APPENDIX F
SALINITY INTRUSION STUDIES

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SALINITY INTRUSION STUDIES

Introduction

One of the environmental concerns of the proposed improvements to the Columbia River navigation channel is the potential effect that deepening could have on salinity (salt water) patterns in the Columbia River estuary and on the distributions and abundance of estuarine organisms. Because of the density of the salt water, salinity concentrations are higher in deep water, such as the navigation channel, than in adjacent shallow areas. A deeper channel extending upstream from the mouth could, therefore, cause increased salinity intrusion.

Salinity concentrations within the Columbia River estuary vary continuously with time, location, and depth. Bottom concentrations decrease from around 32 parts per thousand (ppt), or nearly equal to seawater, in the entrance to about one ppt in the vicinity of Columbia River mile (CRM) 25 to 30. Surface concentrations are generally 5 to 10 ppt less than the bottom concentrations at any specific location along the navigation channel. Salinity concentrations in the shallow areas of the estuary are similar to those of the adjacent navigation channel surface concentrations.

The extent of salinity intrusion into the Columbia River estuary is determined by tide stages and freshwater discharge. During high tide and low fresh water runoff, salinity levels usually extend farther upstream and have less mixing with freshwater. The low river discharges that occur in the autumn, coupled with high tides produce the greatest upstream salinity intrusion.

Three salinity workshops were held to determine the effects of channel improvement on the salinity in the estuary and the subsequent impacts to estuarine organisms. Agencies participating in the workshops are shown on table 1. The Corps' Waterways Experiment Station (WES) was contracted to run a numerical model that predicted changes in salinity in the estuary. The Corps also contracted with a biological consultant to assist in evaluating the biological impact as a result of the physical change in salinity.

The goal of the workshops was to reach consensus among the participating agencies regarding potential salinity impacts from deepening the Columbia River using existing data and tools. The workshops were held during July 1995, January 1996, and April 1996. The minutes from the three workshops are attached as Exhibits A, B, and C, respectively. A final report, *Columbia River Channel Deepening Report of the Interagency Workgroup on Salinity Intrusion* was prepared by Woodward-Clyde Federal Services (July 1996) to describe the group's activities and findings. This report is attached as Exhibit D.

Table 1 – Agencies and Groups Participating in the Salinity Intrusion Workshops

Agency/Group	Workshop Attended
National Marine Fisheries Service	July 1995, January 1996, April 1996
US Fish and Wildlife Service	July 1995, April 1996
Bonneville Power Administration.	July 1995, January 1996
US Environmental Protection Agency	July 1995, April 1996,
Oregon Department of Fish and Wildlife	July 1995, January 1996, April 1996
Oregon Department of Environmental Quality	July 1995, April 1996
Washington Department of Fish and Wildlife	July 1995, April 1996
Washington Department of Ecology	July 1995
Columbia River Estuary Study Taskforce (CREST)	July 1995, January 1996
Port of Portland	July 1995, January 1996, April 1996
Port of Vancouver	July 1995, April 1996

Hydraulic and Salinity Modeling

The WES conducted the model study to evaluate potential changes in salinity concentrations. Their report, *Columbia River Estuary Salinity Study* (August 1996) describes the modeling effort and results (Exhibit E). It was agreed that a combined 2- and 3-dimensional unsteady flow computer model could be used to evaluate the potential changes in salinity concentrations. Because the potential changes in salinity concentration are more important than the absolute salinity concentrations, it was agreed that the model could be validated to existing data and would provide adequate results for the evaluation.

The model was validated to salinity conditions published by the Columbia River Estuary Study Taskforce (CREST). Low flows of 120,000 and 134,000 cfs were used to evaluate the changes in salinity intrusion. The with- and without-project salinity concentrations along the channel are shown in figure 1. The salinity concentration increases predicted by the model for the 43-foot channel were small. The largest increases were around 1 ppt along the bottom of the navigation channel between CRM 15 to 25 (table 2).

Table 2 – Existing Salinity Ranges and Modeled Increases for Bottom Water Salinity

Site	River Mile	Depth (feet)	Existing Range (ppt)	Modeled Maximum Increase (ppt)	New Maximum (ppt)
Mott Island	CRM 20	20	2.3 – 7.5	0.44	7.94
Rice Island	CRM 21	12	1.4 – 6.4	0.28	6.68
E3	CRM 22	50	1.0 – 4.7	2.45	7.15
Miller Sands	CRM 23	15	0.7 – 3.5	0.26	3.76
Minaker Island	CRM 25	15	0.9 – 2.8	0.18	2.98
Pillar Rock Island	CRM 27	15	0.1 – 2.0	0.17	2.17
Km46	CRM 28	33	0.1 – 1.6	0.85	2.45
Tronson Island	CRM 29	15	0.3 – 1.2	0.08	1.28
E4	CRM 30	50	0.0 – 0.9	0.38	1.28
D9	CRM 33.5	6	0.0 – 0.7	0.05	0.75

Figure 1 – With- and Without-Project Salinity Concentrations

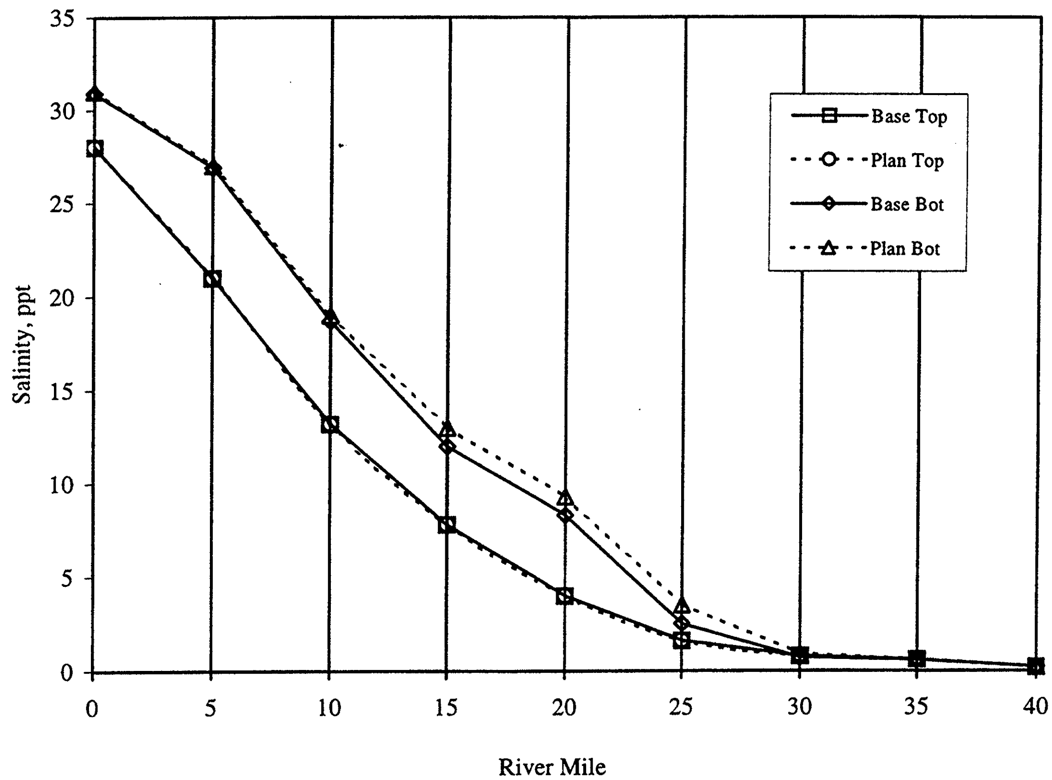

Figure Key:

Base Top – Existing channel conditions, top half of water surface column
Base Bot – Existing channel conditions, bottom half of water surface column
Plan Top – 43-foot Alternative, top half of water surface column
Plan Bot – 43-foot Alternative, bottom half of water surface column

The predicted salinity increases near the surface of the channel and in the shallow areas outside the channel were regularly much less than 1 ppt (table 3).

Table 3 – Existing Salinity Ranges and Modeled Increases in Surface Water Salinity

Site	River Mile	Existing Salinity Range (ppt)	Modeled Maximum Increase (ppt)	New Maximum (ppt)
Mott Island	CRM 20	1.4 – 5.9	0.13	6.03
Rice Island	CRM 21	0.2 – 5.4	0.12	5.52
Miller Sands	CRM 23	0.5 – 3.3	0.08	3.38
Pillar Rock Island	CRM 27	0.2 – 2.1	0.07	2.17
Tronson Island	CRM 29	0.2 – 1.2	0.04	1.24

Conceptual Framework for Biological Impact Analysis

Workshop participants agreed to the following issues regarding a conceptual framework for analysis of potential biological impacts from salinity changes. The approach taken was termed a geographic area/species scenario approach. It was decided that sedentary organisms, such as benthic macroinvertebrates and vascular aquatic plants, would be more susceptible to short-term salinity changes than more mobile species such as fish. The criterion for measuring impacts to species would be a comparison of the maximum expected salinity modeled to their known salinity tolerances.

It was also agreed that the conceptual framework would include a species overlay on specific geographical areas. In addition, scenarios would be generated based on predicted changes in salinity and the flow used in the modeling effort for species and regions. The process was described as follows:

- Select a geographic area of interest/concern.
- Determine the distribution of species in that area.
- Assume that flow conditions are "low flow," for example, the flow used in the modeling effort.
- Determine the predicted salinity changes occurring in the region with the flow using the model results.
- Develop a scenario for salinity effects for the region to determine what will happen if the salinity changes by a certain percentage.

Investigation of Impacts to Benthic Macroinvertebrates

Potential impacts to benthic organisms were evaluated at 10 sites incorporating three habitat types – intertidal, shallow subtidal, and channel bottom. These sites were located within the Tidal-Fluvial zone of the estuary, which is the region between CRM 20 to 30 that is characterized by relatively uniform, low salinity conditions. Small increases in salinity in the Tidal-Fluvial zone are considered more likely to have biological effects than equivalent changes in the Plume and Ocean zone (mouth to about CRM 9) or Estuarine Mixing zone (about CRM 9 to 20) where daily salinity fluxes are relatively large.

Investigation of Impacts to Vascular Aquatic Plants

Potential impacts to vascular aquatic plants were investigated at five sites within the Tidal-Fluvial zone of the estuary. Eleven species of aquatic plants were selected for analysis of salinity tolerances and were chosen based on the availability of information on vascular aquatic plant distributions. Nine species are common and dominant in assemblages throughout the Tidal-Fluvial zone, and two occur infrequently.

Conclusions

Workshop participants reached consensus concerning study results and impacts to benthic macro-invertebrates and vascular aquatic plants, as discussed below.

Impacts to Benthic Macroinvertebrates

- Small increases in bottom water salinity of less than 0.5 ppt due to planned channel deepening would be predicted at intertidal and shallow subtidal sites.
- Short-term increases in bottom water salinity of up to 2.45 ppt due to planned channel deepening would be predicted at channel sites.
- Changes of this magnitude could permit short, up-channel range extensions by salinity-dependent species such as *Eohaustorius estuarius* and *Corophium brevis.*
- *Corophium salmonis*, a microscopic amphipod important as a food item for salmonids, would likely remain the numerically dominant species at most sites, including channels.
- No impact of fish food resources would be expected.

Impacts to Vascular Aquatic Plants

- No significant effect on species examined in the present analysis is expected to result from a 0.5 ppt maximum increase in salinity in the Columbia River estuary.
- Of the species selected for analysis, wapato (*Sagittaria latifola)*, water parsnip (*Sium suave)*, skunk cabbage (*Lysichitum americanum)*, and rush (*Juncus oxymerus)* reflect the species with the high sensitivity to changes in salinity.
- It is likely that factors other than salinity are affecting plant species distribution in the Columbia River estuary.
- Although species of *Sium sauve*, *Sagittaria latifolia*, and *Juncus oxymerus* exhibit a higher degree of sensitivity relative to other species included in this analysis, these species often occur in habitats typified by salinities that exceed the individual species salinity tolerance and therefore, are likely distributed along another gradient (elevation, substrate).

