumed known or could be computed independently. The development of program MIFP (Meteorologic Input File Program) for the FWQA (see reference WRE, 1969, p. 82 of Part I) alleviated the necessity of writing a separate subroutine during the later development stages of the Columbia River program. MIFP can be modified as a standard subroutine to this estuary model.

We will assume the net radiation values (QRNETA) are available in a table, as are winds, air temperature, wet bulb temperature and air pressure. The interval between data points, INT, (usually three hours are used in ESSA weather reports) the number of points, NPTS, and the time of starting in relation to the quality program, NQCSM, are all that are required. Data is then linearly interpolated compatible with time step used in the quality program.

Test Channel Run-Temperature

Appendix 7 (pp 115 to 125) shows temperature calculation output using the 5 junction test channel. Here the initial and boundary temperatures are taken as 10°C. No driving force is provided (heads are zero) and no input flow is assumed, hence the "channel" acts as a dormant slough. No dispersion, waste water, or multiplication factors were input.

The input meteorological data are shown on page 119; these data were also used in the Columbia River run discussed below. Net incoming radiation (kcal m^{-2} sec^{-1}) is input directly as is wind speed, wet and dry bulb temperature, and atmospheric pressure. There are 24 hourly observations; the program assumes that these values are repeated for every day of the run (10 days, here). Actual hourly (or other interval) variations from day to day can, of course, also be used as input.

Output from the program for several cycles is shown on pp 120 to 125 as are the computed radiation terms and equilibrium temperatures; normally these terms will be suppressed.

Format specifications for QUALTEMP and METDTA are given in Table 1. The input list for the QUALTEMP listing in Appendix 7 is shown in Table 3. The output for HYDRA-HYDEX (required for getting into QUALTEMP) is not shown although the input listing is.

COLUMBIA RIVER DATA AND TEST RUNS

Feigner and Harris (1970) have presented results of the San Francisco Bay-Delta model. They show the influence of varying the magnitude of the dispersion coefficient on output concentrations as well as several other examples of model use. Although temperature is not discussed, the reader is referred to their work as it presents some types of examples which will not be reported here, and provides further insight as to model use.

Flow Data and Hydraulics Verification

The next few paragraphs deal with verification attempts in the Columbia. We were not overwhelmed with actual field data and relied mainly on USC&GS tide tables (U.S. Department of Commerce, 1970) for verification of the hydraulics. Stage elevations at Bonneville Dam were taken from a report by Bonneville Power Administration (1966).

Because of the volume of water contained in the Columbia, the response of the system to hourly heat fluxes will not be as dramatic as in the case of wide, shallow streams. This shows up in real life and is reflected in the computations since a large volume of water is a rather effective reservoir of heat.

A typical record of outflow and tailwater elevation at Bonneville is shown in Figure 2. Data from these graphs were picked off at several flows in order to obtain the correlation shown in Figure 3, a plot of tailwater elevation versus flow. The two flows and elevations used in the runs to be described are also shown in this figure.

Although the actual records indicate rather wide diurnal fluctuations, steady flows were assumed in our runs in order to obtain (and be able to observe) dynamic steady-state as rapidly as possible.

At the upper boundary condition the flow from the junction representing Bonneville Dam was input. Water elevation above datum was then approached as the channel depths responded to the amount of discharge. At the outset of this study, we were not sure just what the elevations should be and it was pleasurable to find that the computed elevations fell within 1-2 inches of observed, even when the difference in tailwater elevations for two flows was about seven feet. The flows referred to are shown in Table 4 and the remainder of this section deals with verification using these flows.

In Figure 4, computed and observed co-range lines are given. The computed tide range is output in subroutine HYDEX, the values at each junction were plotted and isopleths drawn through equal

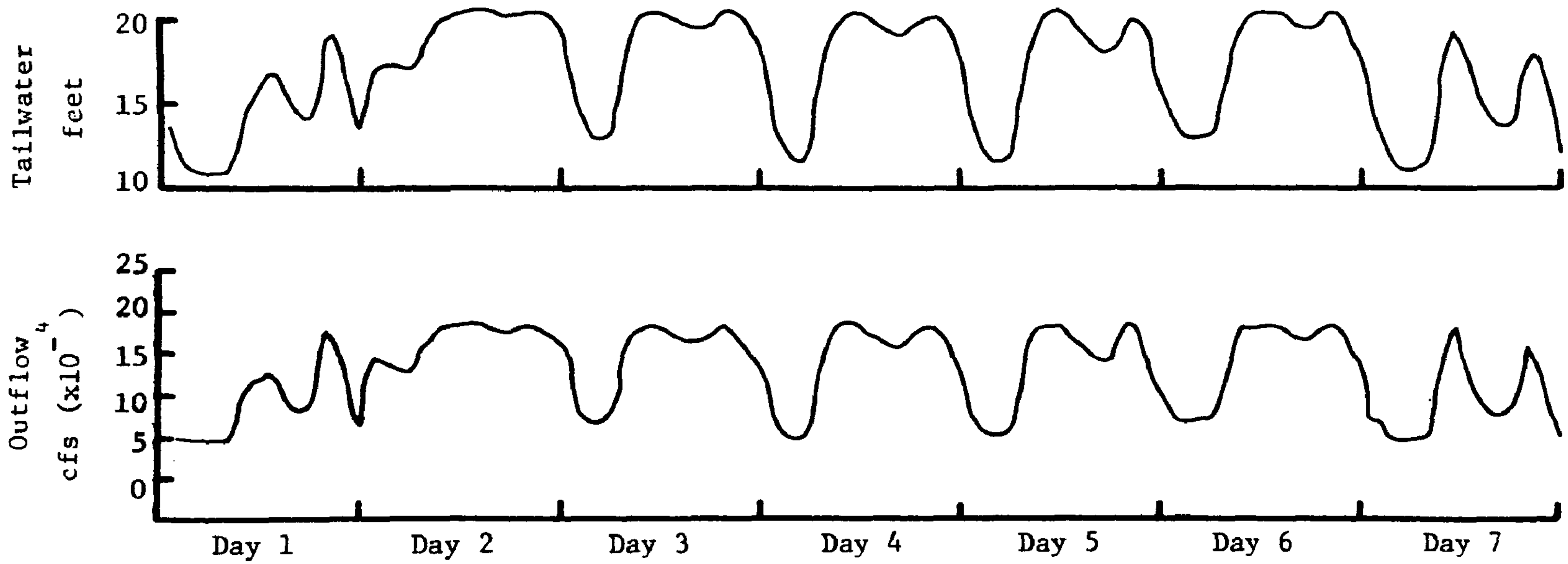


FIGURE 2. TIME-SERIES OF TAILWATER AND OUTFLOW RECORDS. BONNEVILLE DAM. (From BPA, 1966)

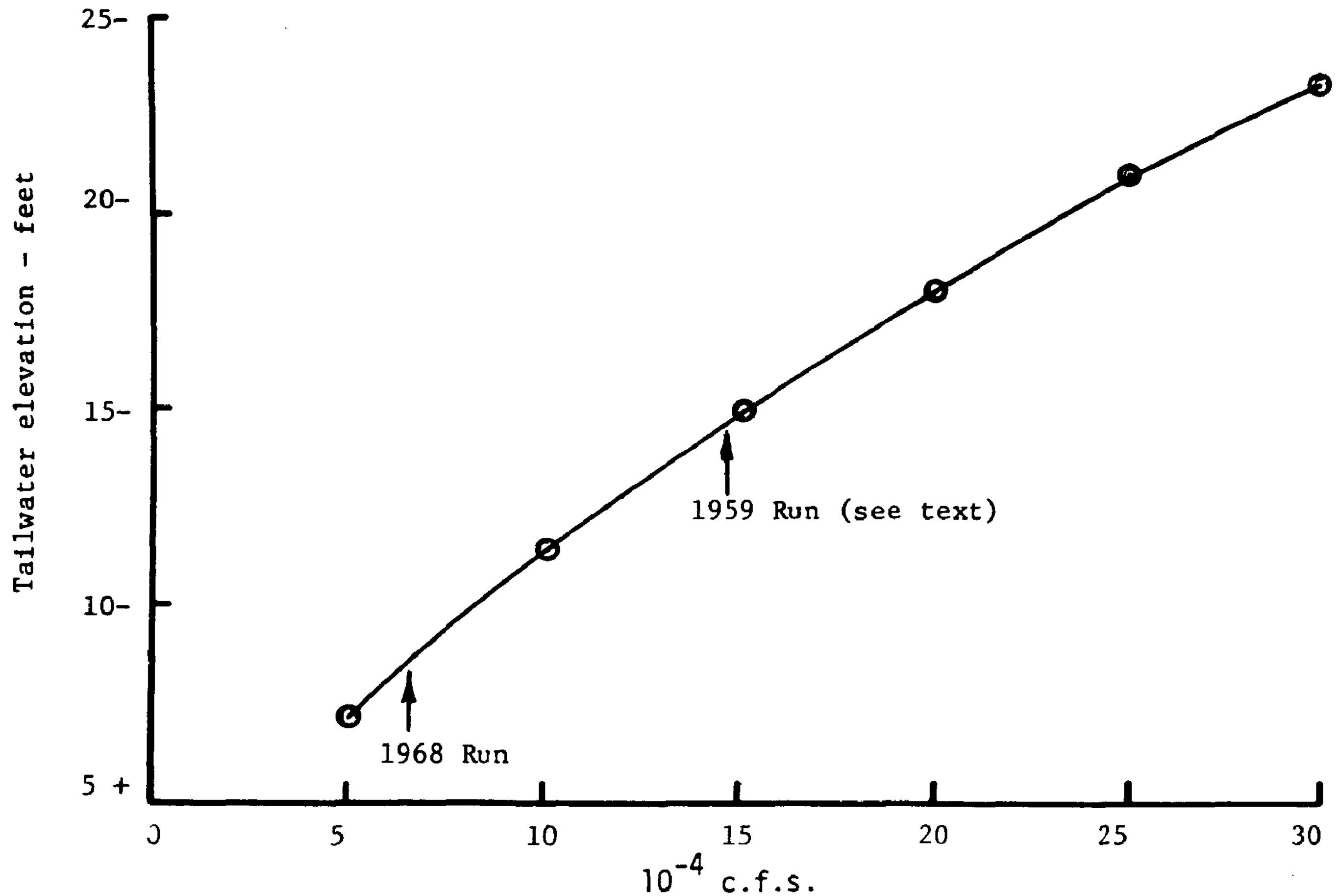


FIGURE 3. TAILWATER ELEVATIONS VERSUS OUTFLOW. BONNEVILLE DAM.

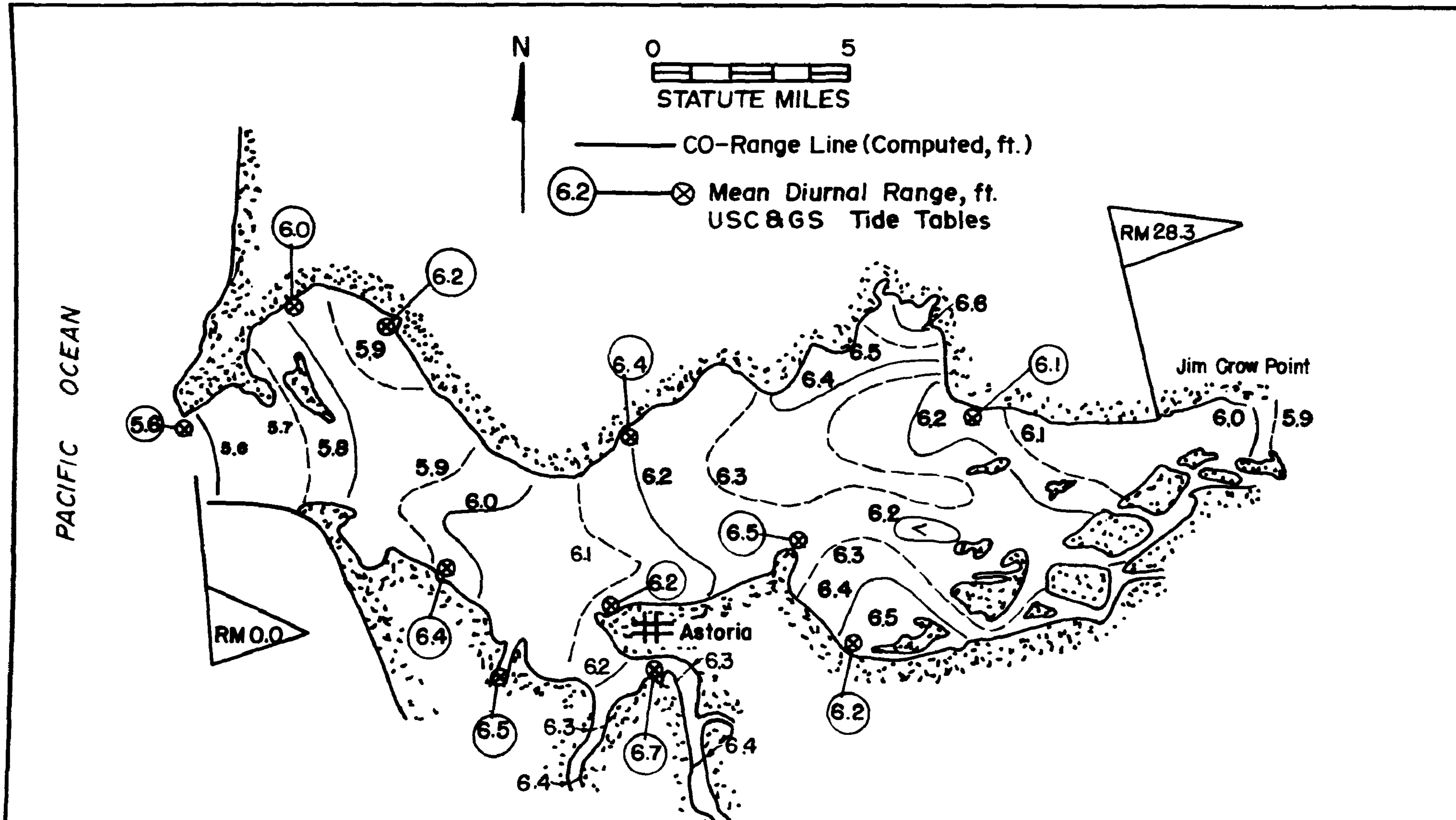


FIGURE 4. COMPUTED AND OBSERVED TIDAL RANGES, COLUMBIA RIVER, MILE 0-30.

ranges. Also shown in the figures are "observed" ranges as taken from the C&GS tide tables. In general, the agreement between computed and observed values is excellent.

