UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREDICTED EFFECTS OF PROPOSED NAVIGATION IMPROVEMENTS ON RESIDENCE TIME AND DISSOLVED OXYGEN OF THE SALT WEDGE IN THE DUWAMISH RIVER ESTUARY, KING COUNTY, WASHINGTON

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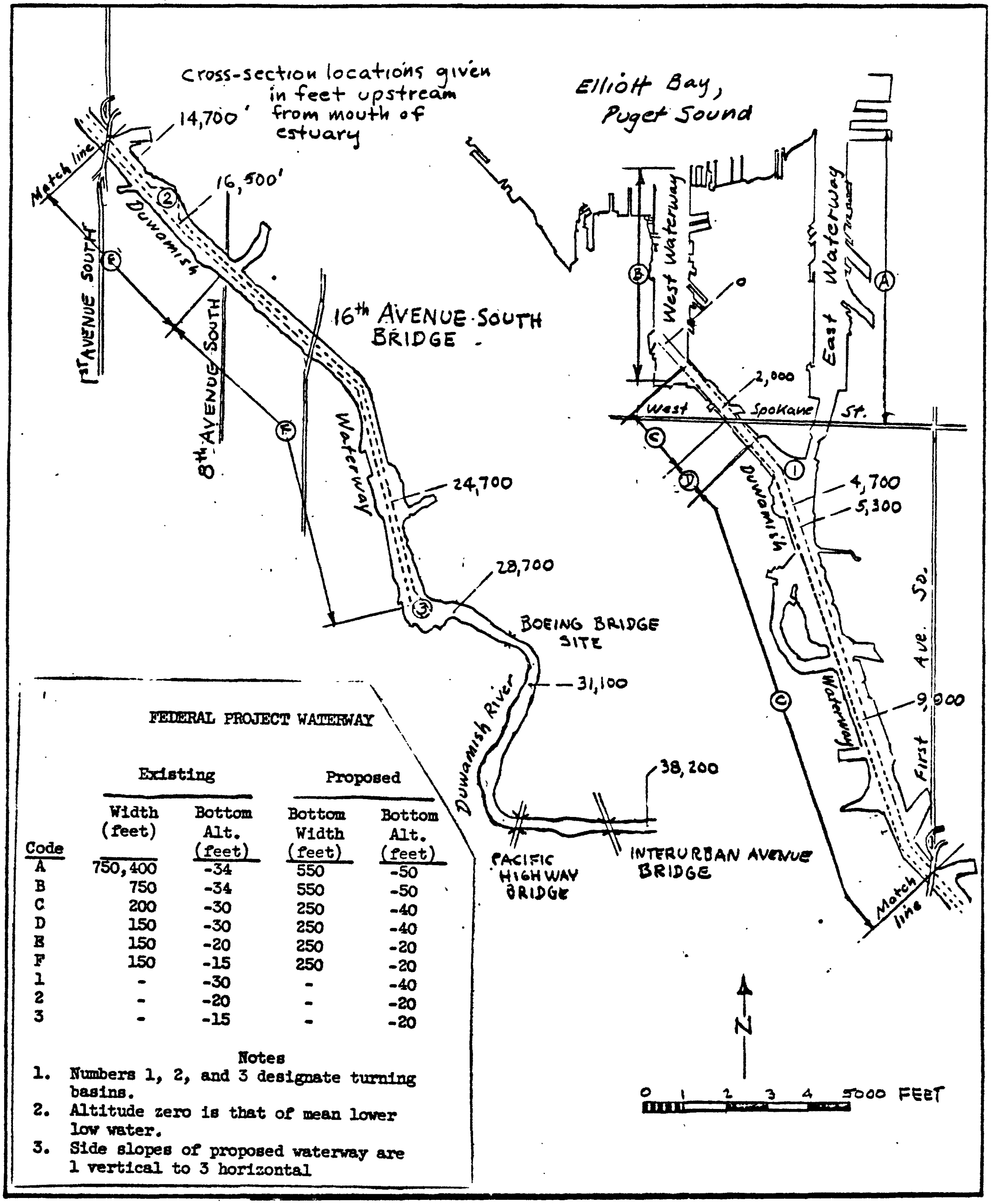
ABSTRACT

A model of the circulation and quality of water in the Duwamish River estuary has been sufficiently developed to allow prediction of the effects of a proposed widening and deepening of waterways on residence time and dissolved oxygen in the estuary's salt wedge. For a low river-discharge period in August 1970, use of the model yielded an estimated residence time of wedge water to be 6.3 days in the present-waterways estuary and 8.6 days in the wider and deeper proposed-waterways estuary--a 37-percent increase. For June-September 1970 and for the estuary about 4 miles upstream from its mouth, the model estimates indicate that dissolved-oxygen values in the wedge of the proposed-waterways estuary would be as much as 1.4 milligrams per liter lower and would average 0.4 milligram per liter lower than (average difference significant at 95-percent confidence level) dissolved-oxygen values in the wedge of the present-waterways estuary. Extrapolation to low dissolved-oxygen values of a regression between the predicted dissolved oxygen for both the proposed- and present-waterways estuaries suggests that 4 miles upstream of the estuary mouth oxygen would be completely depleted from the proposed-waterways estuary wedge whereas there still would be 0.2 milligram of oxygen per liter of water in the wedge of the present-waterways estuary.