Overall, workshop participants reached consensus and accepted the following statement:

> *No significant biological impact would result from salinity changes predicted for the proposed channel deepening.*

EXHIBIT A

COLUMBIA RIVER CHANNEL DEEPENING

SALINITY INTRUSION
WORKSHOP #1 MINUTES

JULY 13-14, 1995

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PORTLAND DISTRICT

Introduction

On July 13-14, 1995 the Army Corps of Engineers, Portland District Office (COE) convened a workshop series regarding potential salinity effects of the proposed channel deepening of the Columbia River. The 2-day workshop was held at the Red Lion Hotel, Vancouver, Washington. This was the first of at least three planned salinity workshops for the Columbia River Channel Deepening Project. The tentative plan is to have follow-up workshops in January 1996 and in the Spring of 1996. In addition to the Corps of Engineers, the following nine federal and state agencies attended the first 2-day workshop -- Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife, U.S. Fish and Wildlife Service, National Marine Fisheries Service of the National Oceanic & Atmospheric Administration, Washington Department of Ecology, Bonneville Power Administration, Oregon Department of Environmental Quality, U.S. Environmental Protection Agency, and CREST. Also in attendance were representatives of the Ports of Portland and Vancouver. With the exception of CREST, the Washington Department of Fish and Wildlife, and the Washington Department of Ecology, all participants attended both days of the workshop. A neutral facilitator, Valerie Ann Lee of Environment International, led the workshop, and notes of the proceedings were taken by Margaret Merrens, also from Environment International. This document briefly outlines the major points discussed at the workshop and outlines the points of unanimous agreement among the participants.

Day 1: Morning Session.

9:00 - 9:30 Workshop Introduction and Status Report.

Karl Eriksen of the U.S. Army Corps of Engineers (COE) opened the workshop with a general introduction of the workshop focus and goals of the workshop process. In his opening statement, Mr. Eriksen, COE, briefly described proposed channel deepening improvement options for the existing 40 x 600 foot lower Columbia River navigation channel. The scoping letter, which includes the alternatives being considered, was distributed to all participants. Mr. Eriksen explained that the COE would like the resource agencies to address the potential changes in salinity patterns that might result from channel improvements and determine what effect any such changes might have on biological communities in the Columbia River estuary. Mr. Eriksen explained that the goal of Workshop #1, as contemplated by the Corps, was to have the resource agencies identify specific concerns they have with regard to salinity changes in the estuary, and to identify specific geographic areas of concern. He also explained that representatives from the U.S. Army Corps of Engineers Waterways Experiment Station (WES) at the workshop would present a hydraulic model that will be used to predict potential salinity changes that could result from the channel deepening project. He noted that later workshops will address the potential biological impacts of salinity changes estimated with salinity model runs.

9:30 - 12:30 Discussion of Ground Rules for the Process.

Valerie Lee, the group facilitator, outlined the role of a neutral facilitator, and led the agencies in a discussion of the proposed ground rules for the workshop process and the proposed overarching goal of the workshop series. Of the ten proposed ground rules, the agencies present unanimously agreed to seven without revision. The agencies rejected one proposed rule and adopted a different rule by unanimous agreement of the agencies present. The group did not reach unanimous agreement on two other ground rules and no substitutes were adopted. The agencies accepted by unanimous agreement the proposed overarching goal for the workshop series.

Set forth below are the overarching goal and ground rules for the workshop series. Notes are provided outlining the discussion concerning the proposed rule for which a substitute was adopted and detailing common understandings reached with respect to the interpretation of certain ground rules.

Overarching Goal for the Process:

The overarching goal of the Workshop Series is to reach a consensus among participant agencies regarding potential salinity impacts from deepening of the Columbia River.

Ground Rules for the Workshop Process:

(1) Participants will treat each other with respect and not interrupt during presentations.

(2) Everyone should be given a fair opportunity to share their views with the participants.

(3) The facilitator will ensure that ground rules are followed.

(4) Because consistency is important in the process, each participating entity will make its best efforts to ensure that at least one person representing the agency is present at all workshop meetings. (Note: Emphasis was placed on "best efforts," since budgetary constraints and scheduling conflicts may make it impossible for an agency to attend particular workshops.)

(5) Agencies with more than one representative at the workshops will designate one person to speak for the agency. (Note: All agencies are of the understanding that anyone representing the agency may participate in workshop discussions, but one representative will be designated to vote for the agency.)

(6) Agency representatives agree to keep decision-makers within their agencies apprised of the developments in the workshops.

(7) Minutes will be recorded at each workshop and will be reviewed by the participants and adopted (with or without revisions) at the start of each consecutive workshop. (Note: Since it is a ground rule to keep agency decision makers apprised of the developments in the workshops, all efforts will be made to ensure that the minutes are as detailed as possible.)

(8) The process will be open to input of technical information on salinity and the impacts of salinity intrusion.

(Note: In adopting this rule by unanimous consent, the agencies explicitly rejected the following proposed rule: "The meetings will be closed to all but the participants and those invited to the meetings by consensus." In the discussion concerning the proposed rule, several agencies expressed concern about meetings that are not open to interested parties, even in the absence of consensus, and indicated that their typical agency practice was to allow attendance at meetings by any interested parties. Some participants wanted to be sure that they were aware of any issues related to salinity about which interested parties are concerned. Other participants expressed an interest in having the tribes invited to participate in the workshops. The COE indicated that the tribes have already received notice of the workshops (via the scoping letter), and that there has been no intent or attempt to exclude any parties from the process, but participation is limited to those with salinity concerns. Various agency representatives drew a distinction between "participation" and attendance." Participation, they believed, connoted decision-making authority, whereas attendance did not carry such a meaning. Following a full discussion of these issues, the agencies adopted the above rule by unanimous agreement and shared a common understanding that meetings are to be to kept open to all who have technical input on salinity issues, but "participation" in the process (i.e. voting and decision-making) will remain restricted to the resource agencies.)

The group was unable to agree upon an acceptable version of the following proposed rule:

- Consensus shall be reached by unanimous agreement of all agencies present at a workshop.

And the following proposed rule was never addressed:

- Ground rules may be modified by unanimous consent of the participants.

Day 1: Afternoon Session.

1:30 - 3:00 Explanation of Salinity Model.

The following summary describes the general substantive issues raised by Dr. McAdory in his overview of the WES salinity model. In addition to this summary, the participants may wish to review the overhead charts that were used by Dr. McAdory throughout his presentation. It was agreed upon at the meeting that the COE would make these charts available, upon request, to the participants.

<u>WES Model Description: Dr. Rob McAdory</u>.

The WES representative, Dr. McAdory, began the afternoon with a basic introduction to the WES numerical salinity model. He described how the model was developed, its purpose, and its components. Several sample outputs were displayed on an overhead projector to exemplify various types of modeling outputs that could be generated for the agencies' use for the lower Columbia River. He also described the basic assumptions of the sample model, i.e., ocean salinity was set at 35 ppt, inflow at the Bonneville Dam was 134,000 cfs, no winds, and no islands had been incorporated into the particular schematization of the river used to create the output. He explained that if tides and flows are adjusted the results may change, and emphasized that the model may be as detailed or as simplified as the group decides.

Dr. McAdory explained that the model is a schematization which incorporates all of the river, from its mouth to the Bonneville Dam. Agencies can input details they find important (such as islands or split channels) in this schematization. He indicated that the model has the capacity to account for salinities at different depths (e.g., surface, bottom salinities, or something in between), and that WES can supply the velocities of the channel if the agencies desire.

Dr. McAdory summarized the process by indicating that WES would first design a model based on the inputs of the resource agencies. Then WES would validate the model to see if the model behaves properly. For the purpose of this study, he indicated that WES was not seeking to exactly replicate river behavior, but only to get in the ballpark with the results of the prototype. After validating the model, two tests would be run at different depths: (1) using the existing channel conditions, and (2) using the deepened channel conditions. As a final step, the two outputs would be interpreted by overlaying them (see sample outputs) to identify changes in salinity.

Comments Regarding Specific Overhead Charts:

Referring to several gridded overheads Dr. McAdory explained how the model makes calculations at discreet points. These calculation points are referred to as nodes.

Referring to three different bathymetric overheads, Dr. McAdory explained that the depths are charted in 16 foot increments. He indicated that the detail of the depths (resolution of the model) is somewhat dependent upon how many calculation nodes there are. The greater the number of nodes for an area, the greater the resolution of the model. It is the responsibility of the agencies to determine whether greater detail is necessary. In response to a question regarding greater resolution in the channels (as opposed to the bays) in the sample overheads, Dr. McAdory indicated that this was based in part on the fact that salt tends to intrude into deeper regions, and because this is where the actual depth changes will take place.

In response to a question about the inflow value, Dr. McAdory indicated that the value is a sum total of inflow at the Bonneville Dam and the Willamette River. WES would be adding the inflow at one point at Bonneville.

Referring to a river discharge chart, Dr. McAdory pointed out WES's belief that low flow periods (typically in the fall) are important times to make measurements for salinity changes in the river. In addition, during neap tides there is less mixing in the river, and therefore more intrusion. He added that it is the ultimate decision of the resource agencies to select the flow and tide conditions though.

3:30 - 5:00 Questions / Answers Regarding Salinity Model.

Several questions arose after the WES presentation, with regard to the salinity modeling techniques.

Model "Ground Truthing" or Verification:

The participants questioned the modelers to learn to what extent the model has been "ground truthed" to determine if the salinity modeling results are accurate. Dr. McAdory of WES fielded these questions and explained that modelers might call this process "model verification" rather than "ground truthing." He explained that a full detailed "verification" is time intensive and requires collection of an enormous amount of field data. He also explained that it was the intent of the COE to conduct a less detailed "verification" of the model using preexisting data rather than detailed data collected specifically for the purpose of a detailed model verification.

Expected Output of the Model:

The participants then asked about the expected outputs of the model. They inquired as to whether the modelers had made any presumptions about specific locations in the river where salt water may concentrate if the channel is deepened (e.g., in the bays or in the channel). Dr. McAdory explained that WES had made no presumptions yet, but other modeling on the Columbia River has shown that the salt generally concentrates in the deeper areas. In response to a question about the sample velocity chart, Dr. McAdory explained that the tighter arrows along the channel are indicative of the rapidly changing bed geometry.

Sensitivity of the Model:

One participant inquired about the model's capacity to accurately predict salinity changes in the sensitive areas around islands that were not included in the schematization of the river currently found in the model, specifically in Cathlamet Bay. Dr. McAdory replied that the model would give salinity output values for the bay area, with or without the islands. Inclusion of the islands in the modeling regime might not change the results, but if the agency participants view Cathlamet Bay as an area of importance, then WES can study it with greater modeling detail by inserting islands in their schematization.

Overdraft Issue and Modeling Depths:

Participants completed the afternoon session with a discussion about modeling depths. The agencies expressed concern over using river depths of 40 and 43 feet for the two model runs. Participants pointed to the 5 foot additional maintenance and overdraft that currently exists with the 40 foot channel, and requested that a model be run using a 48 foot channel depth (43 feet plus 5 foot overdraft). The agencies expressed an interest in having a model reflect a worst case channel depth.

Mr. Eriksen, COE, responded by indicating that this was a valid issue. He agreed that the controlling depth was currently set at 40 feet, but in reality it was greater than this. He indicated that one of the two models may need to be run at variable depths in order to gain more confidence in the results. He said that he had not made a final decision on the bathymetric assumptions for the two runs.