Figure 5 shows a longitudinal section of computed and observed ranges. Note the agreement in the lower river which shows an increase in mean diurnal range with distance upstream, passing through 6 feet about mile 5 and again at mile 25. The agreement is rather good along the entire river stretch with the exception of from about mile 70 to 100. The reasons for the discrepancy here are not known at this time, but could be due to channel modifications made after the USC&GS computations base data were collected, but which are incorporated on the charts from which the input data was taken.

The 1959 flow data (Table 4) were chosen as representative of a "normal" low flow period. Starting at river mile 27, a wave with 6 foot range, Manning coefficient of 0.02 $ft^{1/6}$ and 12.5 hour period was input at a river level of 3.8 feet (as determined from Corps of Engineers data for the flows used). It was assumed that 25 hours would be sufficient for convergence, hence these output data (first 25 hours) were discarded. Figure 6 shows the progression of the wave with distance upstream. Agreement between computed and Tide Table phase lags and amplitudes was on the order of minutes and inches, respectively.

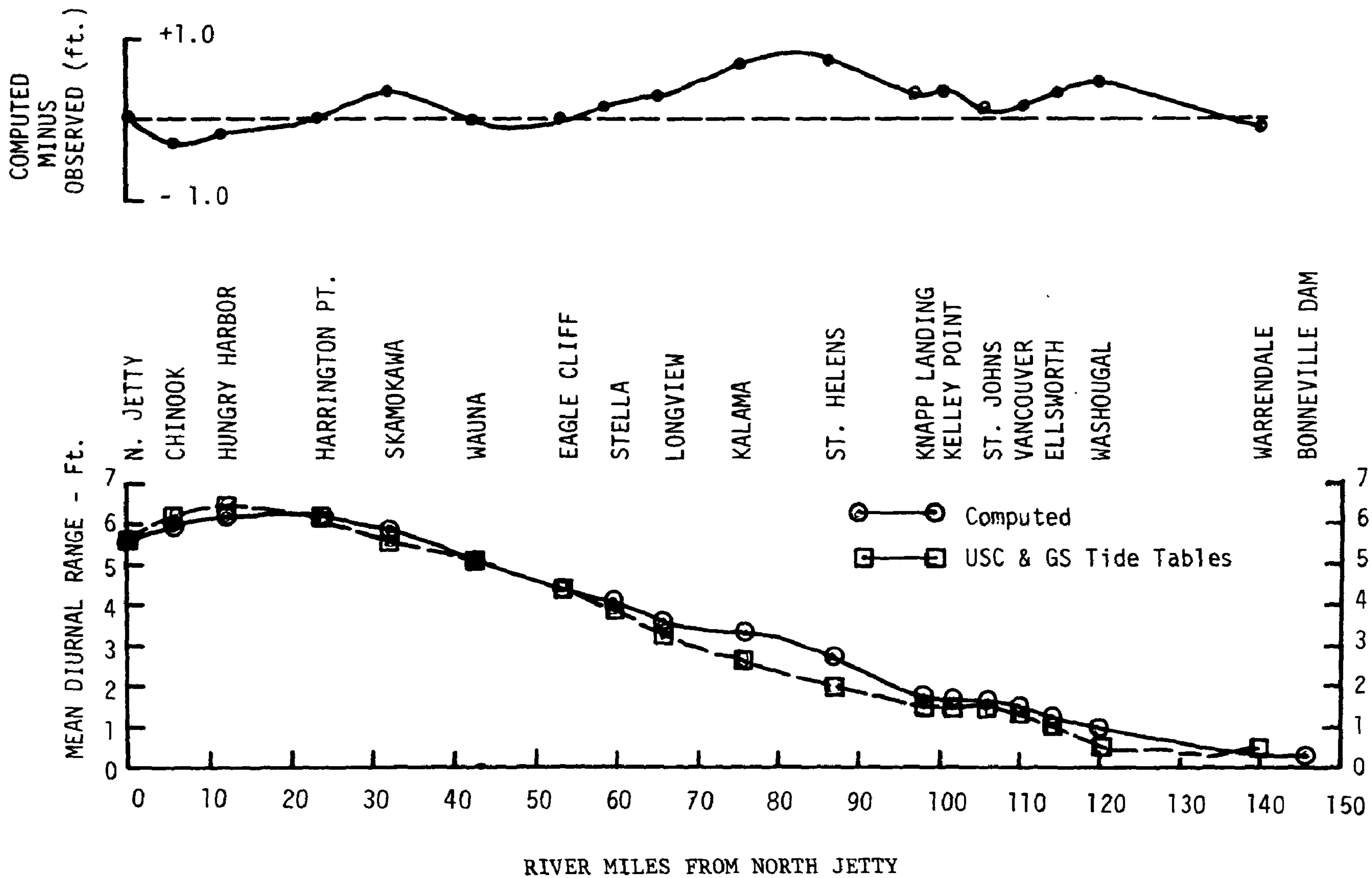


FIGURE 5. COMPUTED AND OBSERVED TIDAL RANGES, COLUMBIA RIVER, MILE 0-146.

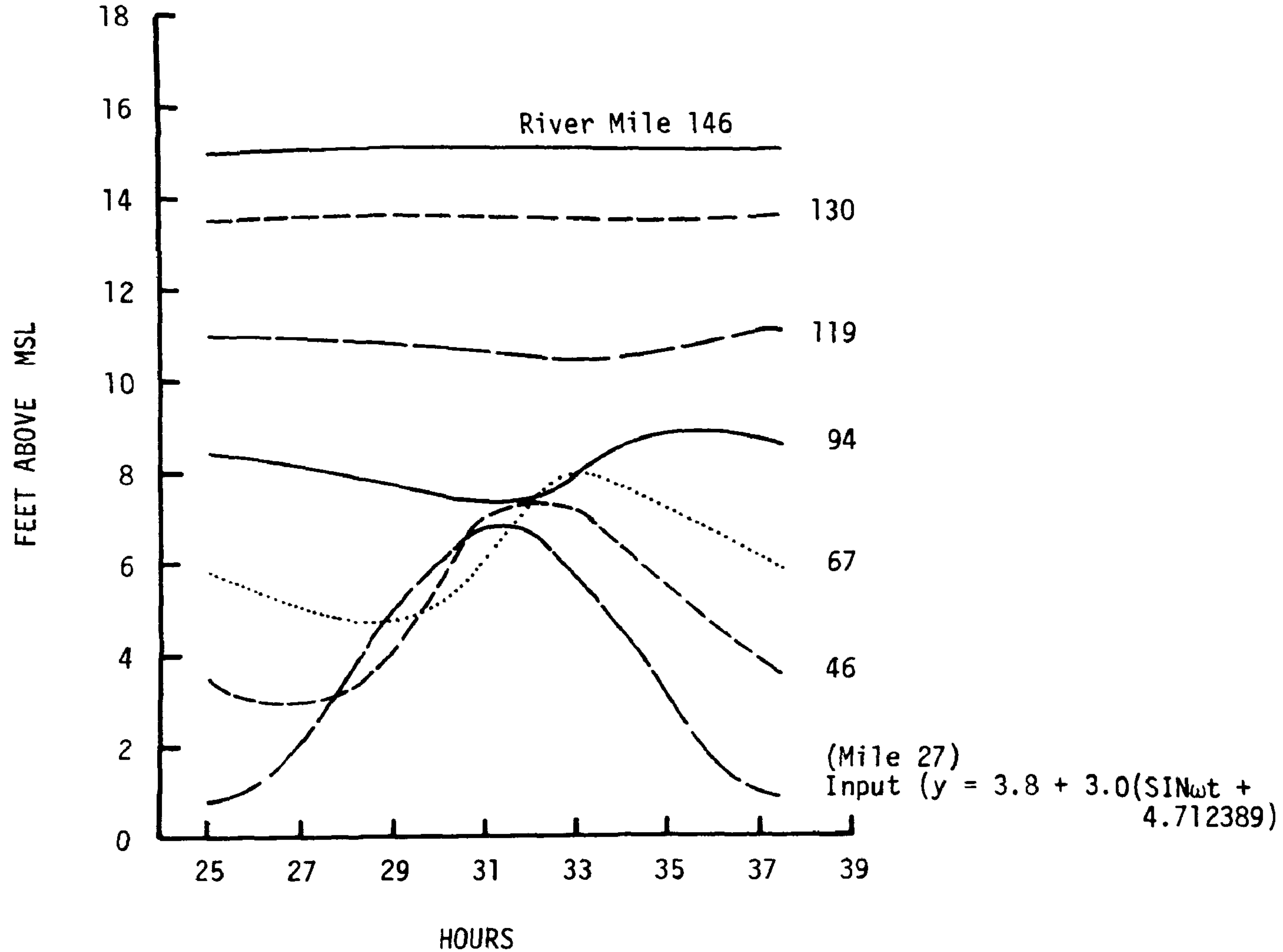


FIGURE 6. COMPUTED STAGE ELEVATIONS VERSUS TIME, MILE 27-146.

Clark and Snyder (1969) published a note on their observations of current reversal 70 miles (113 km) upstream from the mouth of the Columbia River, near the proposed site of two thermal electric power plants. The particular river stretch was chosen because heated cooling water returned to the stream might interfere with the endemic and anadromous fishery, especially if there were to be periods of low current speeds as during a current reversal. The purpose of their study was thus to determine if reversal occurred, and if so, to measure its duration during a very low flow period of less than half the river's mean annual discharge (of 84,500 cfs at Astoria). A rather extensive field study using dye dumps and fluorometry was reported; in summary, they found that reversal occurred over a four-hour period from about 3:50 a.m. to 8:00 a.m. on April 16-17, 1968.

The low flow occurring during their study was the result of filling the then just-completed John Day Reservoir. Such events are not recurrent; the flow magnitudes occurring, however, have been projected as future possibilities.

A sine wave with a period of 12.5 hours and range of 7.5 feet, the diurnal range at the North Jetty, was input at the ocean end of the model. A Manning coefficient of 0.02 $ft^{1/6}$ was employed and conditions simulated for two tidal cycles.

Figure 7 is a computer plot of tidal elevations, velocities and flows at river miles 67 to 74. The somewhat erratic traces in

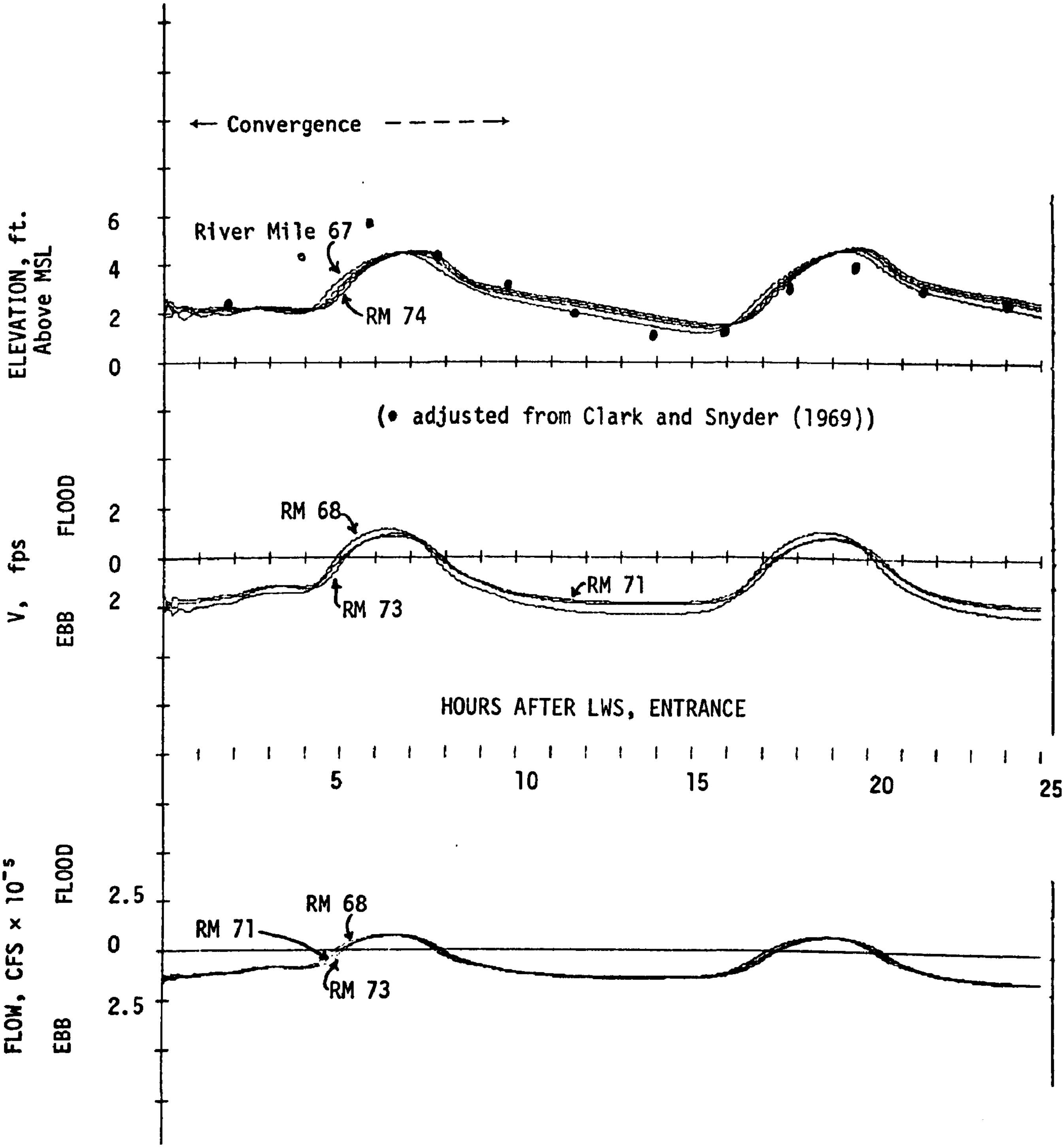


FIGURE 7. COMPUTED TIDAL ELEVATION, CURRENT VELOCITY AND FLOW. COLUMBIA RIVER AT ABOUT RIVER MILE 70 FOR LOW FLOW CONDITIONS.

the first few hours of simulation are due to the convergence of the numerical solution from the given set of initial conditions. In this case, convergence was complete in about 10 hours. The open circles on the figure are tidal elevations as taken from Figure 2 of Clark and Snyder and adjusted so that the computed second high water maximum is in phase with the observed.

