THE ESTUARINE VERSION OF THE COLHEAT
DIGITAL SIMULATION MODEL

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Water and Land Resources Department
Environmental and Life Sciences Division

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ABSTRACT

The COLHEAT simulation model, developed jointly on Division of Production and Division of Reactor Development and Technology funds for the Atomic Energy Commission, was modified to simulate spatial and temporal variations of temperature, chemical, and radionuclide concentration above the salt intrusion in coastal plain estuaries where the river flow is dominant. This report explains these modifications and describes a case study on the Columbia River estuary. Funding for the case study was provided by Clark and Cowlitz County Public Utility Districts.

FOREWORD

The number of power plants operating along the estuaries is increasing and projections based on the rate of increase suggest that many additional plants will have to be located along estuaries in order to meet the growing power demands of the future. Increasing the number of power plants along these waterways could have an adverse effect upon the ecological communities. As a result, the Division of Reactor Development and Technology authorized the development of a simulation model which could be used to estimate the effect of these power plants on the estuarine environment. The basic model was developed as a version of the COLHEAT river simulation model originally used for Division of Production work on the Columbia River. This report describes a simulation model for use above the zone of salt water intrusion where tidal fluctuations are still salient.

With the permission of Clark and Cowlitz County Public Utility Districts, the use of the estuarine version of COLHEAT is presented as a case study to relate the model to an actual siting problem currently receiving public attention. All work required to modify the program for use in the case study of the Kalama site was fully authorized under Contract AT(45-1)-1831. A separate report of this investigation was published for the Public Utility Districts and portions are included in this report for continuity. Requests for complete copies of the original report should be directed to the attention of R. W. McKinney, Cowlitz County Public Utility District, 960 Commerce Avenue, Longview, Washington, 98362.

Further estuarine case studies have been authorized by the Division of Reactor Development and Technology under the program "Regional Modeling of Surface Water Temperatures from Projected Power Growth." These cases are still under investigation and will be reported separately as soon as they are completed.

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INTRODUCTION

In order to predict the effects of dam and power plant construction on the temperature of rivers, in 1963 the Atomic Energy Commission Division of Production provided funding to the Pacific Northwest Laboratories to develop a river simulation temperature prediction system. The system conceived was a model based on continuity retaining enough flexibility to describe temporal and spatial variations of both thermal energy and mass in a moving fluid.⁽¹⁾ Originally developed to predict temperatures of the Columbia River, the model has proven its versatility in other river systems.⁽²⁻⁵⁾ In addition, the flexibility of the COLHEAT river simulation system has recently been demonstrated by Jaske and Spurgeon in predicting the transport of radioactive iodine in the Columbia River.⁽⁶⁾

Because many power plants are presently on or planned to be located on estuarine portions of river systems, a simulation model was developed to examine their effects. This model, which is called the estuarine version and is the subject of this report, is a special purpose version of the basic COLHEAT system which allows for volume changes owing to stage variation resulting from tidal action. Homogeneity in the vertical direction has been assumed and, therefore, specific treatment of mixing across the halocline has not been included.

SUMMARY

As is necessary in the basic COLHEAT model⁽¹⁻⁵⁾ the estuarine version of the model requires that the flow as a function of time be specified at or within the system boundaries. The nature of flow within coastal plain estuaries requires that the following two ideas be implemented to achieve this capability:

MODEL DEVELOPMENT

The major modifications of the existing COLHEAT model which were necessary to develop an estuarine version are described below.

SPATIAL VARIATIONS IN FLOW

The major physical difference of interest to this discussion between flow in rivers and flow in estuaries results from the influence of tides. Tidal activity causes variations in stage which produce changes in channel volume and variation in flow. To adapt the COLHEAT model for use in estuaries, one must be able to describe this stage variation and the accompanying flow variation as functions of time during the tidal cycle.

To do this the estuary is broken into river sections just as the river is broken into river sections in the COLHEAT model. However, in the estuarine river section, volume changes associated with changes in stage are used to determine changes in flow. Figure 1 shows a typical river section in plan view. The model is based on a single equation for mass conservation within a river section:

$$q_{i-1}(t) = q_i(t) + \frac{dV_i(t)}{dt} \quad (1)$$

where

$q_{i-1}(t)$ = flow into the i^{th} river section

$q_i(t)$ = flow out of i^{th} river section

$\frac{dV_i(t)}{dt}$ = change in volume of i^{th} river section
with respect to time.

Because all river sections presently used in the estuarine versions are right rectangular prisms, the change in volume with respect to time can be represented as a change in river stage.

$$\frac{dV_i(t)}{dt} = L_i W_i \frac{dS_i(t)}{dt} \quad (2)$$

where L_i = length of i^{th} river section

W_i = width of i^{th} river section

$$\frac{dS_i(t)}{dt} = \text{variation in river state with respect to time for } i^{\text{th}} \text{ river section.}$$

Substituting Equation (2) into Equation (1) yields

$$q_{i-1}(t) = q_i(t) + L_i W_i \frac{dS_i(t)}{dt} \quad (3)$$

Therefore, by knowing the flow as a function of time at or within the system boundary and the variation in river stage with respect to time for each river section, Equation (3) can be used to describe the flow in an estuary. Figures 2 and 3 are system flow charts which depict the flow of information for the stage and flow calculations respectively.