INTRODUCTION

The Seattle District of the U.S. Army Corps of Engineers (USACE) has been conducting a study of the East, West, and Duwamish Waterways of the Duwamish River estuary to determine the advisability of modifying the existing project so as to improve and extend navigation in these waterways (fig. 1). In spring 1972 USACE selected one of several alternatives for detailed study. The selected alternative would result in a widening and deepening of all waterways but not in extending the Duwamish Waterway upstream. (See table in fig. 1.) An increase in the residence time and depletion of oxygen for water in the highly stratified (salt-wedge) estuary, which would result from widening and deepening of the waterways, is of concern to (1) the USACE, because it will influence the decision about whether the waterways should be modified, and (2) Metro (the Municipality of Metropolitan Seattle) because it may either have to reduce or altogether stop discharging effluent into the Duwamish River from a secondary treatment plant located about 6.6 miles upstream from the upstream end of the Duwamish Waterway.

In cooperation with Metro, the U.S. Geological Survey is studying the effects of changes in waste-water disposal on water quality in the Duwamish River estuary and Puget Sound. As part of the study, the Geological Survey is developing a numerical model of the circulation and quality of water in the estuary. The model now (December 1972) credibly simulates both observed salinity distributions in the estuary and DO (dissolved oxygen) observed in the salt wedge during June-September of various years. The model therefore can be used to predict residence time and DO of salt-wedge water in a modified Duwamish River estuary whose waterways would have the geometry of the proposed alternative. Predictions for June-September 1970 are described in this report. A subsequent report will discuss details of the model and modeling results; the present report includes only enough information to generally support the use of the model in predicting effects of the proposed dredging.



FEDERAL PROJECT WATERWAY

Code	Existing Width (feet)	Existing Bottom Alt. (feet)	Proposed Bottom Width (feet)	Proposed Bottom Alt. (feet)
A	750,400	-34	550	-50
B	750	-34	550	-50
C	200	-30	250	-40
D	150	-30	250	-40
E	150	-20	250	-20
F	150	-15	250	-20
1	-	-30	-	-40
2	-	-20	-	-20
3	-	-15	-	-20

Notes
1. Numbers 1, 2, and 3 designate turning basins.
2. Altitude zero is that of mean lower low water.
3. Side slopes of proposed waterway are 1 vertical to 3 horizontal

FIGURE 1.--East, West, and Duwamish Waterways, Duwamish River estuary.

MODELING PRESENT-WATERWAYS ESTUARY

The Model

The model simulates the hydrologic conditions in the Duwamish River estuary, namely an oscillating saline wedge that is topped by a layer of mixed fresh and salt water. For numerical simulation in the model, the wedge is idealized to consist of a body of Elliott Bay water with a fixed downstream boundary (model mouth at the zero station, fig. 1) about 2,400 feet downstream from West Spokane Street Bridge. The upstream boundary (wedge toe) is represented by a vertical face that moves upstream and downstream during a tidal cycle.

In order to numerically model the transport and dispersion of constituents in the water, both the wedge and upper layer are divided longitudinally into elements. An element is an identified volume of fluid that completely fills the channel cross section and has a length that is determined by dividing the element's volume by the appropriate cross-sectional area. Cross-sectional areas used in the model are determined from the cross sections shown for the present-waterways estuary in figure 2; it should be noted that the flow into and out of the upstream end of the East Waterway--which is small relative to the flow into and out of the upstream end of the West Waterway--is accounted for by larger downstream cross sections.

The model, which operates on a 15-minute time step, essentially adds or subtracts elements at the model mouth, moves (advection) elements upstream or downstream, computes transport due to dispersion (diffusive transport) between adjacent wedge elements, adds fresh-water and salt-water discharges at the upstream end of the upper layer, transports salt water out of the wedge at the toe, computes entrainment, mixes the water in the elements, computes new concentrations for conservative constituents, computes gains and (or) losses and new concentrations for nonconservative constituents, determines volumes, lengths, and positions of elements, combines elements if volume and (or) length limits are exceeded, furnishes called-for outputs, and does any other needed computer-related functions.