Even though no attempt was made to input the existing mixed tide at the entrance (although it could easily have been at the expense of more computer time) the computed curve is in good agreement with the observed. It can be seen that the frictional and non-linear terms in the equation of motion have distorted the ocean input sine wave to the output shown near Prescott. Computed tide reversal (middle figure) occurs for about three hours as compared with four hours observed. Closer agreement could be accomplished by adjusting the friction coefficient. Computed maximum flood velocity was 1.2 fps; maximum ebb velocity was 2.1 fps. These velocities are integreated vertically across channel and will generally be lower than observed peak velocities in mid-channel.

Computed transport through the channels is shown in the lower part of the figure. Net flow in the Columbia channels for the last 12.5 hours of the run was 78,606 cfs; the remaining flow being diverted north through another channel. For the low flow period of 1968, Figures 8 and 9 show computer plots of head, velocity, and volume of flow with river mile upstream for the tidal cycles. These results have not been "verified" as such but are given here as additional examples of output.

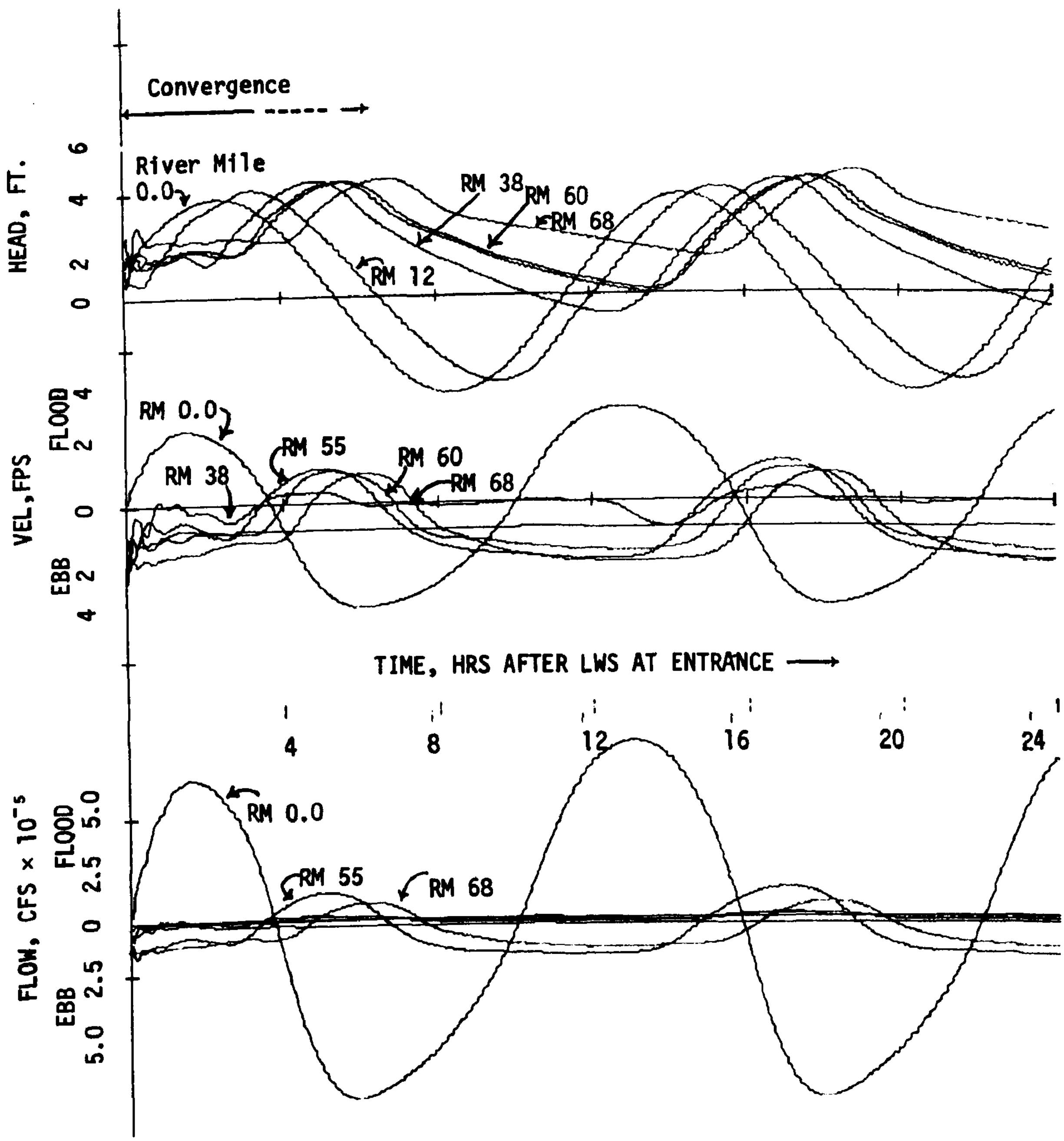


FIGURE 8. COMPUTED TIDAL ELEVATION, VELOCITY, FLOW - RIVER MILE 0-68, COLUMBIA RIVER LOW FLOW RUN.

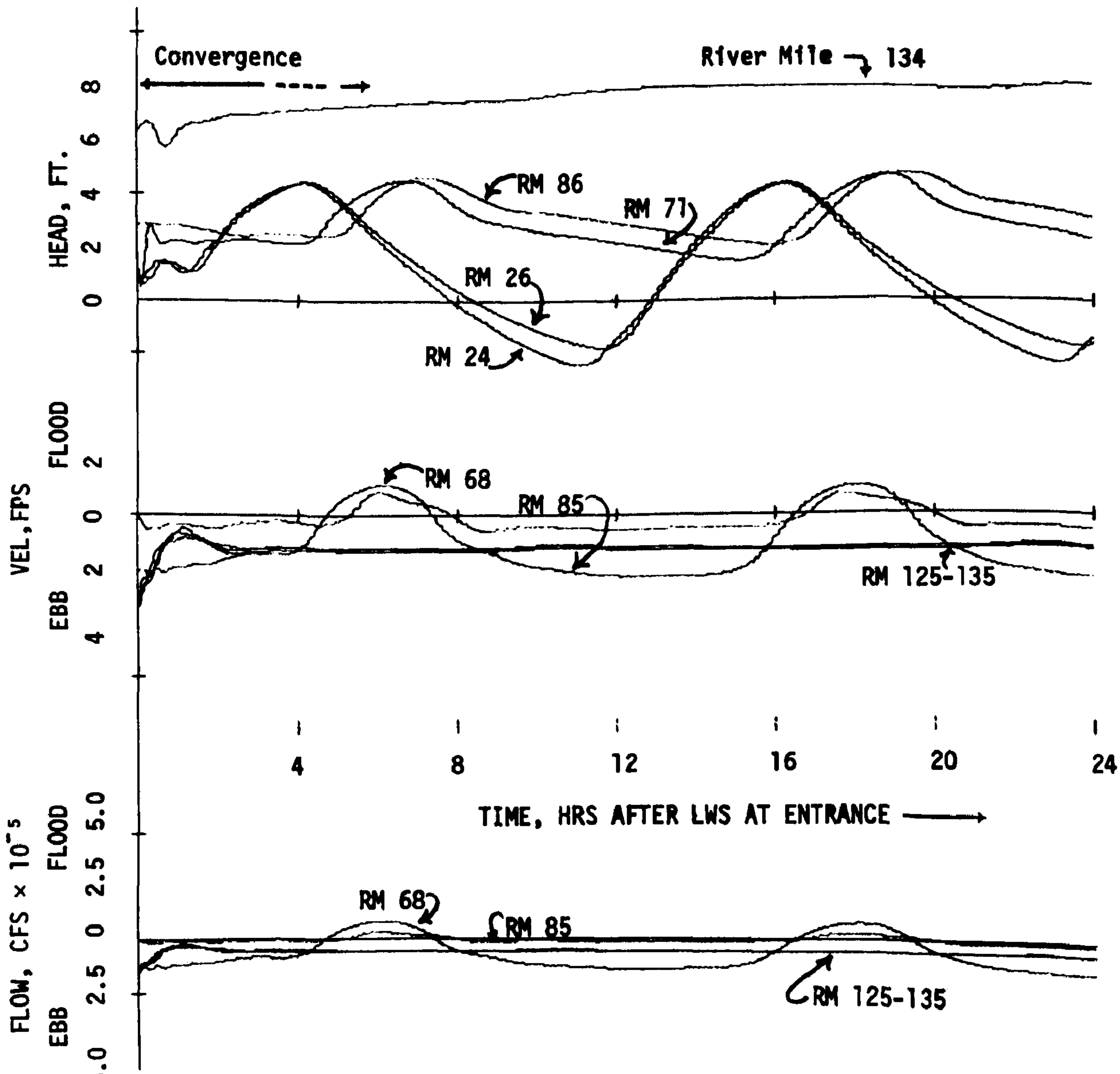


FIGURE 9. COMPUTED TIDAL ELEVATION, VELOCITY, FLOW - RIVER MILE 24-134, COLUMBIA RIVER LOW FLOW RUN.

Columbia River Run

Temperatures on the Columbia were computed from Jim Crow Point to the Dam. Hydraulic output from HYDRA-HYDEX is input to QUAL; initial conditions are taken from Sylvester (1958) and range from 17.5°C at the lower end to 18.2°C below the dam. Figures 10 and 11 show examples of computed values at selected river miles. The 'error' and 'corrected' values are discussed later.

Computations were made for 10 days assuming that the initial 24 hour meteorological data repeated itself for each day. The computations were made using 1/2 hourly hydraulic output averages; computed values are shown only for the beginning of every second day.

The largest variations in computed temperatures occur at mile 100 which is the confluence of the Willamette and Columbia Rivers. Although verification data are lacking, this fluctuation appears realistic given that mixing of the Columbia and Willamette will result in relatively large temperature fluctuations when Willamette temperatures are different from those of the mainstream.

Figure 12 summarizes 10-day temperature at all four locations. It can be seen that in the absence of any large temperature gradients under the assumed meteorological input data that temperatures will converge to about 18°C after four days of simulation.

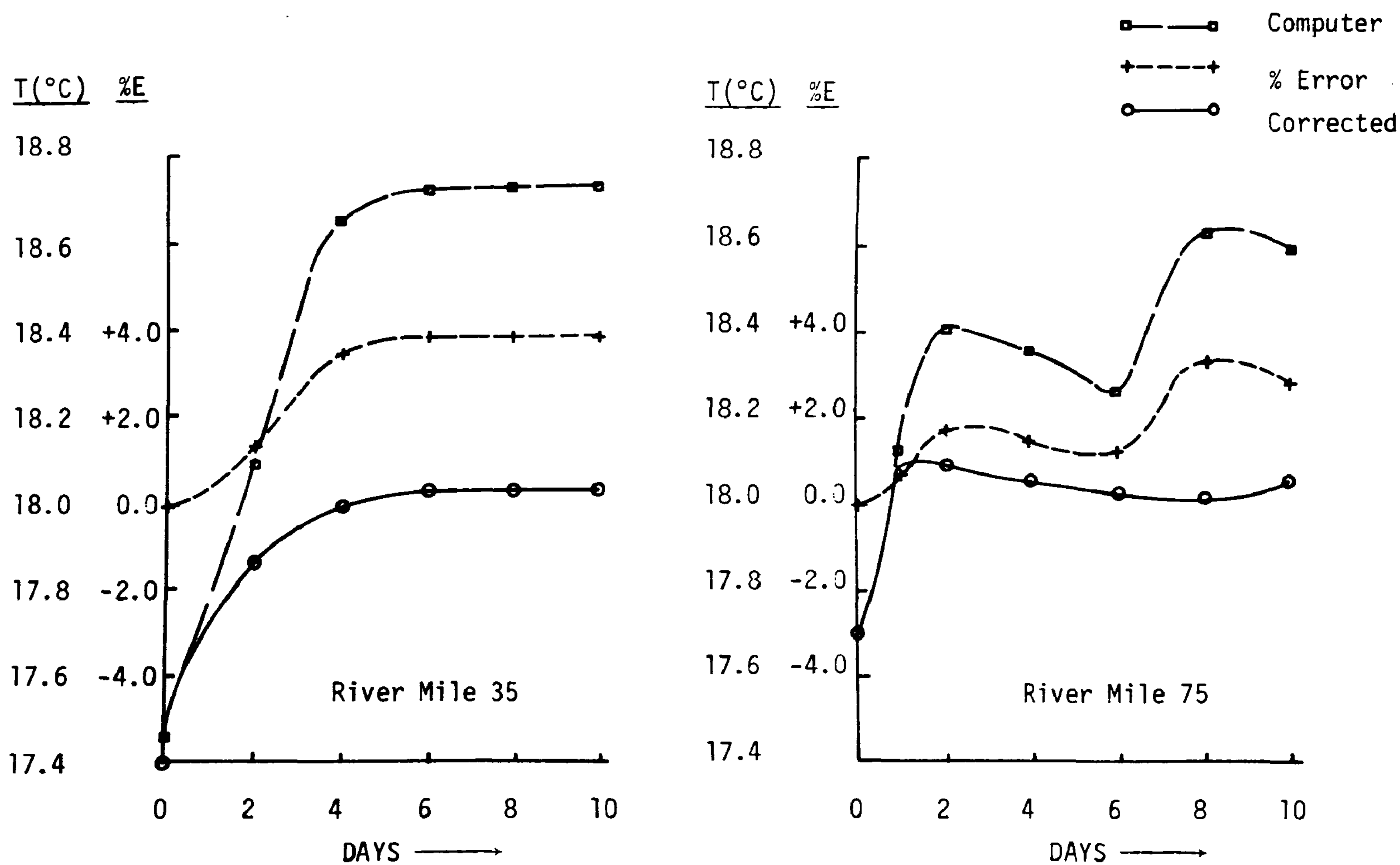


FIGURE 10.