WATER TRANSPORT

In programming flow through an ordinary river system, allocating flow from one river section to the next is simple if river sections are assumed to maintain constant volume, and flow is always downstream and constant with respect to distance downstream. However, the problem is not so simple when simulating estuaries. Not only can estuary river section volumes change so that flow into a river section is not equal to flow out of that river section, but also the flows can change direction and actually be directed upstream during portions of the tidal cycle. Thus, allocating flow in an estuarine river section becomes more complicated. Figure 4 shows the four possible cases and governing equations. Flow is defined as positive downstream; negative upstream. Figures 5 through 11 show the transport flowchart.

FIGURE 3. Flow Calculation Flow Chart for Estuarine Version

FIGURE 5. Flow Chart for Water Transport
--Initiation for n Trough Flow

FIGURE 7. Flow Chart for Water Transport
--High Flow

FIGURE 9. Flow Chart for Water Transport
--Complete Normal Flow and Check
for Reverse Flow

$$AP_1 = A_1(1 - y_1) + A_2y_1$$

$$AP_2 = \frac{[A_1y_1V_1 + A_2(V_2 - y_1V_1 - y_2V_3) + A_3y_2V_3]}{V_2}$$

$$AP_3 = A_2y_2 + A_3(1 - y_2)$$

FIGURE 12. Partial Mixing Concept for Mixing in the Three-Trough Model

FIGURE 13. Structure of Executive Program for the Estuarine Version

FIGURE 15. Time Lag for High and Low Water on the Lower Columbia River Based on Tongue Point Tide (By permission of Clark and Cowlitz County Public Utility Districts)

FIGURE 16. U.S.G.S. River Flows at Beaver Compared with River Flows Predicted by the Estuarine Version at Beaver (By permission of Clark and Cowlitz County Public Utility Districts)

Temperature is assumed to follow the same mixing relationship and when good simulation is obtained in the concentration mode, the model using the same partial mixing coefficients is applied to the temperature mode. The appropriate values for both partial mixing coefficients are assumed to be equal and for this reach of the Columbia under steady flow conditions are:

$$y_1 = y_2 = 0.0065$$

Figure 12 on page 17 has the definition of the partial mixing coefficients y_n .

TEMPERATURE SIMULATION

Temperature simulations were run for the two 5 day periods of August 8 through 12, 1967, and September 2 through 6, 1967. Calculated temperatures were compared for both periods with observed temperatures at Beaver, and for the latter period at Longview (River Mile 66.0). Figures 17 and 18 illustrate the quality of the simulation.

Because of sloughs located along the Oregon shore, temperatures at the Beaver Army Terminal are consistently about 0.4 °C higher than the average transect temperatures during the summer months. Therefore, if 0.4 °C is subtracted from the observed Beaver temperature curve, good agreement is obtained between the Beaver observed and Beaver calculated temperatures.

CASES EXAMINED

The estuarine version for the cases examined extended from St. Helens to the lower end of Puget Island (River Mile 37.6). River sections 1000 ft long employing the partial mixing concept were used to simulate the reach between

FIGURE 18. Lower Columbia River Temperature Simulation
(By permission of Clark and Cowlitz County
Public Utility Districts)

Case No.	Plant Generating Capacity, MW	
	<u>River Mile 78</u>	<u>River Mile 72.8</u>
1	1000	0
2	2000	0
3	1000	1000
4	2000	1000

Temperatures for all runs were recorded every hour at selected river mile locations. These temperatures were an average for the water volume through a given river cross section every hour. Then the temperature excesses, that is, temperature differences between the case with no advected heat (natural conditions) and one with advected heat, were calculated for each case every hour and at each of the following river miles:

79.4	72.6
78.5	71.8
77.9	70.7
78.0*	69.7
77.5	68.3
76.6	67.2
75.4	66.0
74.1	53.5
73.0	46.0
72.8*	38.0

* *Plant Site*

Figures 19 through 22 show these temperature excesses, plotted by computer, for Case 1 through Case 4 for the second 5 day period. The horizontal axis represents time in days, the vertical axis represents the temperature excess in degrees centigrade, and the oblique axis at 30° to the horizontal represents distance upstream from the mouth of the Columbia

FIGURE 20. Temperature Excess Surface for Case 2: 2000 MW Plant at River Mile 78, No Plant at River Mile 72.8
(By permission of Clark and Cowlitz County Public Utility Districts)

FIGURE 22. Temperature Excess Surface for Case 4: 2000 MW Plant at River Mile 78, 1000 MW Plant at River Mile 72.8

FIGURE 23. Temperature Excess Curves for Case 1: 1000 MW Plant at River Mile 78, No Plant at River Mile 72.8
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FIGURE 25. Temperature Excess Curves for Case 3: 1000 MW Plant at River Mile 78, 1000 MW Plant at River Mile 72.8

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The authors wish to thank Jesse L. Spurgeon of Computer Sciences Corporation for his key role in the physical programming and operational testing of the various versions of COLHEAT. Figures 2, 3, 5 through 11, and 13 were prepared by Mr. Spurgeon in the course of documentation of the estuarine version.

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