Salinity

Salinity throughout the wedge is considered to be 25 ppt (parts per thousand); the location of the wedge toe in the model was determined from observations of the upstream limit of 25 ppt salinity in the Duwamish River estuary. Salinity in the upper layer increases from near zero at the water surface to 25 ppt at the upper layer-wedge interface. Model salinities were verified by comparisons with observed distributions of salinity along the estuary during high and low slack tides. Because the model estimates of salinity distributions credibly agree with observed distributions, the water circulation within the estuary appears to be adequately modeled. Therefore, the model could be used in estimating oxygen depletion in the salt wedge.

Dissolved Oxygen

Once water entering the wedge from Elliott Bay becomes trapped and starts a net movement upstream, it can only leave the wedge either by being entrained upward into the overlying layer or by moving out of the wedge toe. Water in the overlying layer does not move downward into the wedge. During its residence in this one-way system, DO in the wedge water is depleted by oxygen-demanding benthic, dissolved, and suspended materials. In modeling the DO depletion for June-September 1970, DO concentrations in the entering water were determined from continuously monitored values at 1 meter above the streambed at West Spokane Street Bridge. Modeling DO in the wedge was verified when closest agreement was obtained between hourly values of the model and the DO monitored at 16th Avenue South Bridge. The "best-fit" agreements indicate that the model estimates DO there with a standard error of 0.82 and 0.57 mg/l (milligram per liter) for June-September of 1970 and 1971, respectively.

MODELING PROPOSED-WATERWAYS ESTUARY

Assumptions and Conditions

The thickness of the upper layer and the slope of the upper surface of the wedge were assumed to remain the same in the proposed deeper-and-wider-waterways estuary as they are in the present-waterways estuary. Therefore, the wedge depth must increase, as, in general, the volume of the wedge would increase much more than would the volume of the upper layer in the proposed-waterways estuary. Evaluating the effect of the proposed waterways on the wedge-toe location and entrainment velocities is difficult because little information is available to use in an evaluation. When the wedge toe is upstream of the upstream end of the Duwamish Waterway (fig. 1) its location probably will be unaffected by the changes in geometries of the waterways. When it is in the Duwamish Waterway, the wedge toe will be farther upstream in the proposed-waterways estuary than it is in the present-waterways estuary. However, field observations show that the farthest downstream location of the toe usually was where the present-waterways estuary becomes, relatively, much deeper downstream from 16th Avenue South Bridge. Therefore, changes in the wedge-toe location are assumed to be small enough that their effects on modeling the proposed-waterways estuary would be negligible and the same for present- and proposed-waterways estuaries. Because little or no information about entrainment in stratified estuaries is available, effects of the proposed changes in estuary geometry on entrainment velocities were not determinable and are assumed to be negligible.