COMPUTED TEMPERATURE (°C) VS TIME (DAYS)

COLUMBIA RIVER

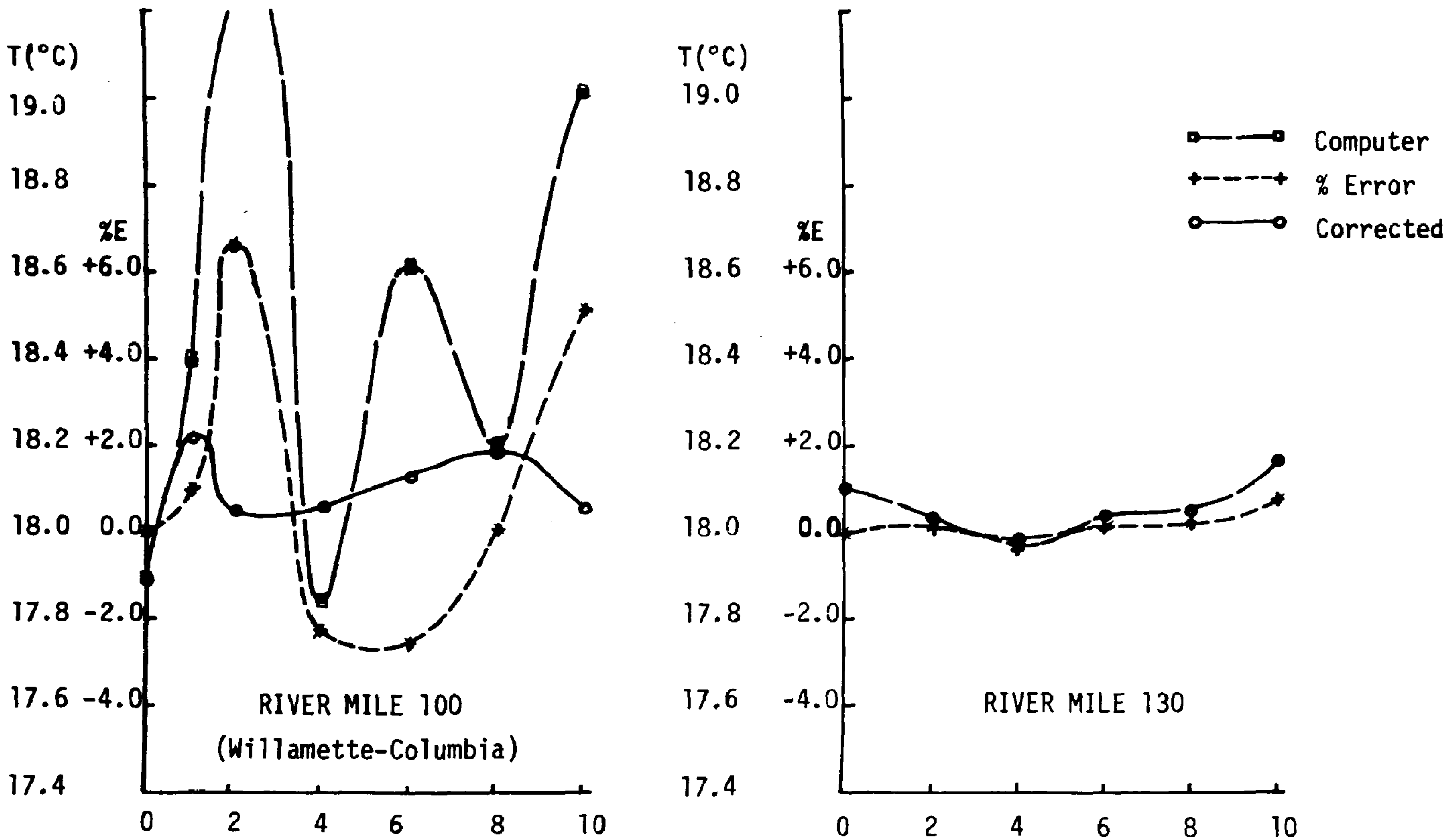


FIGURE 11.

COMPUTED TEMPERATURE (°C) VS TIME (DAYS)

COLUMBIA RIVER

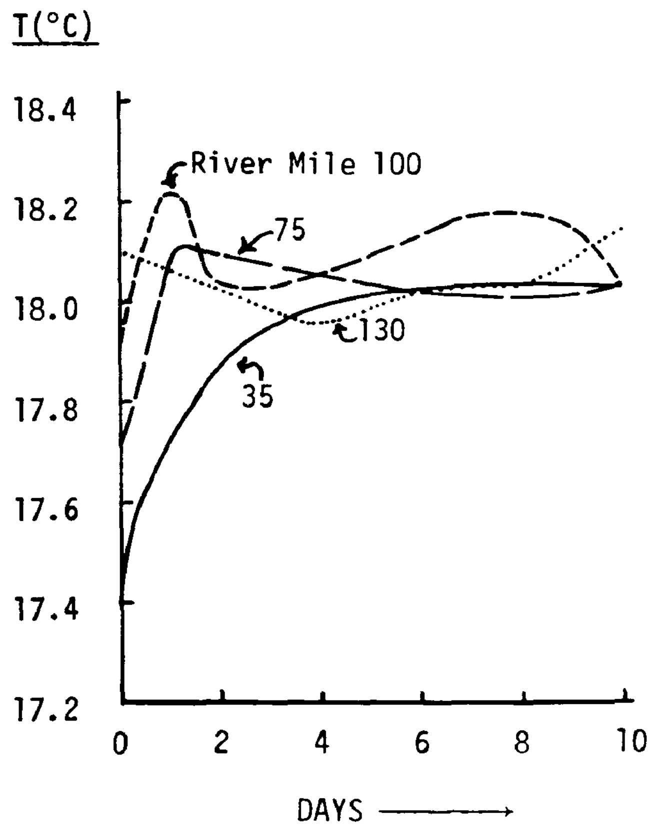


FIGURE 12.

COMPUTED TEMPERATURES (SUMMARY)

Reducing Errors

In this section a discussion is given on means of controlling 'pseudo-dispersion' errors. As a first step in evaluating a particular schematization a "continuity check" should be made. This is illustrated in Appendix 8 (pp 126 to 130), where the initial boundary values are taken as 15.0 arbitrary units (p 128). An inflow of 100 cfs of pollutant with concentrations of 15.0 is assumed. As discussed earlier, any numerical 'leakage' will show up as differences from 15.0 over so many cycles. The output for the first quality cycles is shown on p.130 . All further cycles showed no deviation from 15.0.

Checks as above should be made to determine the magnitude of the error (if it exists). The time step should be reduced if large errors occur. If the time step cannot be adjusted to minimize this error, the following "brute force" correction can be tried. A running account of the error is made by inputting a second constituent with initial and boundary conditions equal to 100.00 arbitrary units. If instabilities occur, they will be reflected as a certain percent error at each junction for each time step. This error can then be subtracted from the constituent of interest, reset to 100.00, and reapplied at each time step.

Figures 10 and 11 show the percent errors and the corrected temperatures according to this scheme. It is believed that the method suggested will work for any constituent in the absence of any large gradients. Where errors associated with large gradients occur, the quarter-point method discussed in Part I will minimize, but not completely eliminate, the associated pseudo-dispersion error (which is not the same as that discussed above).

DISCUSSION

The model discussed here is of the 'macro' variety in that small scale detail is neglected. So-called 'micro' models deal with conditions in the immediate vicinity of outfalls, hence must be capable of treating entrainment and jet-flow in terms of the depth and angle of discharge and prevailing Reynolds and Froude numbers. The equations relating to buoyancy dependent flows such as heated discharges are at least two-dimensional in nature and somewhat more involved than the wave equations solved for in this report. As stated before, then, the model presented does not purport to treat discharges in the near vicinity of an outfall, whether it be heat or any other substance.

It is felt that the greatest use of this type of model is as a descriptor of currents and water levels at given points in the system and as an indicator of space averaged concentration profiles. In a system as complex as the Columbia the use of the model in predicting currents under different river and tidal inputs seems justification enough in undertaking the work. The hydraulic portion of the model is relatively simple to use and trouble free or trouble obvious as far as numerical problems are concerned. Predicting effluent concentrations and salinity intrusion should be attempted only with an attentive eye to the problems associated with explicit solutions and 'pseudo-dispersion'.

Extension of the model to a treatment of phytoplankton dynamics is somewhat obvious for the well-mixed case. Certain assumptions would be required regarding the penetration of light, etc., but computation of relatively simple predator-prey relationships would not be a major problem.

Use of the model in shallow lakes and reservoirs has not been attempted by us; in certain cases the model could be so used, such as in treating dye releases on a short term (order of days) basis. Provisions could be made to provide for bottom uptake of material through the decay coefficient.

Obvious modifications of the program would be to include wind stress as a forcing function, to provide for graphical output, to include tidal flat areas, etc. We have displayed the data (see Figures 8 and 9) but have not attempted to include this as part of the package. Inclusion of wind would require a simple bookkeeping scheme for orienting the channels with the wind; in this regard several wind regimes could be employed as could several meteorological systems. In particular this would be more realistic than assuming the same weather over as diverse a climatological setting as the lower Columbia; it was felt, however, at the beginning stages that this would amount to lily gilding.

In summary, it is felt that the model is as good as any of the one-dimensional models on the market, especially in those cases where complex channels, islands, and tributaries must be considered. If a broad embayment is to be treated then by all means employ a two-dimensional scheme such as Leendertse's - keeping in mind that one should, in the final analysis, employ the simplest tool possible. If a slide rule will do the work don't use this model or anyone else's.

ACKNOWLEDGEMENT

Thanks are due K. Feigner, D. Fitzgerald, and J. Yearsley, Environmental Protection Agency, for reviewing this document.

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Sylvester, R. O., 1958, Water quality studies in the Columbia River basin. U.S. Fish and Wildlife Serv. SSR #239. 134 pp.

U.S. Dept. of Commerce, 1970, Tide tables, West Coast North and South America including the Hawaiian Islands. Envir. Sci. Serv. Adm. U.S. Coast & Geodetic Survey. 226 pp.

Input Card Preparation

Table 1 shows the cards required for input to HYDRA, HYDEX and QUALTEMP in addition to format specifications and sequence number location in the Part I program listings.

Table 2 shows the input listing for the output given in Appendix 1, a HYDRA-HYDEX run.

In Table 3 the input list for the QUALTEMP output shown in Appendix 7 is given. Output for the HYDRA-HYDEX is not shown although the input list is given.

TABLE 1

Input Card Preparation

HYDRA-HYDEX-QUALTEMP-METDTA

TABLE 1A

INPUT FORMAT - HYDRA, HYDEX

Reference #[1]	Information	Card Content	Format	Number of Cards	Always Required?
19 (HYDRA)	Identification	ALPHA	18A4	2	Yes
20	Control	NJ,NC,NCYC,NPRT, NOPRT,DELT,TZERO, NETFLW,ISTART,INSUP	5I5,2F10,3I5	1	Yes
22	Output Control	IPRT,IWRTE,KPNCHI	3I5	1	Yes
35	Junction Data	JJ,AREAS(J),(NCHAN (J,K),K=1,5),Y(J) QIN(J),YT(J)	I5,F10,5X, 5I3,F10.5,F10, F10.5	NJ	Yes
49	Channel Data	NN,CLEN(N),(NJUNC(N, K),K=1,2),R(N),CN(N), B(N),V(N)	I5,F8,2I3,F6.1 F5.3,F5,5X,F10.3	NC	Yes
62	Junction No's where output is desired	(JPRT(J),I=1,NOPRT)	14I5	$\frac{NOPRT+13}{14}$ [2]	Yes
63	Ocean Boundary Conditions; Fourier Series	A1,A2,A3,PH12,PH13, PERIOD	6F10	1	Yes
24 (HYDEX)	Identification	ALPHA	18A4	2	Yes[3]
25	Number of dynamic cycles	NODYN	5I5	1	Yes[3]

Note:

1. Reference # refers to numbers on the right-hand side of the program listings in Part I.
2. Truncated value.
3. Only if subroutine HYDEX is to be called (NETFLW≠0)

TABLE 1B

INPUT FORMAT - QUALTEMP, METDTA

Reference # 1/	Information	Card Content	Format	Number of Cards	Always Required?
36	Control	NJ,NC,NSTART,NSTOP, NODYN,NOJ,ITEMP, IEQTEM	8I5	1	Yes
37	Control	NRSTRT,INCYC,NQCYC, NOEXT,CDIFFK,NTAG	4I5,F10,I5	1	Yes
38	Output	IPRT,NQPRT,NEXTPR, INTBIG,IWRITE,NEXTWR, IWRINT	7I5	1	Yes
54	Identification	ALPHA	18A4	2	Yes
62	Number of Constituents	NUMCON	I5	1	Yes
65	Identification	ALPHA	18A4	NUMCON	Yes
67	Concentration Upper Limits	CLIMIT	5F10	1	Yes
71	Constituent with a reaction rate?	(NCONDK(K),NCONOX(K), K=1,NUMCON)	10I5	1	Yes
74	Reaction rates & saturation values	DECAY(K),REOXK(K) CSAT(K)	3F10	NUMCON	No
84	Diversion-return pairs	NUNITS	I5	1	Yes

TABLE 1B (Cont'd)

INPUT FORMAT - QUALTEMP, METDTA

Reference # 1/	Information	Card Content	Format	Number of Cards	Always Required?
90	Diversion-return junctions and factors	JDIV1(I),JDIV2(I) JRET1(I),JRET2(J) (RETRNF(I,M),CONST(I,M), M=1,NUMCON)	I3,3I4,5(F5, E8.2)	NUNITS	No
101	Waste inflows & concentration	JJ,QINWQ(J),(C(J,K), CSPEC(J,K),K=1,NFIRST)	I5,7F10	NJ	Yes
109	Waste inflows & concentration	JJ,(C(J,K),CSPEC(J,K), K=NFIRST,NUMCON)	I5,7F10	NJ	No
118	Convergence factor groups	NGROUP(I)	I5	NUMCON	Yes
121	Convergence factor and junctions where applied	(FACTR(I,K),NJSTRT (I,K),NJSTOP(I,K), K=1,NG)	5(F5,I5,I5)	NUMCON	No
143	Number of Ocean boundary values to be read	NSPEC	I5	1	Yes
145	Boundary con-centrations or values	(CIN(M,I),I=1, NSPEC)	7F10	NUMCON x $\frac{(NSPEC+6)}{7}$	Yes
148	Number of junctions' data to be output	NOPRT	I5	1	Yes

TABLE 1B (Cont'd)

INPUT FORMAT - QUALTEMP, METDTA

Reference #[1/]	Information	Card Content	Format	Number of Cards	Always Required?
149	Junction numbers where output is to be made	(JPRT(I),I=1, NOPRT)	14I5	(NOPRT+13)/14 [2/]	Yes
629 (METDTA)	Meteorological interpolation & evaporation coefficients	INT,NPTS,NQCSM, A,BB	3I10,F5.2, E9.2	1	No
632	Meteorological data	QRNETA(I),UWINDA(I), TAA(I),TAWA(I),APA(I)	F4.4,3F3.1, F4	NPTS	No

1/ Reference # refers to numbers on the right-hand side of the program listings in Part I.