The participant agencies agreed unanimously to have Mr. Eriksen and Dr. McAdory review the bathymetric charts to determine a worst case modeling regime, and to present, the following morning, their understanding of what the worst case depth scenario would be. Following the agreement the meeting was adjourned for the day.

Day 2: Morning Session.

9:00 - 9:30 Review Day 1 Issues and Agenda for Day 2.

The facilitator began the session by summarizing the overarching goal and ground rules that were accepted by workshop participants on the previous day. Agency participants from the previous day's meeting were present, with the exception of Peter Britz from CREST and Ken Mohoric from the WA Department of Fish and Wildlife. Additional participants included Bonnie Shorin from the WA Department of Ecology.

9:30 - 11:00 Develop a Salinity Modeling Study for Presentation at Workshop 2.

Selecting Two Depths for the Modeling Runs:

Having agreed, on the previous afternoon, to investigate the most currently recorded depths for the channel, Mr. Eriksen, COE, opened the day's discussion with a presentation of 1992 bathymetric data. The 1992 bathymetric chart indicates that the channel is currently maintained at 45 feet deep, but several areas exist where the channel is naturally deeper than 45 feet.

After reviewing this data, Dr. McAdory made the suggestion that two modeling runs be conducted: (1) using the variable river bottom depths of 1992, whatever they may be, and (2) a comparison-run at the predicted dredging depth of 48 feet (which accounts for overdraft and maintenance). Agency participants unanimously agreed to use these depths for the preliminary modeling runs, with the understanding that additional modeling may be required after the results are reviewed.

Ocean Salinity:

On the previous day, Dr. McAdory presented an overhead of the model boundary conditions. Ocean salinity and fresh water inflow were discussed. Ocean salinity was assumed to be at 35 ppt (parts per thousand), and fresh water at 0 ppt.

A question was raised concerning the WES assumption that ocean salinity at the mouth of the Columbia River is currently 35 ppt. Actual data for Oregon waters may indicate ocean salinities that are lower than 35 ppt. (A reference was made to: Pruter, AT and DL Alverson. The Columbia River Estuary & Adjacent Ocean Water. University of Washington Press, Seattle, 1972.)

Dr. McAdory responded that 35 ppt was WES's conservative (probably high) estimate for the ocean salinity at the mouth of the Columbia River. A lower salinity value may ultimately be used, once WES conducts the model runs and compares the runs to historical data. Whether the value is 35 ppt or 34 ppt, however, Dr. McAdory explained that these are input values for the ocean boundary, which is of less significance than the ultimate estuary salinity readings. The ocean "boundary condition" salinity may be used to tune the model to ensure the model properly predicts salinity in the estuary. The agency participants unanimously agree to use 35 ppt for ocean salinity at the mouth of the Columbia River and to allow the modeler to make reasonable modifications to tune the model.

Inflow (at the Bonneville Dam):

Another assumed value of the WES model would set the upstream inflow at the Bonneville Dam at 134,000 cfs (cubic feet per second). Dr. McAdory explained that the 134,000 inflow value was obtained by estimating a long-term flow average for a period between 1943 - 1957. It is meant to be indicative of "typical" flow over many years. Since flow conditions may go as low as 85,000 cfs, some agency participants questioned how the model would account for these low flow periods. Dr. McAdory explained that any level of flow data may be used in the modeling, but a more realistic picture might result if "typical" flow data is used.

A discussion ensued among agency participants as to whether the model should assume "typical" flow data or "extreme" flow data (i.e., extreme minimum flow). Due to an inability to predict what stream flows might look like in the future, some participants had difficulty accepting average flow data as representative of "typical" flow. Some participants expressed an interest in focusing on extreme low flow data, since salt intrusion would typically be at its worst during these periods. Others thought that it might be helpful to use flow data from critical salmon spawning times of the year (spring to fall), since these flows were likely to have an impact on the salmon. At least one participant was of the opinion that the use of extreme or worst-case data was limiting and that the NEPA/EIS process may require obtaining modeling results from the fullest range of flow variables (high and low flow data).

Ultimately, the group unanimously agreed to use the first two modeling runs as initial runs. They agreed that additional modeling may be required later, if the results from the first two runs show any significant changes in salinity. Dr. McAdory offered to run the models using flow that he would select and defend to them in the second workshop. All the participants unanimously agreed to let the WES modelers use their professional judgment to choose the flow values, and to present the reasons for their decisions at the next workshop.

Sensitivity of the Model:

Participants expressed a need for testing the sensitivity of the model. They agreed to wait until workshop #2, however, when they would have a chance to review the results of the first two model runs. It was agreed that the first two runs would help to define further needs and other workshops that may be necessary.

Scope of the Model:

One participant inquired as to whether the COE and WES would be focusing the modeling runs on specific areas within the channel. Mr. Eriksen replied that the COE would focus on the areas that the resource agencies identify as warranting concern, whether this be in the channel or in the bays. Dr. McAdory added that the point was not to model the channel alone, even though this is where the greatest bathymetric changes will occur, but to model the whole system.

Tides:

With respect to tides, Dr. McAdory explained that WES intended to run enough modeling data to include one full neap / spring sequence (approximately 14 days). The assumption being that this would provide a model of a full variety of tidal ranges. The resource agencies unanimously agreed that this was an acceptable input for the first two modeling runs.

Other Modeling Issues:

Before concluding, Dr. McAdory expressed his desire to receive further information from the resource agencies on critical concerns and interests they might have in the estuary. He was interested in knowing what could be done to enhance the model in this regard (i.e. geographic areas of concern, features, such as islands, specific depths that may be of critical value, or split channels). The participants agreed to address these issues, and Mr. Eriksen agreed to convey any concerns to WES.

Day 2: Afternoon Session.

11:30 - 1:30 Preliminary Identification of Biological Concerns and Existing Data.

Modeling Concerns for WES:

After a short break, the group returned to identify specific geographic areas and features of concern that would be used to enhance the hydrologic model. Participants agreed that both Youngs and Grays Bays were of critical importance, since these are shallow areas and part of a productive estuary. In addition, they agreed that the addition of islands was important in order to create a more realistic model. Instead of a straight-line, single channel, no island modeling approach to RM 33-45, they would like to see a river flow split to create two channels by adding Puget and Whites Islands as a unit, Tenasilahe and Welch Islands together, Horseshoe, Brush, and Marsh Islands as a unit, and Russian, Seal, and Karlson Islands together.

Biological Concerns:

As a final goal of the workshop, participants went on to identify specific biological concerns and literature sources that would focus the scope of the biological consultant's (Dr. Krasnow) research. Participants engaged in a broad ranging discussion of biological concerns. Some of the general concerns included the following issues:

- Habitat: Where?
  What?
- Species: Which ones?
  Life cycle Stages?
  Distribution and Interaction?
  Place in the Food Web?
- Effects: Chronic?
  Acute?
  Behavioral Responses?
- Priorities for Above?

In an attempt to focus the work of Dr. Krasnow, the participants discussed ways to prioritize her investigations. Participants suggested that Dr. Krasnow's preliminary biological research be focused on those species that are most affected by changes in salinity. They suggested that they would like to see an analysis of all indicator and keystone species, including those species that have been listed as threatened or endangered (as well as those likely to be listed) under the Endangered Species Act. A few participants made the suggestion that Dr. Krasnow focus her research on non-mobile species, based on the theory that salinity changes would have a greater impact on non-mobile species. The participants agreed that corophium, calanoid copepods, and Dungeness crab should be included in the preliminary research, as well as vegetative species (white sturgeon and eel grass communities) and the food sources for the indicator species. One agency participant also expressed concern that an analysis of salinity effects must be sure to take into account uncertainties. It was suggested that one way to account for uncertainty in salinity tolerance data for certain species, is to investigate the existing habitats of these species to obtain a known salinity range that these species can tolerate.

Dr. Krasnow then proposed that she would take these suggestions into consideration, and would begin her research by creating a matrix of indicator species for salinity effects (eg. ESA or candidate ESA species, special habitats, etc.). She would then circulate this list and information to the various agencies via mail, and request their comments and contributions prior to the next workshop. The participants unanimously agreed to provide feedback to Dr. Krasnow.

EXHIBIT B

COLUMBIA RIVER CHANNEL DEEPENING

SALINITY INTRUSION WORKSHOP #2 MINUTES

JANUARY 24-25, 1996

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PORTLAND DISTRICT

COLUMBIA RIVER CHANNEL DEEPENING
SALINITY INTRUSION WORKSHOP 2
January 24 and 25, 1996

Introduction

On January 24-25, 1996 the Army Corps of Engineers, Portland District Office (COE) convened the second session in the series regarding the potential salinity effects of proposed channel deepening of the Columbia River. This workshop follows one held in July 1995. The tentative plan is to have a third and final workshop in early March 1996. The 2-day workshop was held at the Red Lion Inn at the Quay, Vancouver, Washington. In addition to the Corps of Engineers, four federal and state agencies were in attendance, as were representatives from the Port of Portland. The following agency representatives and associated parties participated in the second workshop:

Karl Eriksen	COE	Days 1, 2
Kim Larson	COE	Days 1, 2
Steve Stevens	COE	Day 1
Ben Meyer	NOAA / National Marine Fisheries Service	Days 1, 2
Kathi Larson	NOAA / National Marine Fisheries Service	Days 1, 2
Tom Vogel	Bonneville Power Administration (BPA)	Days 1, 2
Don Bennett	OR Dept Fish and Wildlife (ODFW)	Days 1, 2
Peter Britz	Columbia River Estuary Study Taskforce (CREST)	Days 1, 2
Bob Friedenwald	Port of Portland	Day 1
Danil Hancock	Hartman Associates (biologist for Port)	Days 1, 2
Lynne Krasnow	Woodward-Clyde (biologist)	Days 1, 2
Rob McAdory	WES - COE (salinity modeler)	Days 1, 2
Charlie Berger	WES - COE (salinity modeler)	Days 1, 2
Valerie Ann Lee	Environment International (facilitator)	Days 1, 2
Margaret Merrens	Environment International (notetaker)	Days 1, 2

The following participants were present at Workshop 1, but were unable to attend Workshop 2:

John Malek	EPA, Region X
Ken Mohoric	WA Dept of Fish and Wildlife
Bonnie Shorin	WA Dept of Ecology
Bill Young	OR Dept of Quality
Kirk Beiningen	OR Dept of Fish and Wildlife (Don Bennett attended in his place)

Day 1

9:00-9:30 Adopt Minutes from Workshop 1, Goals for Workshop 2

The minutes from Workshop 1 were discussed and adopted with only two minor changes. The discussion began with Danil Hancock observing that, as reflected on page 3 of the original minutes, in Workshop 1 the group did not come to closure on two proposed ground rules and, as a result, they were never adopted. The proposed rules read as follows:

- Consensus shall be reached by unanimous agreement of all agencies present at a workshop.
- Ground rules may be modified by unanimous consent of the participants.

An interchange among participants followed regarding whether some form of these proposed rules should be adopted. In this discussion, Corps of Engineers representatives emphasized that the workshops are separate from the EIS process. To the extent that formal agreement of the agencies was reached, Corps of Engineers anticipated that this agreement would occur as a part of the EIS review. They noted that the workshops provide an opportunity for the resource agencies to participate in the pre-EIS impact review and to concur on whether impacts due to increased salinity might occur. Following this discussion the Workshop 2 group agreed to adopt the following as a statement of their ground rule:

- Agreements are based on the opinions of those present but do not necessarily reflect the "agency" commitment on the issue.

This becomes ground rule (9). In adopting this ground rule the participants reemphasized the need to adhere to ground rule (6), as agreed upon in Workshop 1, i.e., to keep the decision makers within their agencies apprised of the developments in the workshops.

A brief discussion ensued regarding the proposed ground rule governing amendments to the minutes. This second ground rule was adopted as is, without debate, and becomes ground rule (10).