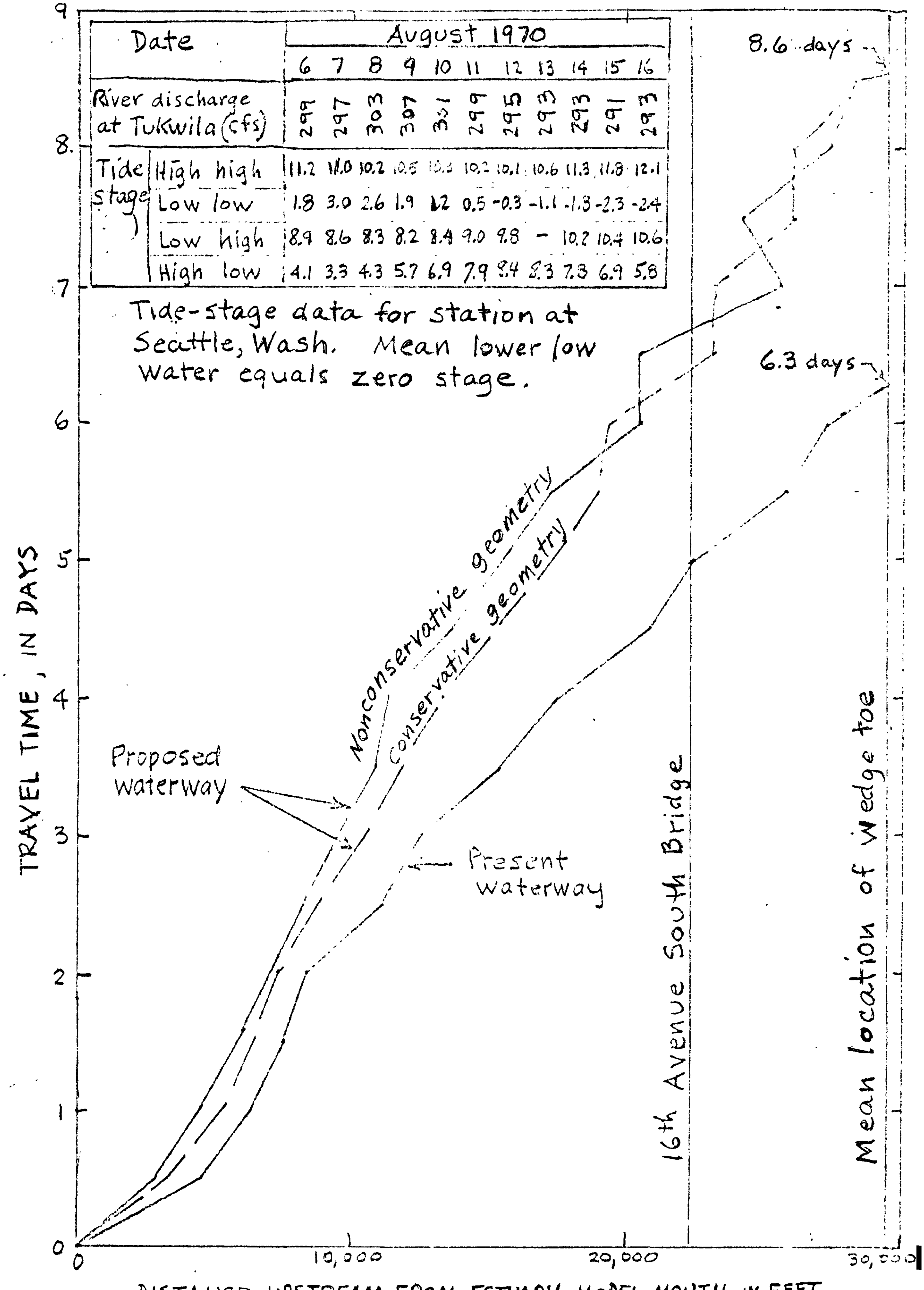
Residence time and oxygen depletion in the salt wedge of an estuary having the proposed-waterways geometry were estimated for June-September 1970 by using the oxygen-demand coefficient (oxygen uptake expressed as milligrams per liter per 15 minutes) that was used for the present-waterways estuary. Two geometries were used in the predictions. The first geometry (shown as the proposed waterway in fig. 2) assumes that the estuary will have cross-sectional areas that closely agree with the depths and sideslopes of the proposed waterways. Therefore, the first geometry is a conservative estimate of increase in estuary size. The second geometry, which is a nonconservative estimate of increase in estuary size, assumes that, at common depths, cross sections for the proposed-waterways estuary will not be narrower than cross sections for the present-waterways estuary. The second geometry is a more probable estimate of the size of the proposed-waterways estuary.

Residence Time

The model estimates traveltime of water from wedge mouth to wedge toe by keeping track of the upstream movement of an entering element of Elliott Bay water that becomes trapped in the estuary. Estimated traveltimes for elements becoming trapped on either August 6 or August 7, 1970, and daily mean river discharges and tide-stage data for August 6-16, 1970 are shown in figure 3. Estimated traveltime in the downstream part of the estuary is less for an estuary with the conservative-geometry waterway than for an estuary with the nonconservative-geometry waterway; traveltimes in the upstream part of the estuary would be about equal in estuaries with the two types of waterway geometry. The 8.6 days estimated for total traveltime (residence time) of water from mouth to toe in the wedge for the proposed-waterways estuary is 37 percent greater than the 6.3 days estimated for residence time of wedge water in the present-waterways estuary.

Dissolved Oxygen

For the wedge at 16th Avenue South Bridge, hourly values of estimated DO in an estuary, for both conservative- and nonconservative-geometry waterways, were plotted against hourly values of estimated DO for the present-waterways estuary, respectively (figs. 4 and 5). Aided by the lines that show an equality between estimated DO for present- and proposed-waterways estuaries, a visual inspection of the data in these figures shows that DO in the wedge for the proposed-waterways estuaries generally is less than in the wedge for the present-waterways estuary. Mean predicted DO values for the June-September 1970 data are 5.3 mg/l for the present-waterways estuary, and 5.0 and 4.9 mg/l for the proposed-waterways estuary, as calculated for conservative- and nonconservative-geometry waterways, respectively.