2/ Trancated value.

TABLE 2

INPUT LISTING FOR OUTPUT GIVEN IN APPENDIX 1

TABLE 2

INPUT FOR EXAMPLE 1 - HYDRA-HYDEX

CARD NUMBER	Card	SEE SEQUENCE NUMBER IN PART 1 PROGRAM LIST
	C CONTROL AND SYSTEM INPUT (UNIT 5)	
1	EXAMPLE 1	19(HYDRA)
2	FIVE JUNCTIONS, FOUR CHANNELS, CONSTANT FRICTION	19
	← NJ → ← NC → ← NCYC → ← NPRT → ← NOPRT → ← DELT → ← TZERO → ← NETFLW → ← ISTART → ← INPSUP →	20
3	5 4 540 30 5 120.0 0.0 1 0 0	
	← IPRT → ← IWRTE → ← KPNCHI →	22
4	1 180 90	
	(JPRT(I), I=1,NOPRT)	62
5	1 2 3 4 5	
	← A1 → ← A2 → ← A3 → ← PHI2 → ← PHI3 → ← PERIOD →	63
6	2.0 12.0	
7	EXAMPLE 1 CONTINUED	24(HYDEX)
8	SUBROUTINE HYDEX OUTPUT	24
	← NODYN →	25
9	15	

TABLE 3

INPUT LISTING FOR OUTPUT GIVEN IN APPENDIX 7

80 COLUMN PUNCHED CARD LAYOUT

```
HYDRAULIC INPUT FOR EXAMPLE SEVEN SEE EX.1 FOR EXPLANATION
OF INDIVIDUAL CARDS.UNIT 5 USED HERE.
    5    4  540   30    5  120.0      0.0        1    0    0
    1  180   90
    1    2    3    4    5
              0.0
EX. 7 CONTINUED.THIS DIFFERS FROM EX.1 IN THAT A2=0.0
AND NODYN=30 INSTEAD OF 15. ALSO CLEN IS 1/2 THAT OF EX 1.
   30

C   JUNCTION DATA FOR EXAMPLE SEVEN (UNIT 7)
    1   2500000       1
    2   2500000       1  2
    3   2500000       2  3
    4   2500000       3  4
    5   2500000       4

C   CHANNEL DATA FOR EXAMPLE SEVEN (UNIT 8)
    1    2500  1  2  10.0  .02 1000
    2    2500  2  3  10.0  .02 1000
    3    2500  3  4  10.0  .02 1000
```

80 COLUMN PUNCHED CARD LAYOUT

I/3

EXAMPLE SEVEN UNIT 2 INPUT

SEE SEQUENCE NUMBER IN PART I PROGRAM LIST

CARD NUMBER	NJ	NC	NSTART	NSTOP	NODYN	NOJ	ITEMP	IEQTEMP	Sequence
1	5	4	180	540	30	1	1	1	36

CARD NUMBER	NRSTRT	INCYC	NQCYC	NOEXT	CDIFFK	NTAG	Sequence
2	180	1	120	0	0.0	0	37

CARD NUMBER	IPRT	NQPRT	NEXTPR	INTBIG	IWRITE	NEXTWR	IWRINT	Sequence
3	1	2	98	50	1	50	50	38

54

4 TEMPERATURE IS THE ONLY CONSTITUENT 54

5 (BLANK CARD REQUIRED HERE)

CARD NUMBER	NUMCON	Sequence
6	1	62

7 (BLANK ALPHAMERIC CARD - COMMENTS CAN BE ADDED) 65

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80 COLUMN PUNCHED CARD LAYOUT

II/3

```
   ← CLIMIT →                                                      67
9      50.0

   (NCOND(K),NCONOX(K),K=1,NUMCON) (10I5)                          71
10          0         0

   ←NUNITS→                                                        84
11      0
   ← JJ → ← QINWQ(J) → ←   C(J,1) → ← CSPEC(J,1) →
12      1             10.0                                         101
13      2             10.0
14      3             10.0
15      4             10.0
16      5             10.0

   ←NGROUP→                                                        118
17      0

   ←NSPEC→                                                         143
18     24

   (CIN(*,I),I=1,NSPEC) (7F10)                                     145
19    10.0      10.0      10.0      10.0      10.0      10.0      10.0
20    10.0      10.0      10.0      10.0      10.0      10.0      10.0
21    10.0      10.0      10.0      10.0      10.0      10.0      10.0
22    10.0      10.0      10.0
```

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80 COLUMN PUNCHED CARD LAYOUT

	Card content	Ref.
	←NOPRT→	148
23	5	
	(JPRT(I),I=1,NOPRT)	149
24	1 2 3 4 5	
	← INT →← NPTS →← NOCSM →← A →← BB →|	629
25	3600 24 0 0 1.56E-09	
	ORMETA(I) VWINDA(I) TAA(I) TAWA(I) APA(I)	632
26	06400 04180 17810 15	
27	06400 04180 17710 15	
28	06400 04183 17810 15	
49	06400 04178 17510 15	

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TABLE 4

COLUMBIA RIVER FLOWS - 1959, 1968

TABLE 4

COLUMBIA RIVER FLOWS - 1959, 1968

River Name	Mile	km	cfs, 1959	m^3sec^{-1}, 1959	cfs, 1968	m^3sec^{-1}, 1968
(Bonneville Dam)	146	235	147160	4167	65014	1841
Sandy	122	196	1250	35	1250	35
Washougal	121	195	600	17	600	17
Willamette	102	164	9910	280	15150	429
Lewis	90	144	2430	69	4238	120
Kalama	73	118	670	19	670	19
Coweeman	70	113	150	4.2	150	4.2
Cowlitz	68	109	4500	127	0	0
Abernathy Cr.	55	88	60	1.7	60	1.7
Mill Cr.	54	87	70	2.0	70	2.0
Elochman	36	58	240	6.8	240	6.8
Grays	22	35	180	5.1	180	5.1

Note: Data for 1959 summarized by FWQA from USA Corps of Engineers Records for September 1959. Data for 1968, where changes occur, were taken from Clark and Snyder (1969).

OUTPUT OF APPENDICES

DISCUSSED IN THE TEXT

EXAMPLE 1
FIVE JUNCTIONS,FOUR CHANNELS,CONSTANT FRICTION

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

JUNCTIONS	CHANNELS	CYCLES	OUTPUT INTERVAL	TIME INTERVAL	INITIAL TIME	WRITE BINARY TAPE	RESTART INTERVAL	START PRINT
5	4	540	30 CYCLES	120 SEC.	0 HRS.	CYCLES 180 TO 540	90 CYCLES	CYCLE 1

** JUNCTION DATA **

JUNCTION	INITIAL HEAD	SURFACE AREA	INPUT:OUTPUT	CHANNELS ENTERING JUNCTION				
1	0	5000000	0	1	0	0	0	0
2	0	5000000	0	1	2	0	0	0
3	0	5000000	0	2	3	0	0	0
4	0	5000000	0	3	4	0	0	0
5	0	5000000	0	4	0	0	0	0

EXAMPLE 1

** CHANNEL DATA **

CHANNEL	LENGTH	WIDTH	AREA	MANNING	VELOCITY	HYD RADIUS	JUNCTIONS AT ENDS	
1	5000	1000	10000.0	.020	0	10.0	1	2
2	5000	1000	10000.0	.020	0	10.0	2	3
3	5000	1000	10000.0	.020	0	10.0	3	4
4	5000	1000	10000.0	.020	0	10.0	4	5

COEFFICIENTS FOR TIDAL INPUT

A1	A2	A3	PHI2	PHI3	PERIOD
0	2.000000	0	0	0	12.00

WHERE

Y(1)= A1+A2*SIN(WT+PHI2)+A3*SIN(WT+PHI3)

EXAMPLE 1 (Cont'd)

SYSTEM STATUS AFTER CYCLE 1 .03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	.0317			
		1	.01348	134.9
2	.0032			
		1	-0.01348	-134.9
		2	0	0
3	0			
		2	-0	-0
		3	0	0
4	0			
		3	-0	-0
		4	0	0
5	0			
		4	-0	-0

EXAMPLE 1 (Cont'd)

SYSTEM STATUS AFTER CYCLE 31 1.03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	.9093			
		1	.45524	5033.2
2	1.1201			
		1	-0.45524	-5033.2
		2	.35141	3912.2
3	1.1814			
		2	-0.35141	-3912.2
		3	.23906	2676.7
4	1.2398			
		3	-0.23906	-2676.7
		4	.12161	1367.1
5	1.2725			
		4	-0.12161	-1367.1

EXAMPLE 1 (Cont'd)

SYSTEM STATUS AFTER CYCLE 61 2.03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	1.5951			
		1	.54672	6422.4
2	1.7786			
		1	-0.54672	-6422.4
		2	.44829	5269.8
3	1.7744			
		2	-0.44829	-5269.8
		3	.31756	3734.5
4	1.7841			
		3	-0.31756	-3734.5
		4	.16432	1933.2
5	1.7901			
		4	-0.16432	-1933.2

RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE 90 TZERO FOR RESTARTING = 3.0000

EXAMPLE 1 (Cont'd)

SYSTEM STATUS AFTER CYCLE 511 17.03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	1.0900			
		1	-0.45632	-5017.3
2	.9843			
		1	.45632	5017.3
		2	-0.34151	-3760.3
3	1.0013			
		2	.34151	3760.3
		3	-0.22748	-2506.7
4	1.0073			
		3	.22748	2506.7
		4	-0.11371	-1253.5
5	1.0100			
		4	.11371	1253.5

EXAMPLE 1 (Cont'd)

SYSTEM STATUS AFTER CYCLE 540 18.00 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	.1395			
		1	-0.57963	-5814.1
2	.0207			
		1	.57963	5814.1
		2	-0.43421	-4363.8
3	.0388			
		2	.43421	4363.8
		3	-0.28937	-2910.8
4	.0450			
		3	.28937	2910.8
		4	-0.14469	-1456.1
5	.0473			
		4	.14469	1456.1

RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE 540 TZERO FOR RESTARTING = 18.0000

END OF FILE WAS WRITTEN ON TAPE 10.

EXAMPLE 1 (Cont'd)

JUNCTION DATA FOR RESTART DECK

JUNCTION	INITIAL HEAD	SURFACE AREA	INPUT-OUTPUT	CHANNELS ENTERING JUNCTION				
1	.1395	5000000	0	1	0	0	0	0
2	.0207	5000000	0	1	2	0	0	0
3	.0388	5000000	0	2	3	0	0	0
4	.0450	5000000	0	3	4	0	0	0
5	.0473	5000000	0	4	0	0	0	0

EXAMPLE 1 (Cont'd)

CHANNEL DATA FOR RESTART DECK

CHANNEL	LENGTH	WIDTH	AREA	MANNING	VELOCITY	HYD RADIUS	JUNCTIONS AT ENDS	
1	5000	1000	10080.1	.020	-0.57963	10.03	1	2
2	5000	1000	10029.7	.020	-0.43421	10.05	2	3
3	5000	1000	10041.9	.020	-0.28937	10.06	3	4
4	5000	1000	10046.1	.020	-0.14469	10.06	4	5

TAPE 10 WAS WRITTEN FROM CYCLE 180 TO CYCLE 540

END OF TWO-DIMENSIONAL EXPLICIT PROGRAM. 540 CYCLES.

EXAMPLE 1 (Cont'd)

EXAMPLE 1
FIVE JUNCTIONS,FOUR CHANNELS,CONSTANT FRICTION
EXAMPLE 1 CONTINUED
SUBROUTINE HYDEX OUTPUT

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

******** FROM HYDRAULICS PROGRAM ******** START CYCLE	STOP CYCLE	TIME INTERVAL	HYDRAULIC CYCLES PER QUALITY CYCLE	TIME INTERVAL IN QUALITY PROGRAM
180	540	120 SECONDS	15	.50 HOURS

CHANNEL NUMBER	NET FLOW (CFS)	* * * * * FLOW * * * * * MIN. (CFS)	MAX. (CFS)	* * VELOCITY * * MIN. (CFS)	MAX. (CFS)	* * * CROSS-SECTIONAL AREA * * * MIN. (SQ. FT)	MAX. (SQ. FT)	AVE. (SQ. FT)
1	-0.36	-5716.05	5876.48	-0.625	.599	7990.8	12005.5	10003.2
2	-0.40	-4287.44	4422.65	-0.473	.450	7974.4	12015.4	10006.9
3	-0.38	-2872.27	2955.26	-0.317	.300	7962.5	12022.4	10007.8
4	-0.23	-1441.25	1479.48	-0.159	.150	7955.3	12026.6	10008.5

EXAMPLE 1 (Cont'd)

JUNCTION NUMBER	MINIMUM HEAD (FT)	OCCURS AT CYCLE	MAXIMUM HEAD (FT)	OCCURS AT CYCLE	AVERAGE HEAD (FT)	TIDAL RANGE (FT)
1	-2.01	274	2.00	454	.00	4.01
2	-2.02	270	2.01	450	.01	4.03
3	-2.03	270	2.02	450	.01	4.05
4	-2.04	270	2.03	450	.01	4.07
5	-2.05	270	2.03	450	.01	4.07

EXAMPLE 1 (Cont'd)

**** OUTPUT FOR CHECKING DATA ON EXTRACTED TAPE ****

HYDRAULIC CYCLE	HEAD AT JUNCTION NO.1	*FLOW IN CHANNEL* NO.1	NO.2
180	.13	-5671.30	-4248.18
195	-0.38	-5663.47	-4283.36
210	-0.87	-4702.56	-3531.69
225	-1.31	-3765.51	-2844.41
240	-1.65	-2539.96	-1935.26
255	-1.89	-892.50	-680.48
270	-2.00	787.25	595.96
285	-1.97	2184.11	1633.43
300	-1.80	3486.86	2606.34
315	-1.51	4697.05	3530.98
330	-1.12	5434.64	4083.18
345	-0.65	5810.66	4363.21
360	-0.14	5876.48	4422.65
375	.38	5428.57	4081.34
390	.88	4666.59	3508.98
405	1.31	3618.48	2726.48
420	1.66	2254.45	1696.15
435	1.89	819.00	621.88
450	2.00	-710.55	-528.45
465	1.97	-2156.87	-1613.26
480	1.80	-3434.56	-2568.69
495	1.51	-4531.67	-3395.99
510	1.12	-5287.85	-3962.95
525	.65	-5716.05	-4287.44

END OF NET FLOW PROGRAM.