9:30-11:00 WES Presentation:
Results of Salinity Model Runs on the Columbia River

Rob McAdory began his presentation by giving a brief overview of the Columbia River Numerical model. Each of the participants received a packet of draft copies of the overhead charts and tables used in his presentation. In addition to this summary, the participants may wish to review their packet of charts and tables. For the purpose of these minutes, the pages in the packet have been numbered after the title page from 1- 65; the charts will be referenced by page number and title.

The WES team returned to Workshop 2 to present the results of the numerical study, the conditions of which were agreed upon by the resource agencies in Workshop 1.

<u>Comparison of Existing and Plan Salinities - Results Plotted on Graphs</u>
To begin, Rob presented two graphs comparing existing and plan salinities for the ship channel by river mile (RM) (pp. 2-3). Each point on the graph represented for a river mile, the average salinity values of all salinity values generated by the model over a 1200 hr period (2 months of tides) at that mile. Surface and bottom salinity values are presented. Referring to the graphs, Rob noted that the <u>surface</u> salinity values for existing and planned channels are virtually identical, with little or no measurable change. He noted that there is a small change between <u>bottom</u> salinity values for the existing and plan model runs. Between RM 15 and 20 the difference between bottom salinity values for planned and existing channels are at their greatest. The maximum difference represents about a 1.35 parts per thousand (ppt) change in salinity. Given the fact that surface salinity values were close to identical, he said he would focus on some model results for the bottom of the river in his presentation.

<u>Existing versus Plan Channel - Isohaline Results For the Bottom</u>
Rob explained a map of isohalines. The map, through a display of isohalines for the plan (heavy lines) and existing (light lines) cases, depicts salinity changes along the bottom of the river as predicted by the model. (See p.4). An isohaline is a line indicating points of equal salinity. In his viewgraph, Rob noted the salinity for each isohaline by handwritten numbers along the edge of the river.

Rob noted that the smallest incremental isohaline value used for this map/viewgraph was 0.5 ppt. Rob emphasized that from the map it is clear that salinity changes on the bottom are on average 1 ppt or less, and at a maximum are only about 1.35 ppt. The greatest difference is in the area of Tongue Point where a shoal must be cut. Since the existing shoal depth of 41 feet does not include overdraft (the plan depth of 48 feet includes overdraft), the salinity change is slightly exaggerated here. Regardless of this overdraft issue, the compared differences in salinity in Cathlamet Bay are much smaller.

Overview of the Modeling Effort

WES ran the model for two different inflow values, 134,000 and 120,000 cubic feet per second (cfs). A comparison of each run gave slightly higher average salinities during the lower flow period, but the actual difference between existing and plan salinities was roughly the same - about 1.35 ppt maximum.

Rob explained how he conducted the modeling effort. A grid was established with various measurement nodes and elements, boundary conditions were established with the help of the resource agencies in Workshop 1, and a code was used to calculate equations of motion that are the heart of the model (pp. 5-13). Boundary conditions included tides, ocean salinity, and fresh water inflow. Rob also noted that, as requested by the agencies, he included a schematization of the islands in his model. In addition, in the model he mathematically took into account "material types," such as marsh-like areas, channels, and open areas (pp. 10-14). The period over which the model was run included several neap and spring tide episodes (p. 11). Following the suggestion of resource agencies, an ocean salinity of 33 ppt was used, and WES selected an inflow rate at the Bonneville Dam of 134,000 cfs (p. 12). WES, at its own discretion opted to run a second model at 120,000 cfs as a means of comparing how flow might affect salinity.

Rob pointed out again that the model was designed to include different "material types". It incorporates assumptions regarding the amount of friction associated with various types of material/depths over which the water flows (p. 13). For instance, the shallows between Astoria and Gray's Bay have a higher friction value incorporated into the model then does the channel. The model also incorporates the complex system of water conduits, islands, and marshy areas of Cathlamet Bay.

Validation of the Model

The model was validated to determine if the results were "in the ballpark" of how one might expect the river to behave with changing depth conditions (p. 15). WES's conclusion was yes, the model gave an accurate depiction of the river system. Validation consisted of comparing the model's outputs for tide range, qualitative velocity and salinity with existing Columbia River Estuary Study taskforce (CREST) data for these variables (pp. 16-36).

Tide Range and Velocity

According to Rob, when compared to actual tide ranges, the model reasonably simulated Columbia River tide ranges peaking in the same regions of the river (pp. 16-17). Rob indicated that the model also depicted qualitative velocities near the mouth of the river that behaved as a typical river would behave (p. 18). One participant suggested that WES compare the model's velocity data with existing Coast Guard data for the mouth of the river.

The WES team also checked to see if the model could depict stratified salinity within a range that could be expected in this type of estuary (pp. 19-24). During this verification, the model ran for approximately 1500 hours and proved to be highly stratified during the neap/spring tide sequence.

Salinity Comparisons

Rob told the participants to avoid any interpretation of the data from the first 300 hours of the run because the model needs a chance "to settle." The results from this period are not representative of model estimates once the model has run for at least 300 hours. For the bottom of the existing channel at RM 20 and RM 25, maximum salinity values were reached at the 1028th hour (pp. 19, 21). This was the time at which salinity intrusion was at its peak. Comparing the salinity data to the tide charts, the model behaved as one would expect, with the greatest intrusion occurring during the greatest neap tide (pp. 19-23). At the same hour, the stratification between bottom and surface salinity was also at its greatest (p. 24). Since salinity was at its greatest at this hour, WES used the data from this hour in the model for its salinity comparisons (pp. 19, 37).

WES compared the model with CREST atlas data (pp. 26-27, 29) for both mean and averaged salinities to determine if the model was acting as the system should act. The model roughly follows the CREST data, generally decreasing in salinity as it goes upriver, and behaves properly. Rob qualified any discrepancies in the comparison by stating that the CREST data was taken over a set period of time and under certain conditions, and WES had to extract the data points from the atlas, so they are not pure points of data. At approximately RM 35 salinity is virtually nonexistent.

WES also compared output data from the model runs themselves (120,000 and 134,000 cfs) to determine any variability within the modeling system (p. 28). The lower flow rate created slightly higher salinity values at both the surface and bottom of the river, but the models had similar outcomes. WES compared tide range data from the 4 model runs that they ran (p. 30). Ranges within the system were minimal. Rob indicated that differences in tidal range were related more to flow than to channel deepening.

Salinity Locations

Following the advice of the resource agencies at workshop 1, during the model run WES targeted not only the channel, but specific points in Youngs and Cathlamet Bays to produce specific estimates of salinity for use in his presentation at the workshop (p. 25). Most of these points fall within RM 10 and 30. Rob noted that when comparing the surface and bottom salinity values between the planned and existing channels, negligible salinity changes occurred at the surface (pp. 31-34). The greatest salinity changes were in the benthic region.

Comparing the existing and plan salinities in the North Channel,-and Grays, Cathlamet and Youngs Bays, the greatest change in salinity occurs off of Tongue Point at calculation point C1 (pp. 35-36, 25). Rob reminded the participants that this particular salinity location is near the channel and should be expected to have behave like the channel. Salinity changes for the other shallow locations were smaller and were all less than 0.5 ppt.

Hour of Maximum Intrusion

Reemphasizing an earlier point, Rob explained why the hour 1028 was chosen for use in the model. This is the time at which intrusion is at its greatest, and it also marks the beginning of the greatest variability in salinity. The maximum difference in salinity is recorded between the hours of 1028 and 1030 (p. 38).

Isohaline Comparisons

The remainder of the overheads consists largely of isohaline maps. These depict the general movement of salinity as it might be expected to intrude upriver after deepening the channel. The scale on the maps is approximately 6 mm to the mile.

Using the isohalines, Rob pointed out that there were little or no differences in salinity between existing and planned channels in the shallow areas of the North Channel and in Cathlamet Bay. The greatest differences were in the channel or close to the channel (pp. 39-62). There is more uniformity between existing and planned channel salinities at the surface than at depth, since there are fewer points of data incorporated into the model at the surface.

Conclusion

Rob concluded by emphasizing his belief that the salinity changes are well represented by the model, and that it should be a helpful tool for interpretation purposes.

11:00-12:30 Questions and Answers

Following Rob's presentation the participants asked Rob a number of questions regarding the modeling work. In addition, Ms. Lee facilitated a discussion of some of the parameters of the model. The following topics were discussed during this part of the workshop.

Rob discussed how the tides were generated and selected for the model. He explained that synthetically generated tides were used for the period from August-October 1995. These were then compared with NOAA data to ensure accuracy. The tides were representative of last fall's tides. Dr. McAdory indicated that the most important aspect of tide selection is to ensure that variability exists in the tidal cycles.

The participants discussed whether the WES model was "in the ballpark," i.e., whether the model reasonably captured important characteristics of the river system. All the participants agreed that the model results are in the ballpark.

The participants asked about the uncertainty that exists in the model. Rob and Charlie explained that model runs were generated using two different inflow values, 134 cfs and 120 cfs. This produced two sets of data to compare. WES modelers have much more confidence about the certainty of numbers produced within a run, where the depth of the channel is the variable factor, than they do between two different runs, where not only depth, but flow varies. It was clear from their results that a 10% change in flow, from 134 to 120, had a much greater impact on salinity than did the removal of a shoal. In the North channel area, greater salinity differences are apparent, but these are due to flow, not to channel deepening. According to WES, the rate of discharge has a more significant effect on salinity changes than does this particular channel deepening exercise.

The participants asked Rob how WES decided to use the 134 cfs value for one of the runs. Rob noted that in Workshop 1 the agencies agreed upon to allow WES use its judgement discretion as experienced modelers to select the inflow values for the model. Rob explained that using available data for multiple year averages of weekly flows on the lower Columbia River, it was clear to WES that the September to October period had the lowest flow. The CREST data indicated that flows during this time of year typically ranged between 120 and 155 cfs. Although the average low was about 134 cfs, Rob decided to run an additional model using the CREST lowest flow value of 120 cfs to give the resource agencies an idea as to how flow affects salinity. The 120 cfs approximates a worst-case flow scenario.

After a discussion of the flow values selected by WES, all the participants agreed that they are comfortable with the flow values selected. The participants asked Rob where the model predicted that salinity dropped to 0 ppt on the river. Rob explained that the model cannot pinpoint a zero value exactly, but values approach zero on the east side of Puget Island. However, by the time RM 40 is reached, the average salinity is extremely close to "zero." WES has produced model output with a smallest increment of 0.5 ppt., as a result, the "last" isohaline appearing on his overheads up the river is 0.5 ppt. Rob is willing to create output in smaller increments so that he can represent the isohalines with better detail between RM 30 and 40 where the salinity drops from 0.5 and approaches zero. Before requesting this level of specificity in the isohalines, the resource agencies decided to review the biological data.

1:30-2:30 Biologist, Lynne Krasnow's Presentation:

Lynne Krasnow, the COE biology consultant, presented the results of her initial investigations during the afternoon session. The purpose of her investigations was to collect, collate, and summarize existing biological data to assist the resource agencies with their determination of potential environmental impacts within the estuary. Following Workshop 1, she was to assist the agencies in developing a list of species that would be a focus of her investigations. Following Workshop 1, a small interagency workgroup had met to discuss and establish a preliminary list. This list was then presented to participating agencies in the workshop process and all these agencies were invited to attend a meeting to develop a final list that would be the basis of work for Workshop 2. Such a meeting was held, and a final list was developed by the participating resource agencies.

Report Summary

Lynne distributed the results of her research in the form of a spiral-bound report to the participants of Workshop 2. The contents of the report were summarized as follows:

Section 1: includes an introduction, a list of Species of Concern in the Columbia River Estuary, and the methods involved in selecting these species.