Date		August 1970										
		6	7	8	9	10	11	12	13	14	15	16
River discharge at Tukwila (cfs)		299	297	303	307	301	299	295	293	293	291	293
Tide stage	High high	11.2	11.0	10.2	10.5	10.3	10.2	10.1	10.6	11.3	11.8	12.1
	Low low	1.8	3.0	2.6	1.9	1.2	0.5	-0.3	-1.1	-1.3	-2.3	-2.4
	Low high	8.9	8.6	8.3	8.2	8.4	9.0	9.8	–	10.2	10.4	10.6
	High low	4.1	3.3	4.3	5.7	6.9	7.9	8.4	8.3	7.3	6.9	5.8

FIGURE 3.-- Model estimates of travel times of salt-wedge water in Duwamish River estuary for water entering wedge on August 6 or 7, 1970, and for geometry of proposed and present waterways.

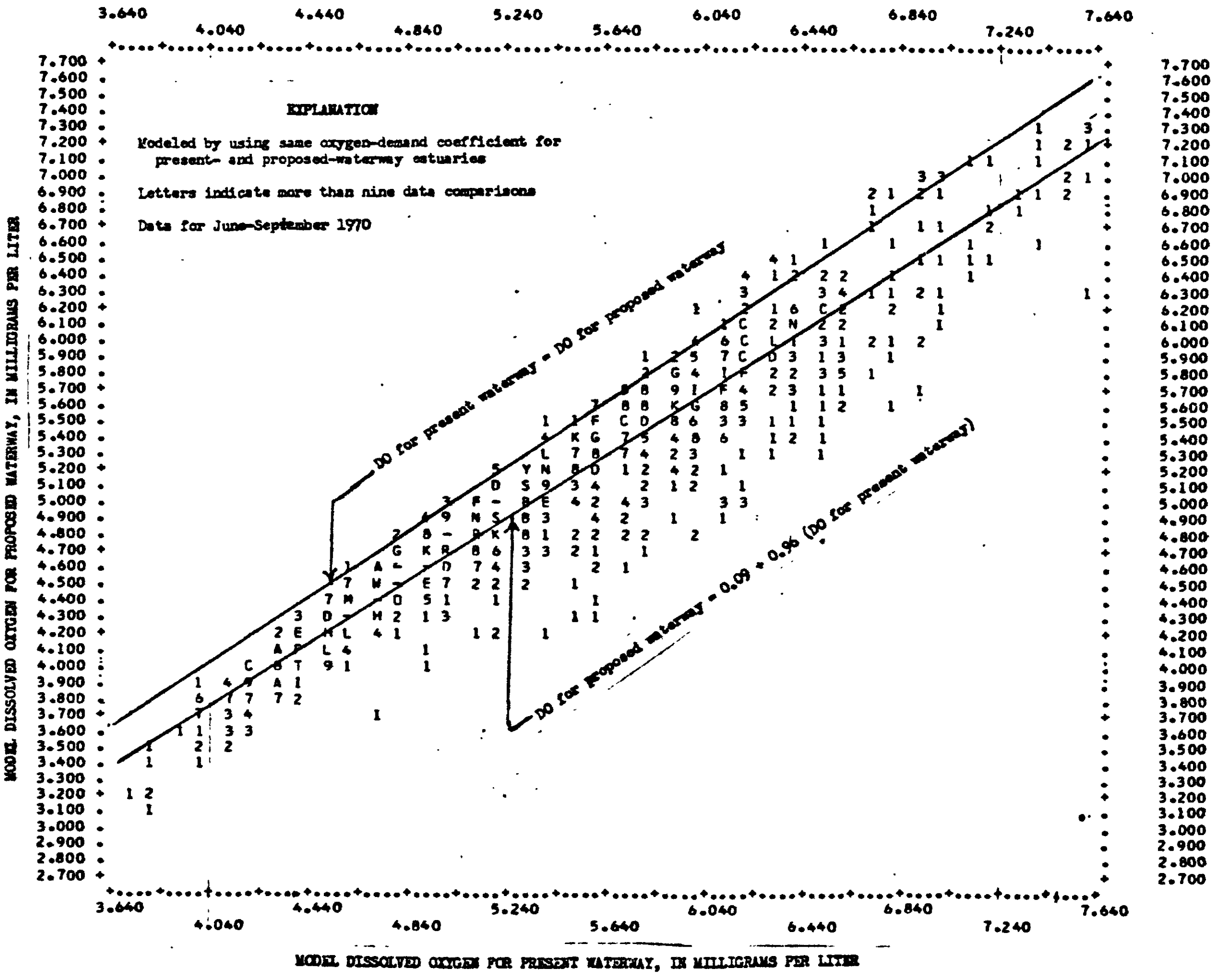


FIGURE 4.--Relation between model dissolved oxygen in salt wedge of present-waterway estuary and proposed-waterway estuary (conservative geometry change) at 16th Avenue South Bridge.