EXAMPLE 1 (Cont'd)

EXAMPLE 2
FIVE JUNCTIONS,FOUR CHANNELS,CONSTANT FRICTION

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

JUNCTIONS	CHANNELS	CYCLES	OUTPUT INTERVAL	TIME INTERVAL	INITIAL TIME	WRITE BINARY TAPE	RESTART INTERVAL	START PRINT
5	4	540	30 CYCLES	120 SEC.	0 HRS.	CYCLES 180 TO 540	90 CYCLES	CYCLE 1

** JUNCTION DATA **

JUNCTION	INITIAL HEAD	SURFACE AREA	INPUT:OUTPUT	CHANNELS ENTERING JUNCTION				
1	0	5000000	0	1	0	0	0	0
2	0	5000000	0	1	2	0	0	0
3	0	5000000	0	2	3	0	0	0
4	0	5000000	0	3	4	0	0	0
5	0	5000000	0	4	0	0	0	0

EXAMPLE 2

** CHANNEL DATA **

CHANNEL	LENGTH	WIDTH	AREA	MANNING	VELOCITY	HYD RADIUS	JUNCTIONS AT ENDS	
1	5000	1000	10000.0	.030	0	10.0	1	2
2	5000	1000	10000.0	.030	0	10.0	2	3
3	5000	1000	10000.0	.030	0	10.0	3	4
4	5000	1000	10000.0	.030	0	10.0	4	5

COEFFICIENTS FOR TIDAL INPUT

A1	A2	A3	PHI2	PHI3	PERIOD
0	2.000000	0	0	0	12.00

WHERE

Y(1)= A1+A2*SIN(WT+PHI2)+A3*SIN(WT+PHI3)

EXAMPLE 2 (Cont'd)

SYSTEM STATUS AFTER CYCLE 1 .03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	.0317			
		1	.01348	134.9
2	.0032			
		1	-0.01348	-134.9
		2	0	0
3	0			
		2	-0	-0
		3	0	0
4	0			
		3	-0	-0
		4	0	0
5	0			
		4	-0	-0

EXAMPLE 2 (Cont'd)

SYSTEM STATUS AFTER CYCLE 31 1.03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	.8986			
		1	.49626	5478.1
2	1.0868			
		1	-0.49626	-5478.1
		2	.38460	4262.0
3	1.1159			
		2	-0.38460	-4262.0
		3	.26160	2908.6
4	1.1523			
		3	-0.26160	-2908.6
		4	.13247	1476.6
5	1.1738			
		4	-0.13247	-1476.6

EXAMPLE 2 (Cont'd)

SYSTEM STATUS AFTER CYCLE 61 2.03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	1.6352			
		1	.40456	4750.3
2	1.7625			
		1	-0.40456	-4750.3
		2	.32375	3801.4
3	1.7538			
		2	-0.32375	-3801.4
		3	.22570	2650.0
4	1.7569			
		3	-0.22570	-2650.0
		4	.11575	1359.2
5	1.7595			
		4	-0.11575	-1359.2

RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE 90 TZERO FOR RESTARTING = 3.0000

EXAMPLE 2 (Cont'd)

SYSTEM STATUS AFTER CYCLE 511 17.03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	1.0884			
		1	-0.45002	-4949.6
2	.9915			
		1	.45002	4949.6
		2	-0.33596	-3702.4
3	1.0136			
		2	.33596	3702.4
		3	-0.22349	-2465.6
4	1.0219			
		3	.22349	2465.6
		4	-0.11166	-1232.5
5	1.0251			
		4	.11166	1232.5

EXAMPLE 2 (Cont'd)

SYSTEM STATUS AFTER CYCLE 540 18.00 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	.1380			
		1	-0.57319	-5753.3
2	.0344			
		1	.57319	5753.3
		2	-0.42829	-4312.1
3	.0620			
		2	.42829	4312.1
		3	-0.28502	-2874.2
4	.0722			
		3	.28502	2874.2
		4	-0.14244	-1437.4
5	.0756			
		4	.14244	1437.4

RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE 540 TZERO FOR RESTARTING = 18.0000

END OF FILE WAS WRITTEN ON TAPE 10.

EXAMPLE 2 (Cont'd)

JUNCTION DATA FOR RESTART DECK

JUNCTION	INITIAL HEAD	SURFACE AREA	INPUT-OUTPUT	CHANNELS ENTERING JUNCTION				
1	.1380	5000000	0	1	0	0	0	0
2	.0344	5000000	0	1	2	0	0	0
3	.0620	5000000	0	2	3	0	0	0
4	.0722	5000000	0	3	4	0	0	0
5	.0756	5000000	0	4	0	0	0	0

EXAMPLE 2 (Cont'd)

CHANNEL DATA FOR RESTART DECK

CHANNEL	LENGTH	WIDTH	AREA	MANNING	VELOCITY	HYD RADIUS	JUNCTIONS AT ENDS	
1	5000	1000	10086.2	.030	-0.57319	10.04	1	2
2	5000	1000	10048.2	.030	-0.42829	10.07	2	3
3	5000	1000	10067.1	.030	-0.28502	10.08	3	4
4	5000	1000	10073.9	.030	-0.14244	10.09	4	5

TAPE 10 WAS WRITTEN FROM CYCLE 180 TO CYCLE 540

END OF TWO-DIMENSIONAL EXPLICIT PROGRAM. 540 CYCLES.

EXAMPLE 2 (Cont'd)

EXAMPLE 2
FIVE JUNCTIONS,FOUR CHANNELS,CONSTANT FRICTION
EXAMPLE 2 CONTINUED
SUBROUTINE HYDEX OUTPUT

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

******** FROM HYDRAULICS PROGRAM ********			HYDRAULIC CYCLES PER QUALITY CYCLE	TIME INTERVAL IN QUALITY PROGRAM
START CYCLE	STOP CYCLE	TIME INTERVAL		
180	540	120 SECONDS	15	.50 HOURS

CHANNEL NUMBER	NET FLOW (CFS)	* * * * * FLOW MIN. (CFS)	* * * * * MAX. (CFS)	* * VELOCITY MIN. (CFS)	* * MAX. (CFS)	* * * CROSS-SECTIONAL AREA MIN. (SQ. FT)	MAX. (SQ. FT)	* * * AVE. (SQ. FT)
1	.73	-5684.69	5916.32	-0.597	.604	7989.9	12005.5	10003.3
2	.61	-4259.19	4456.07	-0.447	.454	7972.0	12015.2	10006.9
3	.42	-2838.27	2978.39	-0.298	.304	7958.8	12022.2	10007.7
4	.21	-1419.27	1491.04	-0.149	.152	7950.9	12026.3	10008.3

EXAMPLE 2 (Cont'd)

JUNCTION NUMBER	MINIMUM HEAD (FT)	OCCURS AT CYCLE	MAXIMUM HEAD (FT)	OCCURS AT CYCLE	AVERAGE HEAD (FT)	TIDAL RANGE (FT)
1	-2.00	275	2.00	454	-0.00	4.01
2	-2.02	270	2.01	450	.01	4.03
3	-2.04	271	2.02	450	.01	4.06
4	-2.05	271	2.02	450	.01	4.07
5	-2.05	271	2.03	450	.01	4.08

EXAMPLE 2 (Cont'd)

**** OUTPUT FOR CHECKING DATA ON EXTRACTED TAPE ****

HYDRAULIC CYCLE	HEAD AT JUNCTION NO.1	*FLOW IN CHANNEL* NO.1	NO.2
180	.14	-5684.69	-4259.19
195	-0.38	-5480.52	-4123.92
210	-0.88	-4820.81	-3635.26
225	-1.31	-3873.17	-2935.66
240	-1.65	-2614.75	-1997.77
255	-1.89	-1023.20	-793.35
270	-2.00	775.41	586.04
285	-1.97	2170.75	1624.31
300	-1.80	3322.11	2464.37
315	-1.51	4591.76	3439.21
330	-1.12	5445.90	4092.44
345	-0.65	5846.15	4393.60
360	-0.14	5916.32	4456.07
375	.38	5521.45	4161.29
390	.88	4730.57	3564.43
405	1.31	3654.21	2756.85
420	1.66	2305.46	1740.51
435	1.89	816.11	619.34
450	2.00	-708.20	-526.70
465	1.97	-2122.09	-1583.26
480	1.80	-3400.62	-2539.88
495	1.51	-4471.28	-3344.32
510	1.12	-5224.16	-3908.73
525	.65	-5655.24	-4235.78

END OF NET FLOW PROGRAM.

EXAMPLE 2 (Cont'd)

EXAMPLE 3
FIVE JUNCTIONS,FOUR CHANNELS,CONSTANT FRICTION,100 CFS INFLOW

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

JUNCTIONS	CHANNELS	CYCLES	OUTPUT INTERVAL	TIME INTERVAL	INITIAL TIME	WRITE BINARY TAPE	RESTART INTERVAL	START PRINT
5	4	540	30 CYCLES	120 SEC.	0 HRS.	CYCLES 180 TO 540	90 CYCLES	CYCLE 1

** JUNCTION DATA **

JUNCTION	INITIAL HEAD	SURFACE AREA	INPUT:OUTPUT	CHANNELS ENTERING JUNCTION				
1	0	5000000	0	1	0	0	0	0
2	0	5000000	0	1	2	0	0	0
3	0	5000000	0	2	3	0	0	0
4	0	5000000	0	3	4	0	0	0
5	0	5000000	-100.00	4	0	0	0	0

EXAMPLE 3

** CHANNEL DATA **

CHANNEL	LENGTH	WIDTH	AREA	MANNING	VELOCITY	HYD RADIUS	JUNCTIONS AT ENDS	
1	5000	1000	10000.0	.020	0	10.0	1	2
2	5000	1000	10000.0	.020	0	10.0	2	3
3	5000	1000	10000.0	.020	0	10.0	3	4
4	5000	1000	10000.0	.020	0	10.0	4	5

COEFFICIENTS FOR TIDAL INPUT

A1	A2	A3	PHI2	PHI3	PERIOD
0	2.000000	0	0	0	12.00

WHERE

Y(1)= A1+A2*SIN(WT+PHI2)+A3*SIN(WT+PHI3)

EXAMPLE 3 (Cont'd)

SYSTEM STATUS AFTER CYCLE 1 .03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	.0317			
		1	.01348	134.9
2	.0032			
		1	-0.01348	-134.9
		2	0	0
3	0			
		2	-0	-0
		3	0	0
4	.0002			
		3	-0	-0
		4	-0.00093	-9.3
5	.0022			
		4	.00093	9.3

EXAMPLE 3 (Cont'd)

SYSTEM STATUS AFTER CYCLE 31 1.03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	.9120			
		1	.44517	4921.5
2	1.1179			
		1	-0.44517	-4921.5
		2	.34171	3803.3
3	1.1783			
		2	-0.34171	-3803.3
		3	.23001	2574.6
4	1.2362			
		3	-0.23001	-2574.6
		4	.11283	1267.9
5	1.2689			
		4	-0.11283	-1267.9

EXAMPLE 3 (Cont'd)

SYSTEM STATUS AFTER CYCLE 61 2.03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	1.5989			
		1	.53321	6263.7
2	1.7781			
		1	-0.53321	-6263.7
		2	.43529	5117.0
3	1.7746			
		2	-0.43529	-5117.0
		3	.30560	3594.0
4	1.7844			
		3	-0.30560	-3594.0
		4	.15393	1811.0
5	1.7905			
		4	-0.15393	-1811.0

RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE 90 TZERO FOR RESTARTING = 3.0000

EXAMPLE 3 (Cont'd)

SYSTEM STATUS AFTER CYCLE 511 17.03 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	1.0923			
		1	-0.46515	-5114.5
2	.9847			
		1	.46515	5114.5
		2	-0.35036	-3858.0
3	1.0022			
		2	.35036	3858.0
		3	-0.23638	-2605.0
4	1.0084			
		3	.23638	2605.0
		4	-0.12269	-1352.6
5	1.0113			
		4	.12269	1352.6

EXAMPLE 3 (Cont'd)

SYSTEM STATUS AFTER CYCLE 540 18.00 HOURS

JUNCTION NUMBER	HEAD (FT)	CHANNEL NUMBER	VELOCITY (FPS)	FLOW (CFS)
1	.1418			
		1	-0.58922	-5910.5
2	.0214			
		1	.58922	5910.5
		2	-0.44381	-4460.7
3	.0400			
		2	.44381	4460.7
		3	-0.29905	-3008.6
4	.0465			
		3	.29905	3008.6
		4	-0.15449	-1555.0
5	.0491			
		4	.15449	1555.0

RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE 540 TZERO FOR RESTARTING = 18.0000

END OF FILE WAS WRITTEN ON TAPE 10.

EXAMPLE 3 (Cont'd)

JUNCTION DATA FOR RESTART DECK

JUNCTION	INITIAL HEAD	SURFACE AREA	INPUT-OUTPUT	CHANNELS ENTERING JUNCTION				
1	.1418	5000000	0	1	0	0	0	0
2	.0214	5000000	0	1	2	0	0	0
3	.0400	5000000	0	2	3	0	0	0
4	.0465	5000000	0	3	4	0	0	0
5	.0491	5000000	-100.00	4	0	0	0	0

EXAMPLE 3 (Cont'd)

CHANNEL DATA FOR RESTART DECK

CHANNEL	LENGTH	WIDTH	AREA	MANNING	VELOCITY	HYD RADIUS	JUNCTIONS AT ENDS	
1	5000	1000	10081.6	.020	-0.58922	10.03	1	2
2	5000	1000	10030.7	.020	-0.44381	10.05	2	3
3	5000	1000	10043.3	.020	-0.29905	10.06	3	4
4	5000	1000	10047.8	.020	-0.15449	10.07	4	5

TAPE 10 WAS WRITTEN FROM CYCLE 180 TO CYCLE 540

END OF TWO-DIMENSIONAL EXPLICIT PROGRAM. 540 CYCLES.