Section 2: includes a summary table of all the species of concern with their salinity tolerance ranges, comments and research references. This table is based on existing laboratory experiments on salinity effects. Section 2 also includes several tables and figures to support and supplement the figures and comments listed in the summary table.

Section 3: consists of a list of factors that limit the distributions and abundance of species. Lynne encouraged the participants to consider these factors when interpreting the distribution data for each species.

Section 4: consists of a table of species distribution data from other estuarine systems. This data should provide additional insights into the species listed in Section 2.

Section 5: contains a map of various sampling stations for plant species in the Columbia River Estuary. It also includes a table, listing the estuarian distribution of the seven plant species identified by the agency workgroup.

Section 6: is a compilation of invertebrate data by taxonomic group. It includes a map of sampling stations for each invertebrate listed in Section 2, as well as the distribution data that was available from these stations. Blue dividers separate two reports near the end of Section 6. The first report includes the results of a benthic sampling study in Cathlamet Bay. Lynne pointed out that the 4 sampling stations in the bay had a large variability in species distribution, particularly of *Corophium salmonis*. The second report contains distribution and community structure data on benthic infauna in both the channel and protected flats of the estuary.

Section 7: consists of fish data from the estuary. It includes a map of fish sampling stations, as well as a table of distribution data. Lynne cautioned that this sampling data is less reliable since the fish tend to be highly mobile in the estuary. Also included in Section 7 is a report that was used to compile the above distribution table.

Section 8: consists of several graphs depicting distribution of species in the San Francisco Bay Delta. The y axis on the first few graphs refers to the average number of species per meter squared, and the x axis refers to the salinity in parts per thousand.

Section 9: provides a list of references of salinity studies that relate to the Columbia River Estuary.

Upon learning that the WES model predicted a maximum salinity change of 1.35 ppt, at a given time and place on the river, Lynne indicated that she turned to the existing data to determine if that 1 ppt change would create a significant impact with regard to individual species tolerance.

She investigated the following question: Is the scientific body of data representative of the questions that are to be answered by the resource agencies?

In her opinion, the (laboratory) treatments conducted for individual species were inconclusive, since they were not conducted at small enough resolutions to have much value for an impact determination. It is her belief no studies have been conducted at such a fine scale of resolution. Existing studies have a lowest treatment resolution of 1 ppt and use an exposure time of 96 hours. The 96-hour exposure is much greater than the duration of the peak salinity changes for the plan that a species might experience during a tidal cycle. It was her further observation that there was no bioassay work available for certain species distributions. Lynne cautioned that the absence of data for a certain species on a particular reach of the river is not conclusive of that species' salinity tolerance. It is her belief that an absence of available data is indicative of just that and nothing more.

3:00-4:30 Discussion on Species Distribution and Salinity Tolerance

Discussion on Developing a Strategy

Much discussion ensued among the participants as to the best means of correlating the biological data with the model results to provide a conceptual framework for potential biological effects from salinity changes. One suggestion was to eliminate from consideration species that would be tolerant of a 1ppt change in salinity. Lynne, reiterating an earlier remark, cautioned the participants not to assume that an absence of data signifies that a species does not exist at a certain salinity level. Referring to the San Francisco Bay data, she also emphasized that not only salinity will affect distributions.

One participant remarked that the currently existing species in the estuary had to be extremely tolerant to salinity changes since within any year there are multiple variations of flow and tides to upset any salinity balance. It was presumed that most organisms experience a 1 ppt change on a daily basis anyway. Freshwater species in the upper reaches of river at the edge of the saline zone should receive special scrutiny because these might be most susceptible to an increase in salinity. Some participants suggested that the mobility of a species would affect that species' capacity to adjust to a significant change in salinity, and that substrate would be an important point to consider when looking at impacts.

It was generally agreed by all participants that further analysis biological information should focus on the "margins." The participants thought salinity impacts, if any existed, were most likely at the margins. The group struggled with an exact definition of what they meant by the "margin" concept. Generally, they described "margins" as the extreme ends of the suitable habitat of a species (i.e., habitats that have salinities that are marginal for the species) or salinities at the ends of the tolerances for a species. There was some disagreement as to where the "margins" might exist in a geographic sense. Some participants thought that the regions around Welch Island and between Marsh and Woody Islands were reasonable margins, but others wanted to investigate the lower reaches of the river (between RM 20-22) where Daphnia breed. In connection with this discussion participants thought one focus of analysis might be the investigation of both freshwater tolerant and salinity intolerant species to determine impacts that may arise from a minor change in salinity.

Other participants mentioned other situations in which salinity effects might occur. Suggestions for investigation included an analysis of species that might have improved hatching success within a certain salinity range.

Other ways to conceptualize the analytic approach to the analysis of potential injury were suggested. Among other things, some participants suggested that to assess potential impacts, the trustee agencies would need to determine the duration of a salinity change and how much habitat might be lost on a "permanent" basis. Participants also suggested analyses might be based on a "holistic view" of the habitats and range of species.

The group came back to a discussion centering on whether the small change in salinity predicted by model was a "permanent" change. Rob said that the change predicted was one that would be "permanent." Rob and Karl also mentioned that the magnitude of salinity changes is different depending upon the stage of the tidal cycle. However, from the facilitator's perspective it appeared that at least some the participants and Rob had a different meaning for the word "permanent" and did not share the same understanding of the model results.

Lynne offered to review and summarize, for the next day's discussion, two studies that she has recently received. The reports consisted of data form the Columbia River Data Development Program (CREDDP) and research done on behalf of the Oregon Department of Fish and Wildlife. The first of the reports reviews the composition and distribution of fish species in the Columbia River Estuary. The second report reviews the community structure, distribution, and concentration of benthos, epibenthos, and plankton in the estuary. It was Lynne's belief that the second report would provide a holistic review of salinity tolerance and distribution in the river.

In addition to Lynne's offer, the WES team offered to provide the resource agencies with additional information regarding durations and concentrations of salinity.

Day 2

9:00-10:30 **Revisiting the WES Model**

Late in the first day of the workshop, Ms. Lee (facilitator) focused the group discussion on whether or not the changes in salinity predicted by the model were "permanent" to ensure that the participants and the WES modelers shared the same understanding of that term and understanding of the nature of the salinity changes predicted by the model. Upon questioning, the group felt it would be useful to receive additional information about the nature of the salinity changes predicted by the model.

Rob McAdory began with a discussion of the duration of salinity changes predicted by the model and the magnitude of such changes. He felt that additional information regarding both of these issues might give the agencies a better understanding of the nature of the salinity changes predicted by the model and the biological effects. He defined duration as the time over which a change takes place. Duration could be displayed by finding the difference between the existing and plan salinities to determine how many times the difference is above 0.5 ppt during a specific time frame of 4, 6, or more hours.

Rob also introduced a way of analyzing the data in terms of what he called "exceedance". He defined exceedance as the length of time that salinity might exceed a certain value or the percentage of time that the salinity might be at a certain value such as 4 ppt or 6 ppt. Rob indicated that WES would be able to reprocess the information they had collected on the first four runs to better address duration and exceedance issues at the margins if the agencies desired.

There was a discussion among the agencies regarding the type of information that the agencies might need to assess salinity effects. There was a discussion regarding a display of model results that would present information regarding changes in salinity (plan vs. existing) over a certain threshold amount (e.g., greater than 1 ppt) that last for at least a 4 hour period. It was suggested that information regarding the size and duration of change at areas of particular concern would be useful.

Karl Eriksen offered that he believed that the agencies had much of the information they sought at their finger tips in the overheads provided to them in the first day of the workshop. Rather than waiting for WES to produce additional extensive model output displays, he offered to address some of the issues raised by the agencies. He offered to present a summary of the WES data in a different way than the prior day's presentation that might be more helpful to the agencies in their analysis of potential biological impacts. He used the following overheads in his discussion:

- Salinity At Mile 20, Existing Conditions (p. 19)
- Salinity at Mile 25, Existing Channel (p. 24)
- Comparison of Existing and Plan Salinities - Ship Channel Values, 1200 Hour Average (p. 3)
- Salinity Difference at Mile 20 (p. 38)
- Salinity Locations (p. 25)
- Comparison of Existing and Plan Salinities - North Channel, Grays, Cathlamet and Youngs bays (p. 35)
- Existing versus Plan Channel - Hour 1028, 134 kcfs, Bottom, (p. 39)
- Existing versus Plan - Hour 1030, 134 kcfs, Bottom, (p. 41)
- Existing versus Plan - Hour 1038, 134 kcfs, Bottom, (p. 43)

Karl began his presentation by pointing out that the existing salinity values at RM 20 fall roughly between 11 ppt and 5 ppt (p. 19), and that the greatest changes in salinity occur between the hours of 1000 and 1050 (p. 24). The difference between the planned channel and the existing channel at its maximum is approximately 1.35 ppt at the graph peak and in the graph trough the value is about 0.5 ppt. Even when the maximum 1.35 ppt value is taken into account, the planned channel will only exceed the existing concentration by 0.5 ppt in the trough, and it will only exceed it for 4 hours or so (the width of the peak) (p. 24).

Referring to a sinusoidal curve (wavy line) of the difference in salinity, at RM 20 between the existing conditions and the plan, Karl noted this trace of the salinity change represents an aggregation of specific points in time (p. 38). There are always increases in salinity of different sizes at any time. All the increases are minimal but they are always present (p. 38). This is important since if we look at averages of salinity change at various points, there is always an increase because the value is an average of all the positive values, not the negative values (p. 38). Averages, therefore, are a conservative measure of salinity change. The range must be small if there is a small amount of change, since only the positive numbers are averaged.

Karl went on to explain that if we look at the averages at the various stations for salinity C4, C5, etc, there is very little change (p. 35 and p. 25). Looking at C4 and the other stations displayed on the bar chart, there is little or no change (p. 35). The bar graph on pages 35 and 36 display the averages in the Cathlamet Bay area, C1-C5, the changes for Cathlamet Bay are quite minimal. In addition, Karl asked the participants to recall that the C1 values are influenced by the channel, and C4 and C5 have the shallowest depths. Referring to the graph of the salinity difference at page 38, Karl noted that the salinity change at RM 20 is going to average out to about 1 ppt (p. 38).

Karl noted that when you see an imperceptible change in the average salinity for existing vs. plan, the range of salinity changes that factor into the calculation of the average are correspondingly small. Karl directed the participants to look at C5. The average salinity at this station is 0.5 ppt; there is a predicted average salinity change of 0.1 ppt maximum. In this case, a maximum salinity change (as opposed to the average) would only be about 0.2 ppt. Karl noted that this must be the case since the values that are used in the calculation of the average are all positive and the range must be small to produce an average change of 0.1 ppt given that there are no negative numbers in the calculation.

Referring to page 24, the salinity at mile 25 vs. time, Karl noted that the durations of the "maximum" changes in salinity are the same on different days, 3 hours or so. They are driven by the tidal cycle. At the areas of the river where the average salinity change is about zero, the magnitudes of changes that comprise this average must be very small because the are no negative values in the calculation of the average.

Referring to the isohaline map on page 39, Karl noted that where the maximum salinity intrusion is occurring in the channel where the deepening occurs. The 0.2 ppt maximum change (mentioned above for C5) appears to move 1/4 mile upstream. Even without the project, a 0.2 ppt. change in salinity is within the range of natural variation for the channel. With the project, the maximum salinity change there will be about 0.2 ppt. Without the project, the natural variation in salinity over a period of time will range from less than 0.5 ppt to 2 ppt. The length or duration of a particular change can be determined using the tide chart, but the highest values are typically 2-4 hours in duration. Karl noted that looking at the distances between the isohalines in the Cathlamet Bay area (an area of concern for the agencies) and based on the results from the model, any change in salinity occurring in this region must be less than 1 ppt.