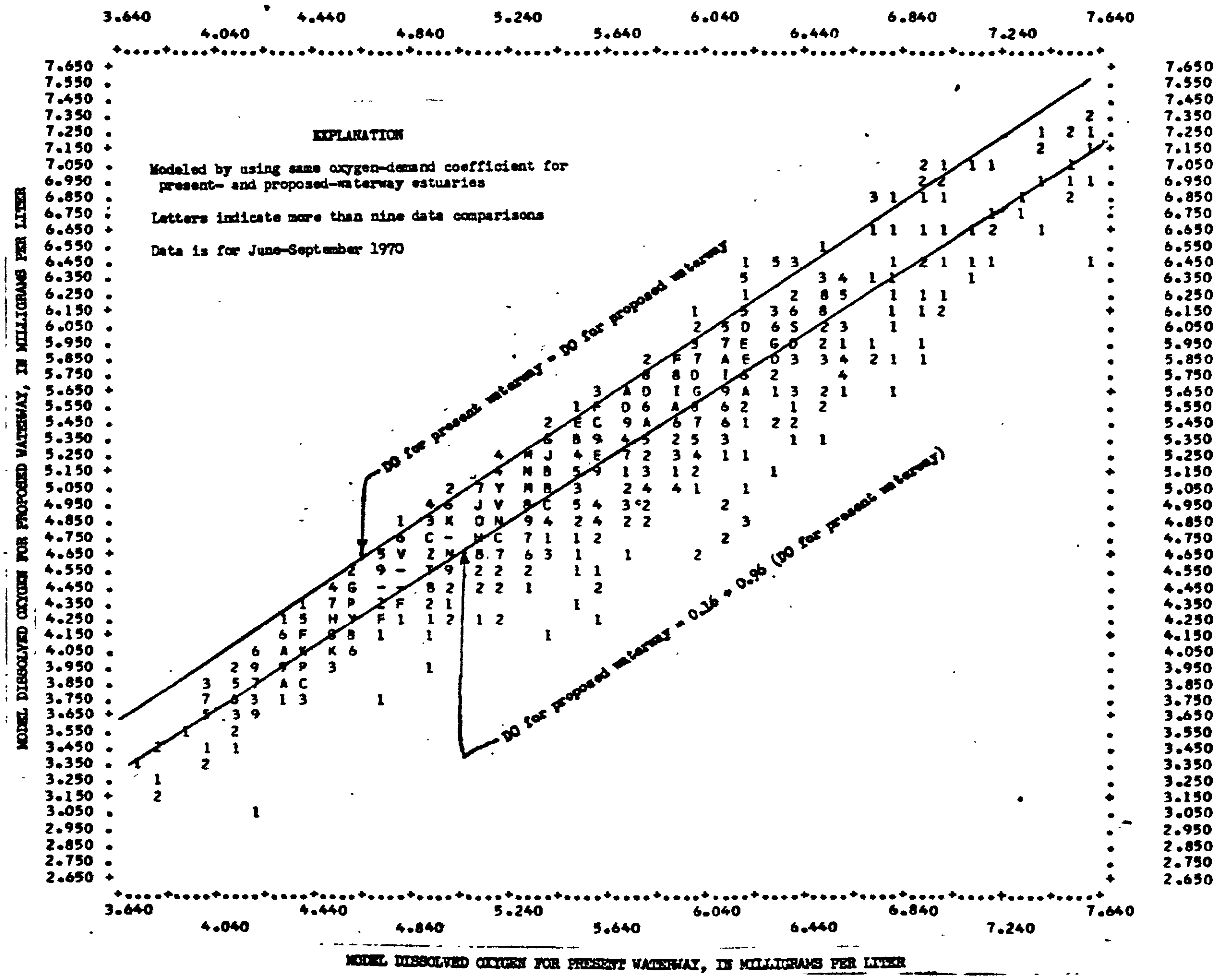


FIGURE 5.--Relation between model dissolved oxygen in salt wedge of present-waterway estuary and proposed-waterway estuary (nonconservative geometry change) at 16th Avenue South Bridge.

Differences in means are significant at the 95-percent confidence level. The regressions shown in figures 4 and 5 provide an evaluation of the overall fit of the DO estimated for the present-waterways estuary with those estimated for the proposed-waterways estuary. Extrapolation to low DO in the wedge by using these regressions indicates that DO in the wedge of the present-waterways estuary at 16th Avenue South Bridge would be 0.1 mg/l and 0.2 mg/l, respectively, when DO had been depleted from the wedge there for an estuary having waterways with conservative and nonconservative geometry.