EXAMPLE 3 (Cont'd)

EXAMPLE 3
FIVE JUNCTIONS, FOUR CHANNELS, CONSTANT FRICTION, 100 CFS INFLOW
EXAMPLE 4 CONTINUED
SUBROUTINE HYDEX OUTPUT

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

******** FROM HYDRAULICS PROGRAM ********			HYDRAULIC CYCLES PER	TIME INTERVAL IN
START CYCLE	STOP CYCLE	TIME INTERVAL	QUALITY CYCLE	QUALITY PROGRAM
180	540	120 SECONDS	15	.50 HOURS

		* * * * * FLOW * * * * *		* * VELOCITY * *		* * * CROSS-SECTIONAL AREA * * *		
CHANNEL NUMBER	NET FLOW (CFS)	MIN. (CFS)	MAX. (CFS)	MIN. (CFS)	MAX. (CFS)	MIN. (SQ. FT)	MAX. (SQ. FT)	AVE. (SQ. FT)
1	-100.34	-5813.33	5772.09	-0.634	.589	7990.8	12005.5	10003.4
2	-100.37	-4385.14	4318.65	-0.482	.439	7974.5	12015.2	10007.3
3	-100.36	-2964.45	2852.30	-0.327	.290	7962.6	12022.2	10008.5
4	-100.22	-1537.11	1377.92	-0.169	.140	7955.5	12026.4	10009.2

EXAMPLE 3 (Cont'd)

JUNCTION NUMBER	MINIMUM HEAD (FT)	OCCURS AT CYCLE	MAXIMUM HEAD (FT)	OCCURS AT CYCLE	AVERAGE HEAD (FT)	TIDAL RANGE (FT)
1	-2.00	274	2.01	454	.00	4.01
2	-2.02	270	2.01	450	.01	4.03
3	-2.03	270	2.02	450	.01	4.05
4	-2.04	270	2.02	450	.01	4.07
5	-2.05	270	2.03	450	.01	4.07

EXAMPLE 3 (Cont'd)

**** OUTPUT FOR CHECKING DATA ON EXTRACTED TAPE ****

HYDRAULIC CYCLE	HEAD AT JUNCTION NO.1	*FLOW IN CHANNEL* NO.1	NO.2
180	.13	-5773.66	-4350.24
195	-0.37	-5751.33	-4372.75
210	-0.87	-4808.35	-3636.79
225	-1.31	-3869.39	-2947.67
240	-1.65	-2641.11	-2036.08
255	-1.89	-1004.17	-790.47
270	-2.00	680.31	490.06
285	-1.97	2098.96	1546.62
300	-1.80	3385.15	2505.14
315	-1.51	4589.56	3424.41
330	-1.12	5342.02	3989.65
345	-0.65	5707.04	4260.14
360	-0.14	5772.09	4318.65
375	.38	5333.36	3985.49
390	.88	4561.76	3404.71
405	1.32	3519.07	2626.83
420	1.66	2156.07	1597.52
435	1.90	715.29	518.50
450	2.00	-805.69	-624.29
465	1.97	-2254.76	-1711.48
480	1.80	-3533.72	-2668.06
495	1.51	-4627.02	-3492.01
510	1.12	-5386.29	-4061.70
525	.65	-5813.33	-4385.14

END OF NET FLOW PROGRAM.

EXAMPLE 3 (Cont'd)

STEADY STATE EXAMPLE.CHANNEL LENGTH REDUCED BY TWO
EXAMPLE OF MIXED CHANNEL-JUNCTION NUMBERING SCHEME

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

JUNCTIONS	CHANNELS	CYCLES	OUTPUT INTERVAL	TIME INTERVAL	INITIAL TIME	WRITE BINARY TAPE	RESTART INTERVAL	START PRINT
5	4	540	30 CYCLES	120 SEC.	0 HRS.	CYCLES 180 TO 540	180 CYCLES	CYCLE 1

** JUNCTION DATA **

JUNCTION	INITIAL HEAD	SURFACE AREA	INPUT:OUTPUT	CHANNELS ENTERING JUNCTION				
1	0	2500000	0	1	0	0	0	0
2	0	2500000	0	1	3	0	0	0
3	0	2500000	-1000.00	4	0	0	0	0
4	0	2500000	0	2	4	0	0	0
5	0	2500000	0	2	3	0	0	0

** CHANNEL DATA **

CHANNEL	LENGTH	WIDTH	AREA	MANNING	VELOCITY	HYD RADIUS	JUNCTIONS AT ENDS	
1	2500	1000	10000.0	.020	0	10.0	1	3
2	2500	1000	10000.0	.020	0	10.0	4	5
3	2500	1000	10000.0	.020	0	10.0	2	5
4	2500	1000	10000.0	.020	0	10.0	4	5

COEFFICIENTS FOR TIDAL INPUT

A1	A2	A3	PHI2	PHI3	PERIOD
0	0	0	0	0	12.00

WHERE

Y(1)= A1+A2*SIN(WT+PHI2)+A3*SIN(WT+PHI3)

COMPATIBILITY CHECK. CHANNEL 1. JUNCTION 3

COMPATIBILITY CHECK. CHANNEL 4. JUNCTION 5

COMPATIBILITY CHECK. CHANNEL 1. JUNCTION 2

COMPATIBILITY CHECK. CHANNEL 4. JUNCTION 3

EXAMPLE 4

JUNCTION DATA FOR RESTART DECK

JUNCTION	INITIAL HEAD	SURFACE AREA	INPUT-OUTPUT	CHANNELS ENTERING JUNCTION				
1	.0480	2500000	0	1	0	0	0	0
2	-0.0153	2500000	0	1	2	0	0	0
3	.0053	2500000	0	2	3	0	0	0
4	-0.0010	2500000	0	3	4	0	0	0
5	.0011	2500000	-1000.00	4	0	0	0	0

EXAMPLE 5

CHANNEL DATA FOR RESTART DECK

CHANNEL	LENGTH	WIDTH	AREA	MANNING	VELOCITY	HYD RADIUS	JUNCTIONS AT ENDS	
1	2500	1000	10016.3	.020	-0.10000	10.00	1	2
2	2500	1000	9995.0	.020	-0.10000	10.00	2	3
3	2500	1000	10002.2	.020	-0.10000	10.00	3	4
4	2500	1000	10000.1	.020	-0.09999	10.00	4	5

TAPE 10 WAS WRITTEN FROM CYCLE 180 TO CYCLE 540

END OF TWO-DIMENSIONAL EXPLICIT PROGRAM. 540 CYCLES.

EXAMPLE 5 (Cont'd)

STEADY STATE EXAMPLE,CHANNEL LENGTH REDUCED BY TWO
FIVE JUNCTIONS,FOUR CHANNELS,CONSTANT FRICTION,1000 CFS INFLOW
STEADY STATE EXAMPLE CONTINUED
SUBROUTINE HYDEX OUTPUT

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

******** FROM HYDRAULICS PROGRAM ********			HYDRAULIC CYCLES PER	TIME INTERVAL IN
START CYCLE	STOP CYCLE	TIME INTERVAL	QUALITY CYCLE	QUALITY PROGRAM
180	540	120 SECONDS	15	.50 HOURS

		* * * * * FLOW	* * * * *	* * VELOCITY	* *	* * * CROSS-SECTIONAL AREA	* * *	
CHANNEL NUMBER	NET FLOW (CFS)	MIN. (CFS)	MAX. (CFS)	MIN. (CFS)	MAX. (CFS)	MIN. (SQ. FT)	MAX. (SQ. FT)	AVE. (SQ. FT)
1	-999.95	-1003.47	-995.70	-0.102	-0.098	9999.9	10000.2	10000.1
2	-999.97	-1003.14	-996.70	-0.102	-0.099	9999.8	10000.7	10000.3
3	-999.98	-1002.34	-997.43	-0.101	-0.099	9999.7	10001.1	10000.5
4	-999.99	-1001.24	-998.67	-0.101	-0.099	9999.8	10001.4	10000.7

EXAMPLE 5 (Cont'd)

JUNCTION NUMBER	MINIMUM HEAD (FT)	OCCURS AT CYCLE	MAXIMUM HEAD (FT)	OCCURS AT CYCLE	AVERAGE HEAD (FT)	TIDAL RANGE (FT)
1	.05	189	.05	180	.05	.00
2	-0.02	182	-0.01	192	-0.02	.00
3	.00	184	.01	195	.01	.00
4	-0.00	184	-0.00	194	-0.00	.00
5	.00	184	.00	194	.00	.00

EXAMPLE 5 (Cont'd)

**** OUTPUT FOR CHECKING DATA ON EXTRACTED TAPE ****

HYDRAULIC CYCLE	HEAD AT JUNCTION NO.1	*FLOW IN CHANNEL* NO.1	NO.2
180	.05	-995.70	-996.70
195	.05	-1003.47	-1003.14
210	.05	-1001.03	-1000.64
225	.05	-997.93	-998.23
240	.05	-1000.15	-1000.25
255	.05	-1000.99	-1000.81
270	.05	-999.61	-999.61
285	.05	-999.63	-999.72
300	.05	-1000.32	-1000.28
315	.05	-1000.08	-1000.05
330	.05	-999.82	-999.84
345	.05	-1000.02	-1000.03
360	.05	-1000.09	-1000.07
375	.05	-999.96	-999.96
390	.05	-999.97	-999.98
405	.05	-1000.03	-1000.03
420	.05	-1000.01	-1000.00
435	.05	-999.98	-999.99
450	.05	-1000.00	-1000.00
465	.05	-1000.01	-1000.01
480	.05	-1000.00	-1000.00
495	.05	-1000.00	-1000.00
510	.05	-1000.00	-1000.00
525	.05	-1000.00	-1000.00

END OF NET FLOW PROGRAM.

EXAMPLE 5 (Cont'd)

JUNCTION DATA FOR RESTART DECK

JUNCTION	INITIAL HEAD	SURFACE AREA	INPUT-OUTPUT	CHANNELS ENTERING JUNCTION				
1	.0239	5000000	0	1	0	0	0	0
2	-0.0007	5000000	0	1	2	0	0	0
3	.0009	5000000	0	2	3	0	0	0
4	.0012	5000000	0	3	4	0	0	0
5	.0016	5000000	-1000.00	4	0	0	0	0

EXAMPLE 6

CHANNEL DATA FOR RESTART DECK

CHANNEL	LENGTH	WIDTH	AREA	MANNING	VELOCITY	HYD RADIUS	JUNCTIONS AT ENDS	
1	5000	1000	10011.6	.020	-0.09970	10.00	1	2
2	5000	1000	10000.1	.020	-0.09974	10.00	2	3
3	5000	1000	10001.0	.020	-0.09980	10.00	3	4
4	5000	1000	10001.4	.020	-0.09988	10.00	4	5

TAPE 10 WAS WRITTEN FROM CYCLE 180 TO CYCLE 540

END OF TWO-DIMENSIONAL EXPLICIT PROGRAM. 540 CYCLES.

EXAMPLE 6 (Cont'd)

STEADY STATE EXAMPLE
FIVE JUNCTIONS.FOUR CHANNELS.CONSTANT FRICTION
STEADY STATE EXAMPLE CONTINUED
SUBROUTINE HYDEX OUTPUT

******** FROM HYDRAULICS PROGRAM ********			HYDRAULIC CYCLES PER QUALITY CYCLE	TIME INTERVAL IN QUALITY PROGRAM
START CYCLE	STOP CYCLE	TIME INTERVAL		
180	540	120 SECONDS	15	.50 HOURS

CHANNEL NUMBER	NET FLOW (CFS)	* * * * * FLOW * * * * * MIN. (CFS)	MAX. (CFS)	* * VELOCITY * * MIN. (CFS)	MAX. (CFS)	* * * CROSS-SECTIONAL AREA * * * MIN. (SQ. FT)	MAX. (SQ. FT)	AVE. (SQ. FT)
1	-1004.06	-1150.08	-935.52	-0.119	-0.084	9998.6	10002.3	10000.3
2	-1003.57	-1131.58	-942.72	-0.117	-0.086	9996.0	10006.6	10000.8
3	-1002.65	-1097.67	-957.47	-0.113	-0.090	9993.8	10010.1	10001.2
4	-1001.41	-1051.94	-977.33	-0.107	-0.095	9992.5	10012.5	10001.5

EXAMPLE 6 (Cont'd)

JUNCTION NUMBER	MINIMUM HEAD (FT)	OCCURS AT CYCLE	MAXIMUM HEAD (FT)	OCCURS AT CYCLE	AVERAGE HEAD (FT)	TIDAL RANGE (FT)
1	.02	210	.03	189	.02	.01
2	-0.00	199	.00	180	-0.00	.01
3	-0.01	200	.01	180	.00	.01
4	-0.01	200	.01	180	.00	.02
5	-0.01	200	.01	180	.00	.02

EXAMPLE 6 (Cont'd)

**** OUTPUT FOR CHECKING DATA ON EXTRACTED TAPE ****

HYDRAULIC CYCLE	HEAD AT JUNCTION NO.1	*FLOW IN CHANNEL* NO.1	NO.2
180	.02	-1150.08	-1131.58
195	.03	-955.98	-962.10
210	.02	-935.52	-942.72
225	.03	-1101.95	-1089.65
240	.02	-938.90	-946.69
255	.02	-989.58	-990.39
270	.03	-1056.74	-1050.06
285	.02	-947.00	-953.55
300	.02	-1014.53	-1012.49
315	.03	-1023.95	-1021.25
330	.02	-963.52	-967.93
345	.02	-1021.24	-1018.53
360	.02	-1004.43	-1004.06
375	.02	-979.42	-981.85
390	.02	-1018.74	-1016.42
405	.02	-995.26	-995.93
420	.02	-991.12	-992.12
435	.02	1013.05	-1011.47
450	.02	-992.64	-993.58
465	.02	-998.16	-998.33
480	.02	-1007.45	-1006.57
495	.02	-993.38	-994.20
510	.02	-1001.53	-1001.31
525	.02	-1003.29	-1002.91

END OF NET FLOW PROGRAM.

EXAMPLE 6 (Cont'd)

DOWNSTREAM BOUNDARY CONSTANT
NO FLOW AT THE UPSTREAM BOUNDARY.
TEMPERATURE TEST.HYDRAULICS.NO TRIB OR MAINSTREAM FLOW.
NO DRIVING FORCE.NO INPUT TIDE.