Following the presentation, Rob McAdory assured the resource agencies that Karl had done a great job at synthesizing the information that WES had presented the previous day, and that the resource agencies should feel confident with the numbers that Karl gave with respect to changes in salinity. Charlie Berger also reiterated that WES has confidence in predicting the differences in salinity between the existing system and the planned system. The numbers that the model has for the differences should be accurate. He noted that the model is less accurate at pinpointing an exact location or point on the river where these changes occur, it is the difference between the existing and planned salinity values that is important and these numbers should be accurate.

One participant pointed out that the minimal salinity must be kept in perspective with the fact that even without the planned dredging of the channel, the amount of variability of salinity change for a given point on the river is likely to be greater than what will be seen with the planned deepening.

Furthermore, given the other inputs of wind, boat travel, and variable flow conditions, the magnitude of impact of the planned channel does not look large.

Satisfied with the model presentations, the group decided to proceed to a biological discussion to determine how significant a 0.2 ppt salinity change is to a specific organism. To assist the resource agencies with this process, Karl agreed to provide them with charts depicting salinity concentration and change data for various locations in Cathlamet Bay. The charts would be similar to those presented for the channel in Overheads (1) and (4), and would graphically show the minimal salinity changes - 0.2 ppt or less - in that area.

11:00-12:30 Addressing the Biological Issues

There was a general consensus among the resource agencies that they were not prepared to make decisions at Workshop 2 in regards to impacts on species in the estuary. As a result, the facilitator focused the remainder of the workshop developing a conceptual framework for analysis of potential biological impacts on which the participants could agree. Such a framework, would among other things, help focus additional work in preparation for Workshop 3.

In developing a conceptual framework to analyze the potential impact of salinity changes, the group discussed which geographical regions of the river to address, and the problems associated with a determination of how salinity might impact a particular species. Lynne recommended that the group take a system wide approach to the problem, instead of focusing too narrowly on individual species.

Lynne went on to summarize the findings of the two studies she had promised to review the previous evening. Lynne thought one study was particularly in that it discussed a system-wide approach to investigating the community structure, distribution, and concentrations of various species within the estuary. Lynne referred the agencies to the community distribution and structure results of the CREDDP study (p. 222). The group 4 taxa were distributed in oligohaline-freshwater salinities, in the tidal-fluvial zone between RM 18-46. Group 4 included species typical of the sensitive upper regions of the estuary between RM 23 and 27 that were identified the previous day as marginal areas. The highest production is in the protected areas of the tidal-fluvial zone. Since salinity tolerance information already exists on some of these species, it was suggested that this study might give the agencies a better idea of species capacity in this region.

It was decided that further investigations should be made in regard to the species in Group 4. The group would need to investigate the salinity tolerances of each species, the ecology of the species, and the species distribution in the Cathlamet Bay Area, but outside of the channel.

Other issues were raised during the discussion of the analytical framework for the impacts analysis. Among other things, the group discussed whether or not it was possible to develop a practical analytic approach to the analysis of injury using an ecosystem level type analysis. Some felt the tools for this approach were not yet available. Others expressed a desire to have at least some literature collected on ecosystem impacts. Tom, who raised the issue in the discussion, was not sure whether it could be done, but thought that at least the agencies should think about it as a possible analytic approach. However, he was comfortable with the tack ultimately taken by the group as one appropriate means for the analysis of injury.

Decisions Regarding Conceptual Framework

The agency participants agreed unanimously to the following issues regarding the conceptual framework for the analysis of potential impacts from salinity changes. The approach taken was roughly termed a geographic area/species scenario approach.

- All the participants agreed that they need not be concerned with further investigations of benthic organisms in the channel, but they would investigate further the drift organisms in the channel.

- All participants also agreed that their new conceptual framework would include a species overlay on specific geographical areas. In addition, they would generate scenarios based on predicted changes in salinities at the flow used in the modeling effort for these species and regions. The process was roughly described as follows:

- Select a geographic area of interest/concern.
- Determine the distribution of species in that area.
- Determine the tolerance of the species.
- Assume that flow conditions are "low flow," i.e., the flow used in the modeling effort.
- Determine the predicted salinity changes occurring in the region with the flow using the model results.
- Develop a scenario for salinity effects for the region to determine what will happen if the salinity changes by a certain percentage.

Working together the agencies identified the geographic areas of interest/concern and circled them on a map (attached). There was unanimous agreement by the participants that these areas circled on the map should be the focus of the analysis. The areas could be roughly identified as:

(1) Miller Sands
(2) Rice Island
(3) Mott Island
(4) Pillar Rock
(5) Horseshoe Islands
(6) Russian and Minaken Islands

The tentative timeframe for Workshop 3 when this data/analysis will be presented is early March.

EXHIBIT C

COLUMBIA RIVER CHANNEL DEEPENING

SALINITY INTRUSION
WORKSHOP #3 MINUTES

April 17, 1996

Prepared by:
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for

U. S. ARMY CORPS OF ENGINEERS
PORTLAND DISTRICT

COLUMBIA RIVER CHANNEL DEEPENING
SALINITY INTRUSION WORKSHOP 3
April 17, 1996

Introduction

On April 17, 1996 the Army Corps of Engineers, Portland District Office (COE) convened the third and final workshop in a workshop series regarding the potential salinity effects of proposed channel deepening of the Columbia River. This workshop was a follow-up to two previous workshops held in July 1995 and January 1996.

The workshop was held at the Leach Botanical Gardens, Portland, Oregon. In addition to the Corps of Engineers, representatives from six federal and state agencies were in attendance, as were representatives from the Port of Portland and Vancouver. The following agency representatives and associated parties participated in the third workshop:

John Malek	U.S. Environmental Protection Agency
Ben Meyer	NOAA / National Marine Fisheries Service
Kathi Larson	U.S. Fish and Wildlife Service
Don Bennett	Oregon Department of Fish and Wildlife
Ken Mohoric	Washington Department of Fish and Wildlife
Bill Young	Oregon Department of Environmental Quality
Karl Eriksen	Army Corps of Engineers, Portland District
Kim Larson	Army Corps of Engineers, Portland District
Steve Stevens	Army Corps of Engineers, Portland District
Rosy Mazaika	Army Corps of Engineers, Portland District
Laura Hicks	Army Corps of Engineers, Portland District
Bernie Bills	Port of Vancouver
Danil Hancock	Hartman Associates, for the Ports of Portland and Vancouver
Rob McAdory	WES - Army Corps of Engineers
Bob Ellis	Woodward-Clyde
Lynne Krasnow	Woodward-Clyde
Valerie Ann Lee	Environment International
Margaret Merrens	Environment International

Not present at Workshop 3, but present at other workshops, were representatives from the Washington Department of Ecology and CREST.

Overview of the Workshop

9:15-9:30 Adopt Minutes from Workshop 2, Goals for Workshop 3

Valerie Lee, the facilitator from Environment International, opened the workshop by presenting a draft agenda to the participants for comments and approval. The agenda was accepted.

The minutes from the second workshop were then addressed and adopted with only one minor change. Page 1 of the original minutes were changed to show that Kathi Larson represents the U.S. Fish and Wildlife Service not NOAA's National Marine Fisheries Service.

Kim Larson, COE, summarized the findings of the second workshop and the goals of the third workshop. Reviewing the second workshop, Kim indicated that an overview of modeling information and available biological studies had been presented, but agency participants had indicated that a determination of potential biological impacts on the river would require the presentation of additional biological information. Specifically, the participants requested a closer examination of community structure and species distribution in six specific areas on the river.

Kim indicated that Lynne Krasnow and Bob Ellis, both of Woodward-Clyde, had compiled, and would present today, a packet of information addressing potential benthic and fishery impacts from proposed dredging at participant-selected areas of the lower Columbia River estuary. Rosy Mazaika, COE biologist, would present the results of her investigation of aquatic vegetation impacts on the river, and Karl Eriksen, COE hydraulic engineer, would discuss salinity concentrations and predicted salinity changes on the river.

Kim further indicated that this would be the last workshop to address salinity intrusion, and that the afternoon session would be used to determine whether or not all participants were in agreement as to predicted salinity changes and impacts on the river. Following the workshop, Lynne will write a final report summarizing the potential biological impacts as a result of proposed dredging.

9:30-10:00 **Presentation by Karl Eriksen - Army Corps of Engineers**
Salinity Concentration and Salinity Changes in Selected Regions of the Columbia River

Karl Eriksen began his presentation by giving a brief overview of the WES Columbia River hydrodynamic model. Each of the participants received a packet of draft copies of the overhead charts and tables used in his presentation.

Chart 1: depicts a schematized model that was used to predict salinity changes resulting from proposed dredging on the lower Columbia River. To initiate the model, a grid was established with various measurement nodes and elements. River features and boundary conditions were established with the help of the resource agencies in Workshop 1.

Chart 2: shows the features of the estuary as determined by agency participants in Workshop 1. The model incorporates features such as the navigational channel, bays, and islands.

Chart 3: depicts the boundary conditions as selected by workshop 1 participants and used by the model. Boundary condition inputs included ocean tide, ocean salinity, and freshwater inflow values. Tide values were taken from tide data from the Fall of 1993. Ocean salinity was set at 33 parts per thousand (ppt) and freshwater inflow was set at 134,000 cubic feet per second (cfs). Boundary conditions were held constant over a 1500 hours modeling period and throughout several tide cycles, in order to predict salinity changes that would result from geometrical changes to the river system.

Chart 4: shows how the model was validated by comparing the mean salinity output of the model with actual river conditions taken from CREST studies. The model's outputs were verified by making a determination that its results were "in the ballpark" of how one would expect the river to behave with changing depth conditions. The model roughly follows the CREST data, generally decreasing in salinity as it goes upriver. Values differ slightly, however, since CREST field conditions varied slightly from the model's conditions.

Chart 5: compares salinity values of the existing channel with those of the planned channel. Both river bottom and top (surface) values are compared. Virtually no changes in salinity are noted at the surface of the river. The greatest bottom salinity change is noted near river miles (RM) 17-22, off Tongue Point and Astoria. Here a shoal must be cut. The existing shoal depth is about 41 feet and planned channel depth, with overdraft, is 48 feet. Salinity differences are slightly exaggerated here, however, since the existing shoal depth does not account for overdraft whereas the planned depth does.

Chart 6: depicts bottom salinity at RM 22 plotted during the 1500 hour model run. Karl indicated that this chart is but one of many charts he created for sites selected by the participants. Peak concentrations exist between 1000 and 1040 hours at this particular river mile. Data from the first 300 hours of the run should not be interpreted since the model is settling during that time and values may not be accurate. Karl indicated that Lynne used this chart and others to select maximum and minimum salinity values for each river site.

Chart 7: compares existing bottom salinity values at RM 22 with planned channel salinity values between the hours of 1000 and 1100, when salinity differences were at their greatest. Karl indicated that the data for RM 22 were taken in the channel and therefore depicts worst scenario salinity intrusion.

Chart 8: is one of several isohaline charts that compares existing surface salinity to planned channel surface salinity. Karl noted that throughout the estuary very little salinity change takes place on the surface. The maximum surface salinity increase was about 0.5 ppt. In order take the most conservative estimate of salinity increase, attention was focused on bottom salinities which are slightly greater.

Chart 9: is an isohaline chart for hour 1028 that compares the existing river to planned channel values. Karl noted that the salinity concentrations, whether planned or existing, move further upstream in the channel. As would be expected, salinity changes are also greatest in the channel. No noticeable changes occurred north of the channel in Grays Bay and minor changes were apparent south of the channel in Cathlamet Bay.

Chart 10: depicts salinity change in the river for hour 1030, the peak hour for salinity increase. Karl noted that the pattern remains the same. The concentration has moved upstream between RM 15 and 20 and is greatest in the channel at RM 22. He indicated that the existing and plan concentration lines overlap in the bays to the north of the channel and advance only slightly in Cathlamet Bay.