Relations and regressions between various combinations of monitor and model DO data were tested for statistical significance (at the 95-percent confidence level) by use of variance and covariance analyses. Results indicate that, in the wedge at 16th Avenue South Bridge (1) model DO for the present-waterways estuary may be used as an estimate of DO, (2) estimated DO for the proposed-waterways estuary (conservative geometry) is significantly less than estimated DO for the present-waterways estuary, and (3) estimated DO for the proposed-waterways estuary is significantly less for the nonconservative-geometry change than for the conservative-geometry change.

SUMMARY AND CONCLUSIONS

This study uses a model of the stratified Duwamish River estuary which credibly simulates observed spatial distributions of salinity, indicating that the circulation of salt and fresh water in the estuary also is reasonably well simulated. Modelings of oxygen demand and DO in the salt wedge have been verified by regressions that indicate that model DO significantly agrees (95-percent confidence level) with monitored DO for June-September 1970 (standard error of 0.82 mg/l) and for June-September 1971 (standard error of 0.57 mg/l) at 16th Avenue South Bridge. Using the verified model, the following conclusions have been established:

1. During the low river discharge and tidal stages of August 6-16, 1970, an 8.6-day residence time estimated for water in the salt wedge of the proposed-waterways estuary is 37 percent greater than the 6.3-day residence time estimated by the model for wedge water in the present-waterways estuary.

2. At 16th Avenue South Bridge for June-September 1970, nearly all DO estimates for the proposed-waterways estuary were less than those for the present-waterways estuary; estimated DO averaged 0.4 mg/l lower and some values were as much as 1.4 mg/l lower. DO in the wedge was estimated in the model by using the same value of the oxygen-demand coefficient (oxygen uptake expressed as milligrams per liter per 15 minutes) for both the proposed- and present-waterways estuaries. At 16th Avenue South Bridge, wedge DO estimated for the proposed-waterways estuary was regressed against wedge DO estimated for the present-waterways estuary. Extrapolation of the resulting regression equation to low DO values suggests that when DO is completely depleted from the wedge for the proposed-waterways estuary, there would still be 0.2 mg/l of DO in the wedge for the present-waterways estuary.

REFERENCES

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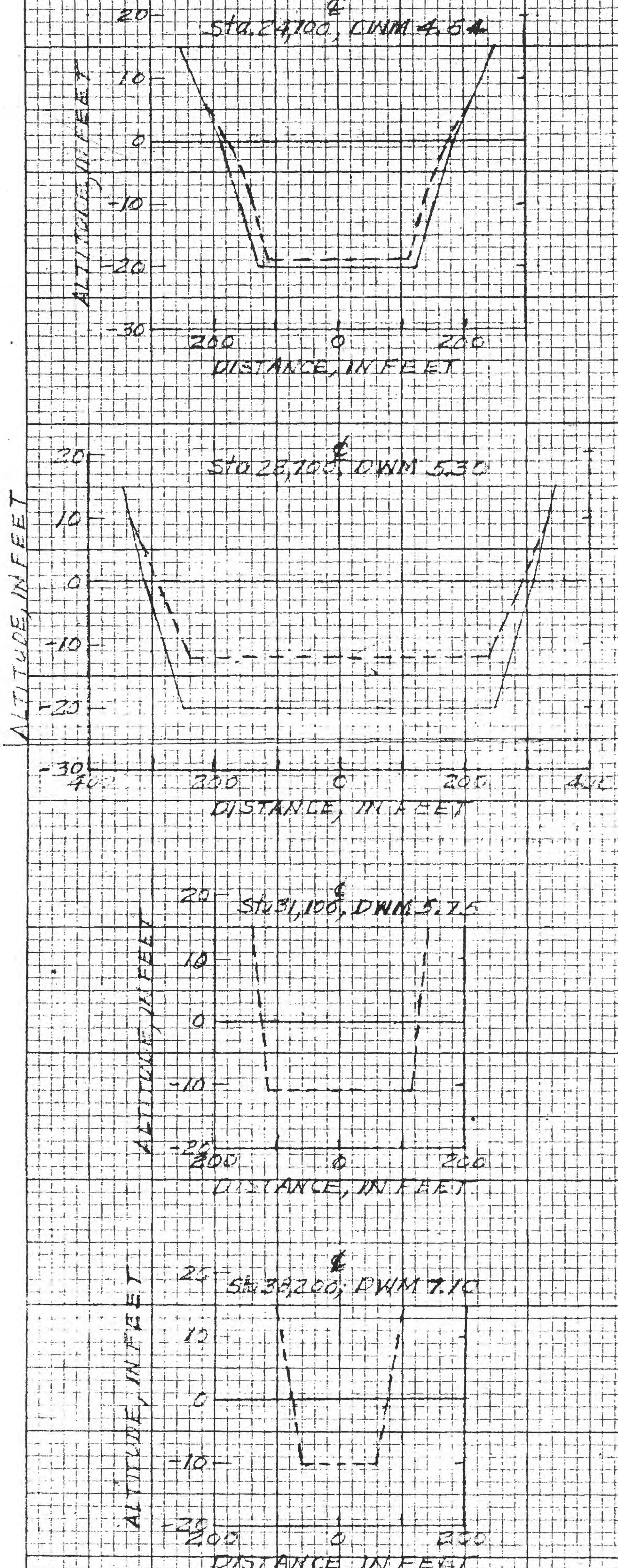

Figure 2.--Cross sections of Duwamish waterway and river used for model study.