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

******** FROM HYDRAULICS PROGRAM ********

START CYCLE	STOP CYCLE	TIME INTERVAL
180	540	120 SECONDS

STARTING CYCLE ON HYD. EXTRACT TAPE	INITIAL QUALITY CYCLE	TOTAL QUALITY CYCLES	*** OUTPUT INTERVALS *** CYCLES	HOURS	TIME INTERVAL IN QUALITY PROGRAM	CONSTANT FOR DIFFUSION COEFFICIENTS
180	1	120	50	2.00	1.000 HOURS	0

PRINTOUT IS TO BEGIN AT CYCLE 1

QUALITY TAPE FOR EXTRACTING IS TO BEGIN AT CYCLE

1 CONSTITUENTS BEING CONSIDERED IN THIS RUN

TEMPERATURE IS THE ONLY CONSTITUENT.

ALL CONSTITUENTS TREATED AS CONSERVATIVE IN THIS RUN

NO WASTE WATER RETURN FACTORS APPLIED

EXAMPLE 7

```
*****MULTIPLICATION FACTORS APPLIED TO OBTAIN STARTING CONCENTRATIONS

CONSTITUENT    GROUP    FACTOR    JUNCTION NUMBERS

NO MULTIPLICATION FACTOR APPLIED TO CONSTITUENT NO. 1
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EXAMPLE 7 (Cont'd)

** WATER QUALITY DATA **

JUNC.	INFLOW	FIRST CONSTITUENT INITIAL CONC.	FIRST CONSTITUENT INFLOW CONC.	SECOND CONSTITUENT INITIAL CONC.	SECOND CONSTITUENT INFLOW CONC.	THIRD CONSTITUENT INITIAL CONC.	THIRD CONSTITUENT INFLOW CONC.	FOURTH CONSTITUENT INITIAL CONC.	FOURTH CONSTITUENT INFLOW CONC.	FIFTH CONSTITUENT INITIAL CONC.	FIFTH CONSTITUENT INFLOW CONC.
1	0	10.0	0								
2	0	10.0	0								
3	0	10.0	0								
4	0	10.0	0								
5	0	10.0	0								

SPECIFIED C-FACTORS AT JUNCTION 1 FOR CONSTITUENT NO. 1

10.00	10.00	10.00	10.00	10.00	10.00	10.00
10.00	10.00	10.00	10.00	10.00	10.00	10.00
10.00	10.00	10.00	10.00	10.00	10.00	10.00
10.00	10.00	10.00				

EXAMPLE 7 (Cont'd)

CHANNEL DATA

CHAN.	LENGTH	WIDTH	AREA	MANNING	NET FLOW	HYD. RADIUS	JUNC. AT ENDS	
1	2500	1000	10000	.020	0	10.0	1	2
2	2500	1000	10000	.020	0	10.0	2	3
3	2500	1000	10000	.020	0	10.0	3	4
4	2500	1000	10000	.020	0	10.0	4	5

JUNCTION DATA

JUNC.	HEAD	CHANNELS ENTERING JUNCTION				
1	0	1	0	0	0	0
2	0	1	2	0	0	0
3	0	2	3	0	0	0
4	0	3	4	0	0	0
5	0	4	0	0	0	0

EXAMPLE 7 (Cont'd)

****************************** TABLE OF METEOROLOGICAL DATA ******************************

NET INCOMING RADIATION (KC/M2/SEC)	WIND SPEED (M/SEC)	DRY BULB TEMP (C)	WET BULB TEMP (C)	ATMOSPHERIC PRESSURE (MB)
6.400E-02	.4	18.00	17.80	1015.0
6.400E-02	.4	19.00	17.70	1015.0
6.400E-02	.4	18.30	17.80	1015.0
6.400E-02	.4	18.40	18.30	1015.0
6.400E-02	.4	18.60	18.30	1015.0
7.650E-02	.4	19.00	18.30	1015.0
8.350E-02	.4	18.50	17.80	1015.0
1.059E-01	.4	17.00	17.00	1015.0
1.220E-01	.4	19.00	18.00	1015.0
1.350E-01	.5	19.20	18.00	1015.0
1.450E-01	.4	22.30	20.00	1015.0
1.490E-01	.5	22.50	19.70	1015.0
1.490E-01	.4	24.50	20.80	1015.0
1.450E-01	.7	24.50	22.00	1015.0
1.350E-01	.4	26.00	21.50	1015.0
1.220E-01	.5	25.00	23.00	1015.0
1.059E-01	1.0	22.50	19.00	1015.0
1.000E-01	.5	19.30	18.00	1015.0
7.600E-02	.6	20.30	19.20	1015.0
6.500E-02	.5	19.10	18.70	1015.0
6.400E-02	.4	18.40	17.70	1015.0
6.400E-02	.4	17.50	17.00	1015.0
6.400E-02	.4	17.60	17.40	1015.0
6.400E-02	.4	17.80	17.50	1015.0

MARK(1,1) = 1

EXAMPLE 7 (Cont'd)

SYSTEM STATUS AFTER QUALITY CYCLE 1 0 DAYS, 1.00 HOURS

		**************************		CONCENTRATION FACTORS	**************************	
JUNCTION NUMBER	HEAD (FT)	1ST. CONSTIT. (MGL)	2ND. CONSTIT. (MGL)	3RD. CONSTIT. (MGL)	4TH. CONSTIT. (MGL)	5TH. CONSTIT. (MGL)
1	0	10.00				
2	0	9.98				
3	0	9.98				
4	0	9.98				
5	0	9.98				

EXAMPLE 7 (Cont'd)

*************** RADIATION TERMS AND EQUILIBRIUM TEMPERATURES ***************

(KCAL IMPLIES KILOGRAM-CALORIES PER SQUARE METER PER SECOND, BTU IMPLIES BTU PER SQUARE FOOT PER HOUR)

NET RADIATION		INCOMING SOLAR		BACK RADIATION		EVAPORATION		CONDUCTION		EQUIL TEMP
KCAL	BTU	KCAL	BTU	KCAL	BTU	KCAL	BTU	KCAL	BTU	CENTIGRADE
0E 00	0	6.40E-02	84.947	0E 00	0	0E 00	0	0E 00	0	0
-1.95E-02	-25.881	6.40E-02	84.947	8.53E-02	113.218	0E 00	0	-1.80E-03	-2.390	.25
-1.95E-02	-25.881	6.40E-02	84.947	8.53E-02	113.218	0E 00	0	-1.80E-03	-2.390	.25
-1.95E-02	-25.881	6.40E-02	84.947	8.53E-02	113.218	0E 00	0	-1.80E-03	-2.390	.25
-1.95E-02	-25.881	6.40E-02	84.947	8.53E-02	113.218	0E 00	0	-1.80E-03	-2.390	.25

EXAMPLE 7 (Cont'd)

SYSTEM STATUS AFTER QUALITY CYCLE 3 0 DAYS, 3.00 HOURS

JUNCTION NUMBER	HEAD (FT)	1ST. CONSTIT. (MGL)	2ND. CONSTIT. (MGL)	3RD. CONSTIT. (MGL)	4TH. CONSTIT. (MGL)	5TH. CONSTIT. (MGL)
		************************** CONCENTRATION FACTORS **************************				
1	0	10.00				
2	0	9.93				
3	0	9.93				
4	0	9.93				
5	0	9.93				

EXAMPLE 7 (Cont'd)

*************** RADIATION TERMS AND EQUILIBRIUM TEMPERATURES ***************

KCAL IMPLIES KILOGRAM-CALORIES PER SQUARE METER PER SECOND, BTU IMPLIES BTU PER SQUARE FOOT PER HOUR)

NET RADIATION		INCOMING SOLAR		BACK RADIATION		EVAPORATION		CONDUCTION		EQUIL TEMP
KCAL	BTU	KCAL	BTU	KCAL	BTU	KCAL	BTU	KCAL	BTU	CENTIGRADE
0E 00	0	6.40E-02	84.947	0E 00	0	0E 00	0	0E 00	0	0
-1.93E-02	-25.617	6.40E-02	84.947	8.52E-02	113.146	0E 00	0	-1.95E-03	-2.583	.50
-1.93E-02	-25.617	6.40E-02	84.947	8.52E-02	113.146	0E 00	0	-1.95E-03	-2.583	.50
-1.93E-02	-25.617	6.40E-02	84.947	8.52E-02	113.146	0E 00	0	-1.95E-03	-2.583	.50
-1.93E-02	-25.617	6.40E-02	84.947	8.52E-02	113.146	0E 00	0	-1.95E-03	-2.583	.50

EXAMPLE 7 (Cont'd)

SYSTEM STATUS AFTER QUALITY CYCLE 120 5 DAYS. 0 HOURS

JUNCTION NUMBER	HEAD (FT)	************************** CONCENTRATION FACTORS **************************				
		1ST. CONSTIT. (MGL)	2ND. CONSTIT. (MGL)	3RD. CONSTIT. (MGL)	4TH. CONSTIT. (MGL)	5TH. CONSTIT. (MGL)
1	0	10.00				
2	0	11.62				
3	0	11.62				
4	0	11.62				
5	0	11.62				

EXAMPLE 7 (Cont'd)

*************** RADIATION TERMS AND EQUILIBRIUM TEMPERATURES ***************

(KCAL IMPLIES KILOGRAM-CALORIES PER SQUARE METER PER SECOND, BTU IMPLIES BTU PER SQUARE FOOT PER HOUR)

NET RADIATION		INCOMING SOLAR		BACK RADIATION		EVAPORATION		CONDUCTION		EQUIL TEMP
KCAL	BTU	KCAL	BTU	KCAL	BTU	KCAL	BTU	KCAL	BTU	CENTIGRADE
0E 00	0	6.40E-02	84.947	0E 00	0	0E 00	0	0E 00	0	0
-2.18E-02	-28.939	6.40E-02	84.947	8.72E-02	115.779	0E 00	0	-1.43E-03	-1.894	.93
-2.18E-02	-28.939	6.40E-02	84.947	8.72E-02	115.779	0E 00	0	-1.43E-03	-1.894	.93
-2.18E-02	28.939	6.40E-02	84.947	8.72E-02	115.779	0E 00	0	-1.43E-03	-1.894	.93
-2.18E-02	-28.939	6.40E-02	84.947	8.72E-02	115.779	0E 00	0	-1.43E-03	-1.894	.93

QUALITY TAPE WAS WRITTEN FROM CYCLE 1 TO CYCLE 25

QUALITY TAPE WAS WRITTEN FROM CYCLE 50 TO CYCLE 74

QUALITY TAPE WAS WRITTEN FROM CYCLE 96 TO CYCLE 120

END OF QUALITY RUN. 120 CYCLES.

EXAMPLE 7 (Cont'd)

EXAMPLE 8
FIVE JUNCTIONS,FOUR CHANNELS,CONSTANT FRICTION,100 CFS INFLOW
EXAMPLE 4--CONTINUITY TEST
HYDRAULICS FROM EXAMPLE 1

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC NORTHWEST WATER LABORATORY

******** FROM HYDRAULICS PROGRAM ********

START CYCLE	STOP CYCLE	TIME INTERVAL
180	540	120 SECONDS

STARTING CYCLE ON HYD. EXTRACT TAPE	INITIAL QUALITY CYCLE	TOTAL QUALITY CYCLES	*** OUTPUT INTERVALS *** CYCLES	HOURS	TIME INTERVAL IN QUALITY PROGRAM	CONSTANT FOR DIFFUSION COEFFICIENTS
180	1	240	50	1.00	.500 HOURS	

PRINTOUT IS TO BEGIN AT CYCLE 1

QUALITY TAPE FOR EXTRACTING IS TO BEGIN AT CYCLE 1

1 CONSTITUENTS BEING CONSIDERED IN THIS RUN

EXAMPLE 8, CONTINUED

ALL CONSTITUENTS TREATED AS CONSERVATIVE IN THIS RUN

NO WASTE WATER RETURN FACTORS APPLIED

EXAMPLE 8

```
*****MULTIPLICATION FACTORS APPLIED TO OBTAIN STARTING CONCENTRATIONS

CONSTITUENT    GROUP    FACTOR    JUNCTION NUMBERS

NO MULTIPLICATION FACTOR APPLIED TO CONSTITUENT NO. 1
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EXAMPLE 8 (Cont'd)

WATER QUALITY DATA

JUNC.	INFLOW	FIRST CONSTITUENT INITIAL CONC.	FIRST CONSTITUENT INFLOW CONC.	SECOND CONSTITUENT INITIAL CONC.	SECOND CONSTITUENT INFLOW CONC.	THIRD CONSTITUENT INITIAL CONC.	THIRD CONSTITUENT INFLOW CONC.	FOURTH CONSTITUENT INITIAL CONC.	FOURTH CONSTITUENT INFLOW CONC.	FIFTH CONSTITUENT INITIAL CONC.	FIFTH CONSTITUENT INFLOW CONC.
1	0	15.0	0								
2	0	15.0	0								
3	0	15.0	0								
4	0	15.0	0								
5	-100.0000	15.0	15.0								

SPECIFIED C-FACTORS AT JUNCTION 1 FOR CONSTITUENT NO. 1

15.00	15.00	15.00	15.00	15.00	15.00	15.00
15.00	15.00	15.00	15.00	15.00	15.00	15.00
15.00	15.00	15.00	15.00	15.00	15.00	15.00
15.00	15.00	15.00				

EXAMPLE 8 (Cont'd)

CHANNEL DATA

CHAN.	LENGTH	WIDTH	AREA	MANNING	NET FLOW	HYD. RADIUS	JUNC. AT ENDS	
1	5000	1000	9967	.020	-100.34	10.0	1	2
2	5000	1000	10038	.020	-100.37	10.0	2	3
3	5000	1000	10035	.020	-100.36	10.0	3	4
4	5000	1000	10035	.020	-100.22	10.0	4	5

JUNCTION DATA

JUNC.	HEAD	CHANNELS ENTERING JUNCTION				
1	0	1	0	0	0	0
2	0	1	2	0	0	0
3	0	2	3	0	0	0
4	0	3	4	0	0	0
5	0	4	0	0	0	0

MARK(1,1) = 1

EXAMPLE 8 (Cont'd)

SYSTEM STATUS AFTER QUALITY CYCLE 1 0 DAYS, .50 HOURS

JUNCTION NUMBER	HEAD (FT)	1ST. CONSTIT. (MGL)	2ND. CONSTIT. (MGL)	3RD. CONSTIT. (MGL)	4TH. CONSTIT. (MGL)	5TH. CONSTIT. (MGL)
		************************** CONCENTRATION FACTORS **************************				
1	-0.37	15.00				
2	-0.49	15.00				
3	-0.47	15.00				
4	-0.46	15.00				
5	-0.46	15.00				

EXAMPLE 8 (Cont'd)