Chart 11: depicts salinity change in the river for hour 1038. Karl noted that after this time the concentrations began to ebb. Again, there was little or no change to the north of the channel and minor increases to the south of the channel.

Chart 12: labeled Figure 2, shows the location of benthic invertebrate sampling stations that are the focus of further investigation during this workshop. Karl noted that the participants had identified six particular areas of interest at the previous workshop, where they wished to have Lynne Krasnow, consulting biologist, investigate species data and Karl provide salinity data. Due to availability of data, Lynne has added four more sites, bringing the number to ten.

The remainder of the charts in Karl's packet provide information similar to Chart 7. Each chart compares existing bottom salinity values with planned channel salinity values between the hours of 1000 and 1100 when salinity differences were at their greatest. Each chart gives salinity data for a particular river mile and corresponds to each of 9 of the 10 sites identified in Chart 12.

Chart 13: Salinity at S20 - Mott Island

This chart compares the existing bottom salinity off Mott Island with planned bottom salinity. Karl noted that over the 100 hour cycle there is a slight continuous increase in salinity that varies with the tides. The maximum increase is less than 0.5 ppt, and it is only for 2-4 hour time periods each day that the concentration exceeds maximum current concentrations. At all other times planned salinity concentrations are below current maximum concentrations. Karl also indicated that this location is in a deeper part of Cathlamet Bay, east of Tongue Point near the channel, where one would expect somewhat higher salinity concentrations, but a 0.5 ppt change is still quite small.

Chart 14: Salinity at S21 - Rice Island

This chart compares the existing bottom salinity off Rice Island with planned bottom salinity. Karl indicated that this location is in the shallows to the southwest of Rice Island. Again, at its peak, planned salinity exceeds current salinity concentration for only a short duration of the tidal cycle. Otherwise, it is below existing maximum concentrations. Karl also noted that this bottom salinity comparison is a conservative measure of salinity increase in this area since it is an intertidal area. Surface salinity values would have little or no change.

Chart 15: Salinity at S22 - in the Navigational Channel between Rice Island and Miller Sands

This chart compares the existing bottom salinity in the navigational channel with planned bottom salinity. Karl indicated that, in general, the salinity increases are greatest in the navigational channel, and the increases at S22 are the greatest among all the sites. The maximum salinity increase here is approximately 2.5 ppt.

Chart 16: Salinity at S23 - Miller Sands

This chart compares the existing bottom salinity off Miller Sands with the planned bottom salinity. S23 is in the shallows south of Miller Sands and the navigational channel. Maximum concentration has dropped to less than 3.5 ppt, and the increase is much less at about 0.5 ppt. Again, like the Rice Island estimates, Karl noted that this is a conservative estimate of salinity increase since the area is intertidal.

Chart 17: Salinity at S25 - Minaker Island

This chart compares the existing bottom salinity off Minaker Island with planned bottom salinity. Here the increase in bottom salinity concentration is down to about 0.1 ppt over a 1-2 hour period.

Chart 18: Salinity at S27 - Pillar Rock Island

This chart compares the existing bottom salinity off Pillar Rock Island with planned bottom salinity. Here the increase in bottom salinity concentration is down to about 0.2 ppt over a 1-2 hour period. Karl noted that this is likely an overestimate of the salinity change, since Pillar Island itself was not factored into the model.

Chart 19: Salinity at S29 - Tronson Island

This chart compares the existing bottom salinity off Tronson Island with planned bottom salinity. S29 is in the shallows to the south of the channel. Here the maximum salinity concentration is in the 1 ppt range and the planned increases are only 0.1 ppt.

Chart 20: Salinity at S30 - in the Navigational Channel

This chart compares the existing bottom salinity in the navigational channel with planned bottom salinity. S30 is in the navigational channel. Existing concentrations are below 1 ppt with a increase below 0.5 ppt.

Chart 21: Salinity at S33.5

This chart compares the existing bottom salinity at RM 33.5 with the planned bottom salinity. Existing concentrations are about 0.5 ppt with increases of 0.1 ppt at times of peak concentration.

To complete and summarize his presentation, Karl displayed Table 3 from Lynne Krasnow's results. Table 3 gives the estimated existing salinity range and maximum increase in salinity at each study site as predicted by the hydrodynamic salinity model. Karl made three points: (1) S22, a site in the channel between Miller Sands and Rice Island has the largest salinity increase; (2) S28, again in the channel, has the second greatest increase; and (3) sites in the shallows, such as 33.5, show very little predicted salinity increase.

Rob McAdory, WES modeler, was asked to respond to a question regarding error bars for the modeling data. He indicated that there were no error bars for the data, because the model was not validated with respect to specific salinity values. Instead, reasonable behavior of the model was confirmed when they compared the model run with CREST data. The modelers, however, do have a high level of confidence in the accuracy of the predicted salinity change between existing and planned salinity. WES also compared output data from the model itself, using two different inflow values - 120,000 and 134,000 cfs to determine any variability within the modeling system. Rob indicated that the lower flow input created a much greater change in salinity than was seen when just depth was varied. It is Rob's conclusion that the greatest potential change in salinity concentration is due largely to outside influences such as flow.

10:30-12:00 Presentation by Lynne Krasnow and Bob Ellis
Benthic Invertebrate and Fisheries Impacts in Selected Regions of the Columbia River

Lynne Krasnow and Bob Ellis, both of Woodward-Clyde, presented the results of investigations into potential benthic invertebrate and fishery impacts at each study site. Participants were asked to refer to the packet of results that was distributed by mail prior to the workshop, as well as an addendum of handouts that was distributed during the workshop. The addendum included a section on literature cited and replacements for Figure 4, Appendix A, and Appendix B.

Lynne Krasnow's Presentation:

Summary of Results
Lynne reviewed the objectives for the day - to revisit in detail the 6 participant-selected sites, as well as 4 additional sites for which data were available. She directed the participants to the conclusions of her and Bob's report and summarized as follows:

- Small increases in bottom water salinity of less than 0.5 ppt at intertidal and shallow subtidal sites.
- Short-term increases in bottom water salinity of up to 2.45 ppt at channel sites.
- Changes of this magnitude unlikely to exclude species from existing habitats in the Tidal-Fluvial Zone of the estuary.
- Changes of this magnitude could permit short, up-channel range extensions by salinity-dependent species (e.g., *Eohaustorius estuarius, Corophium brevis*).
- *Corophium salmonis* likely to remain the numerically dominant species at most sites, including channels.
- No expected impact on fish food resources.

Following this summary , Lynne directed the participants to a number of overheads that are referenced directly in the report as either tables or charts. She described the following:

Figure 1: Columbia River Estuary Zonation
Lynne reviewed for the participants why the study area, upstream from Tongue Point, is referred to as the Tidal-Fluvial Zone. A 1990 study by Simenstad classified the lower Columbia River into 3

distinct zones: the plume and ocean zone, the estuarian mixing zone, and the tidal-fluvial zone. The latter is where one would expect to see large diurnal shifts in salinity concentration. Lynne and Bob directed their study to this zone after agency participants in Workshop 2 identified the area as having sensitive habitats. Fresh water outflow also dominates here, as do freshwater species. Agency representatives were most concerned with the impact that a salinity change would have on species in this zone.

Figure 3: Predicted existing bottom salinity concentrations vs plan concentrations in the Columbia River estuary at 134,000 cfs
This figure is an isohaline map of the estuary, similar to ones that Karl showed the group. Comparing existing concentrations to planned concentrations, Lynne pointed out that the maximum concentration changes would occur in the channel. The change is defined as the longitudinal distance over which the isohaline moves. Lynne indicated that the general trend is for the distance/change to decrease as one moves upstream in the channel.

Karl's Overhead - Chart 6: Salinity at A3 (S22), Existing Channel
Lynne presented an overhead from Karl's earlier presentation as an example of existing salinity conditions at a specific study site. She went on to describe how she used the model results on these charts to obtain maximum and minimum bottom salinity values (the range) for each study site. From these results she also determined a maximum expected change for each site, which was the maximum difference in salinity as predicted by the model.

Table 3: Estimated existing salinity range and maximum increase in salinity at each study site as predicted by the hydrodynamic salinity model
Lynne pointed out that the participants in Workshop 2 identified 6 study sites within the Tidal-Fluvial Zone for further study. She noted that after a preliminary review of the positions and depths of these stations, she and Bob decided to add 4 more sites to provide better representation of the channel and of shallow subtidal habitats. This table depicts the existing range and maximum increase in salinity for each of the 10 sites as deduced from the modeling charts.

Figure 2: Location of Benthic Invertebrate Sampling Stations
Lynne indicated that the 10 study sites fell into three distinct habitat categories: intertidal, shallow subtidal and channel habitats. Intertidal sites include S21, S23, and S27. Shallow subtidal sites include S20, S21, S23, S25, S27, S29, and S33.5. Channel sites include S22, S28.8, and S30.

Figure 4: Salinity tolerances of benthic invertebrate species identified at study sites in the Tidal-Fluvial Zone of the Columbia River estuary
This figure is an updated list Lynne comprised for Workshop 3 of benthic invertebrate species identified at study sites in the Tidal-Fluvial Zone. For each species at each site, Lynne and Bob investigated all salinity tolerance data and any additional biological data relating to habitat. In general, wide tolerance ranges were observed across all species. For clarification, the dotted lines in Figure 4 represent extensions of tolerance ranges based on published field observations. *Corbicula fluminea* is represented by a dotted line. *Corbicula* is a bivalve that lives near the surface of the sediment and filters plankton out of the water column. It has a salinity tolerance range between 0 and 15 ppt, as observed in the laboratory.
Bob Ellis' Presentation:

Bob previewed his presentation by stating that he would present and discuss the following results for each site: (1) species composition, (2) the salinity range, (3) predicted salinity changes, and (4) a comparison of the range and the predicted salinity increase for each site.

Bob reviewed the methodology for the study. First, Lynne Krasnow and Bob Ellis reviewed all benthic invertebrate sampling data collected at each site since 1975 and compiled an overall list of benthic organisms, identified to the species level. The list indicates all taxa and their relative abundance at each site. A community structure analysis was also done for each site. Indices of diversity and equitability were calculated for each site to compare the benthic invertebrate communities of the intertidal, shallow subtidal and channel habitats during the low flow periods. In general, the equitability factors[1] at each station had low values and each station was dominated by only a few species.

Bob went on to review the findings for each site. For each site, he and Lynne determined the maximum salinity concentration that a species would be exposed to, then applied that finding to Figure 4 salinity tolerance ranges for each species to determine the impact to each species. If an individual was deemed to survive, then the population was deemed to have the capacity to survive.

Table 5: Benthic invertebrates identified to species at S20 (Mott Island)

Habitat type:	Shallow subtidal
Species composition:	9 benthic invertebrates were identified to species level at S20. Of these, data was available for *Neanthes limnicola, Corbicula fluminea, Coullana canadensis, Neomysis mercedis, and Corophium salmonis.*
Existing salinity range:	2.3-7.5 ppt
Predicted salinity change:	0.44 ppt
Comparison/likely impact:	No elimination of species at this site.

Additional comments: Bob illustrated for the participants the approach through which he and Lynne determined potential impact to each species. For example, looking at *Corbicula fluminea*, based on the data from Table 3 the maximum concentration *Corbicula* would be exposed to at this site is close to 8 ppt. From Figure 4 it appears that a concentration of 8 ppt is well within the 0.0-13 ppt salinity concentration range *Corbicula* can tolerate. Therefore a 0.44 ppt change in salinity would have no significant impact on *Corbicula* at this site. Looking next at *Coullana canadensis*, an 8 ppt concentration comes up mid-range in its tolerance range, as it does for *Neomyses mercedis*, and *Corophium salmonis*. The 0.44 ppt salinity change would have no significant impact. *Corophium salmonis* has a broad tolerance range and can be found all the way up to freshwater. As for other species at this site, *Manayunkia speciosa* is generally a freshwater species. The low numbers (Table 6) of this species and of *Lithoglyphus virens* indicate that they are not a major community component at this site. Lynne and Bob were unable to find information on *Vejdovskyella intermedia*, but have knowledge that it occurs with oligochaetes, which in Figure 4 have a tolerance range that extends to about 15 ppt. Bob was confident that *Vejdovskyella* , co-occurring with oligochaetes would tolerate this minor change in salinity.