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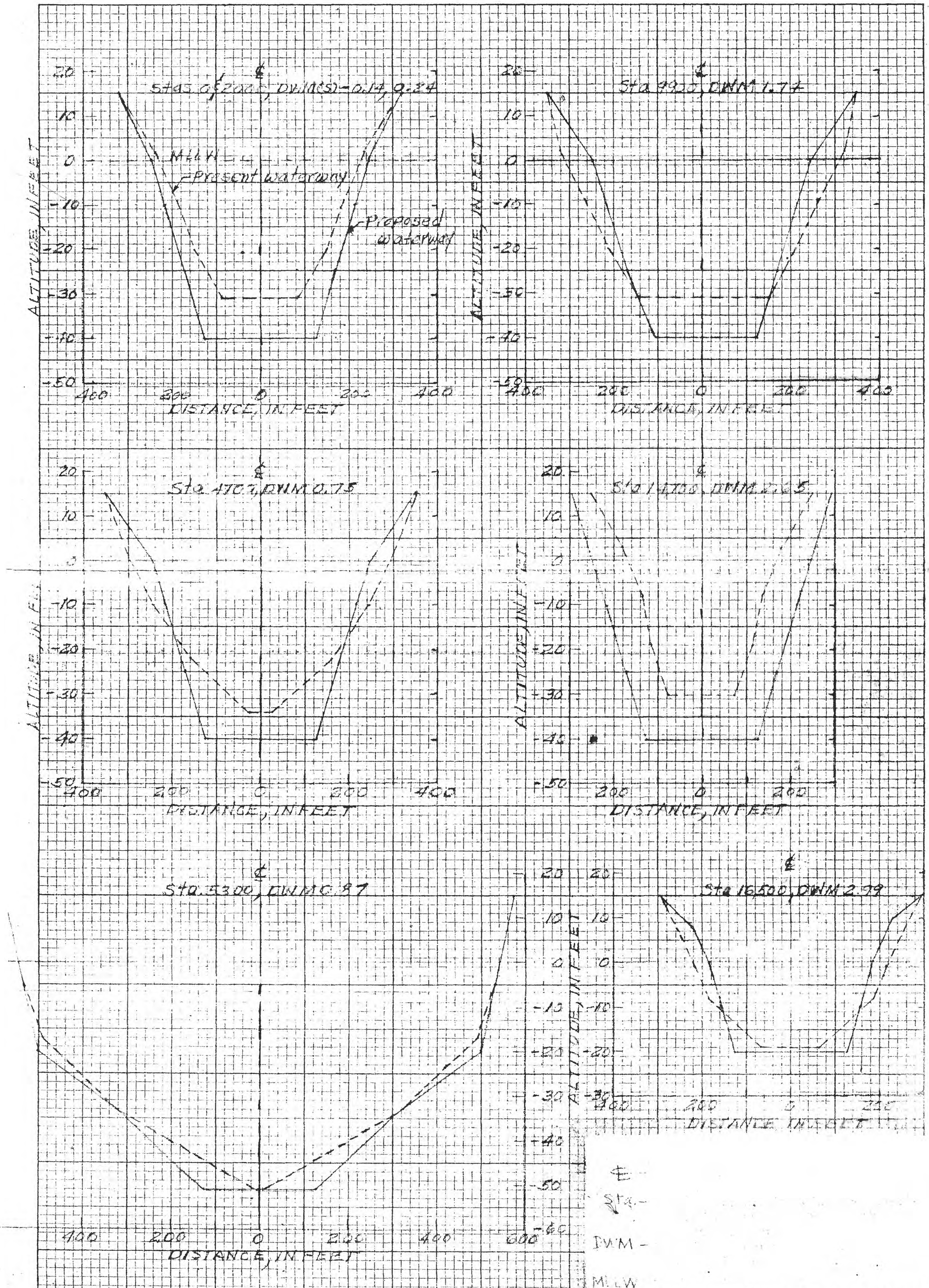

Figure 3 -- Cross sections of Duwamish Waterway and river used for model study.

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