Table 8: Benthic invertebrates identified to species at S21 (Rice Island)

Habitat type:	Both shallow subtidal and intertidal
Species composition:	More species were observed in the intertidal area than in the subtidal area. 8 benthic invertebrates were identified to species level in the intertidal area. Of these species, data was available on *Neanthes limnicola, Corbicula fluminea, Eohaustorius estuarius, Diporeia hoyi, Corophium salmonis,* and *C. spinicorne*. 5 benthic

[1] The draft report entitled: Salinity Intrusion Workshop III, Summary of Potential Biological Effects Due to Channel Deepening in the Columbia River Estuary defines equitability as a measure of "the proportional abundance of the various species in a sample," p.4.

	invertebrates were identified to species level in the subtidal area. Of these species, data was available on *Neanthes limnicola, Corbicula fluminea, Corophium salmonis,* and *C. spinicorne.*
Existing salinity range:	1.4-6.4 ppt
Predicted salinity change:	0.28 ppt
Comparison/likely impact:	No elimination of species at this site.

Additional Comments: Bob ran through the process by which he and Lynn evaluated each species at this site using the same process as the previous example. He indicated, again, that they did not find any species near their sensitive toleration limits.

Table 11: Mean abundances of taxa observed in the channel at S22

Habitat type:	Channel
Species composition:	The table indicates the total number of taxa observed at this station during a low flow period in Sept. In comparison to the previous shallow subtidal sites, distributions are much lower. Only 3 species of benthic invertebrates were identified at S22: *Corophium salmonis*, *Eohaustorius estuarius*, and *Bosmina longirostris*. Data was available for *C. salmonis* and *E. estuarius.*
Existing salinity range:	1.0-4.7 ppt
Predicted salinity change:	2.45 ppt
Comparison/likely impact:	No elimination of species at this site.

Additional Comments: Bob mentioned that both *Corophium salmonis* and *Eohaustorius estaurius* have wide salinity tolerances. The latter, however, exists between 2 ppt and 28 ppt, and does not do well below 2 ppt. *Bosmina longirostris* is typically a freshwater zooplankton. Both it and the *Daphnia spp.* probably drifted in from upstream.

Table 12: Benthic invertebrates identified to species at S23 (Miller Sands)

Habitat type:	Both shallow subtidal and intertidal
Species composition:	More species were observed in the intertidal area than in the subtidal area. 11 benthic invertebrates were identified to species level in the intertidal area. Of these species, data was available on *Neanthes limnicola, Corbicula fluminea, Coullana canadensis, Neomysis mercedis, Corophium salmonis, Diporeia hoyi, Eogammarus confervicolus, Eohaustorius estuarius,* and *Hyallela azteca.* 7 benthic invertebrates were identified to species level in the subtidal area. Of these species, data was available on *Neanthes limnicola, Coullana canadensis, Gnorimosphaeroma oregonensis, Corophium salmonis,* and *Eogammarus confervicolus.*
Existing salinity range:	0.7-3.5 ppt
Predicted salinity change:	0.26 ppt
Comparison/likely impact:	No elimination of species at this site.

Additional Comments: Bob indicated that the majority of the sampling at S23 has been in the intertidal area between the main island and the spit. Two subtidal locations were sampled, one to the south of the main island and the other in deep water between the spit and the main island. In the intertidal area, 50 taxa were identified. This is the largest number of any other station. Bob indicated that the reason for the appearance of relatively rare species was likely due to the large amount of sampling done here. Oligochaetes were dominant in the intertidal area, while *Corophium* *salmonis* was dominant in the subtidal area. Bob indicated that a 0.26 ppt salinity change is barely perceptible and none of the species at this site would be eliminated.

Table 15: Benthic invertebrates identified to species at S25 (Minaker Island)

Habitat type:	Shallow subtidal
Species composition:	8 benthic invertebrates were identified to species level at S25. Of these, data was available for *Neanthes limnicola, Corbicula fluminea, Corophium salmonis, C. spinicorne,* and *Diporeia hoyi.*
Existing salinity range:	0.9-2.8 ppt
Predicted salinity change:	0.18 ppt
Comparison/likely impact:	No elimination of species for this site.

Additional comments: Nematodes were the most abundant organism. The site is dominated by silt clay and fine sand. A 0.18 ppt change in salinity is negligible. No species would be affected.

Table 17: Benthic invertebrates identified to species at S27 (Pillar Rock)

Habitat type:	Both shallow subtidal and intertidal
Species composition:	More species were observed in the subtidal area than in the intertidal area. 9 benthic invertebrates were identified to species level in the subtidal area. Of these species, data was available on *Neanthes limnicola, Corbicula fluminea, Neomysis mercedis, Saduria entoman, Corophium salmonis,* and *Diporeia hoyi.* 6 benthic invertebrates were identified to species level in the intertidal area. Of these species, data was available on *Neanthes limnicola, Corbicula fluminea, Corophium salmonis,* and *Diporeia hoyi*, and *Hyallela azteca.*
Existing salinity range:	0.1-2.0 ppt
Predicted salinity change:	0.17 ppt
Comparison/likely impact:	No elimination of species at this site.

Additional Comments: *Corbicula fluminea* was abundant in both the intertidal and subtidal areas, as was *Corophium salmonis*. *Porcellio scaber* is terrestrial and not typically seen, yet was found in the intertidal area. Oligochaetes were dominant in the intertidal area during two of the sampling periods.

Table 20: Benthic invertebrates identified to species at S28.8

Habitat type:	Deep water
Species composition:	3 benthic invertebrates were identified to species level at S28.8. Data was available for all - *Neanthes limnicola, Corbicula fluminea,* and *Corophium salmonis.*
Existing salinity range:	0.1-1.6 ppt
Predicted salinity change:	0.85 ppt
Comparison/likely impact:	No elimination of species at this site.

Additional Comments: S28.8 had a very short list of species, only slightly longer than reported for samples in the navigation channel (S22).

Table 22: Mean abundances of taxa observed at S29 (Tronson Island)

Habitat type:	Shallow subtidal
Species composition:	The table indicates the mean abundance of taxa observed at this station. 4 benthic invertebrates were identified to species level at S29: *Corophium salmonis*, *Diporeia affinis*, *Lithoglyphus virens*,

	and *Darwinula stevensoni*. Data was available for *Corophium salmonis* only.
Existing salinity range:	0.3-1.2 ppt
Predicted salinity change:	0.08 ppt
Comparison/likely impact:	No elimination of species at this site.

Additional Comments: Data came from the Bi-state study. Information was only available for *Corophium salmonis*.

Table 23: Mean abundances of taxa observed in the channel at S30

Habitat type:	Channel (50 foot depth)
Species composition:	The table indicates the mean abundance of taxa observed at this station. Only 3 benthic invertebrates were identified to species level: *Corophium salmonis*, *Acanthocyclops vernalis*, and *Corbicula fluminea*. Data was available for *Corophium salmonis* and *Corbicula fluminea*.
Existing salinity range:	0.0-0.9 ppt
Predicted salinity change:	0.38 ppt
Comparison/likely impact:	No elimination of species at this site.

Additional Comments: Data came from the Bi-state study and was sampled in the fall. *Acanthocyclops vernalis* is typically found in freshwater and probably floated into this region.

Table 24: Mean abundances of taxa observed at S33.5

Habitat type:	Shallow subtidal
Species composition:	The table indicates the mean abundance of taxa observed at this station. *Corophium salmonis* and *Corbicula fluminea* were the only benthic invertebrates identified to species level at S33.5. Data was available for both.
Existing salinity range:	0.0-0.7 ppt
Predicted salinity change:	0.5 ppt
Comparison/likely impact:	No elimination of species at this site.

Additional Comments: S33.5 had species composition typical of Columbia River freshwater habitat.

Table 25: Presence of benthic invertebrate species at subtidal study sites

This table shows the general distribution of benthic invertebrates throughout the Tidal-Fluvial Zone. Bob pointed out that one or two taxa dominated each station. The equitability range was low at both the intertidal and subtidal sites. The shallow subtidal area was highly dominated by *Corophium salmonis*, whereas the intertidal area was dominated by oligochaetes. *Corophium salmonis* was found in all areas. *Corbicula fluminea* also was relatively abundant.

Bob indicated that there may be some species whose present distribution range could extend upstream in the navigational channel, where predicted salinity increases are highest. Two species, *Eohaustorius estuarius* and *Corophium brevis,* have lower tolerance limits of 2 ppt and 5 ppt, respectively. *Eohaustorius estuarius* was abundant at channel station S22 but absent at channel stations further upstream. If the lower limit of *Eohaustorius estuarius* is presently limited by low salinity, then the predicted increase in bottom salinity might allow it to extend its distribution up the channel. The same could be said about *Corophium brevis*, since its low salinity tolerance limit is 5 ppt. Bob did not expect great impacts in the shallow areas, however, since salinity changes there are predicted to be minimal (about 0.5 ppt). From the fish data, Bob and Lynne determined that fish are mostly feeding in the subtidal and intertidal areas. There are some in the channel, but studies have indicated that there is little feeding going on in the channel. They concluded that up-channel range extensions of *Eohaustorius estuarius* and *Corophium brevis* would not significantly affect fish food relations.

Discussion:

Workshop participants had several questions for Bob and Lynne. Because of the apparent abundance of oligochaetes, a participant wanted to know whether salinity tolerance information was available for oligochaetes. Lynne indicated that they reviewed the data from the 1984 Emmett study. She checked with Peter Chapman in Vancouver and apparently no one has been studying oligochaetes. There is some information on obscure groups, but no taxa data available. Lynne further emphasized that salinity tolerance varies among the oligochaetes. Bob reminded the group that the oligochaete habitat is in the shallows where salinity changes are small. It was his sense that impacts would be unlikely.

Another participant inquired as to the apparent emphasis on benthic invertebrates and not fish. Lynne responded by reminding the participants about the decision they made at the last workshop to examine the worst case scenario on the river. As such, they opted to have Lynne prioritize and examine sedentary organisms, as opposed to mobile ones like fish.

An individual asked Bob whether his conclusion that "no species would likely be excluded or eliminated from a site" also meant that there was no likelihood of affecting the species' abundance. Lynne responded that aside from the phenomenon in the channels, in terms of exclusion, if a salinity change remained within an organism's range of tolerance, than the organism was not likely to be impacted by mortality. If an individual would not be impacted, then it was assumed that a population would not be impacted. Further discussion ensued among the participants on this topic. It was decided that an explanation in the report, as to all assumptions made by Lynne and Bob, would be helpful. Lynne also agreed to strengthen the conclusions in the final report to indicate where no impacts were found. Kim Larson requested to see a species by species account of impacts. Steve Stevens thought it would be helpful to see any further evidence on shifts in abundance in the channel. Lynne indicated that she could look at the Bi-State study for comparison on abundance. It was also suggested that Lynne add to the report more discussion of other factors affecting species distribution, such as outflow.

1:30-2:30 **Presentation by Rosy Mazaika - Army Corps of Engineers**
Aquatic Vegetation Impacts on the Columbia River

Rosy Mazaika from the Army Corps, Portland District, presented the results of her investigation of potential aquatic vegetation impacts at each study site. Participants were asked to refer to the packet of results that she distributed at the workshop.

Rosy focused her investigations on the salinity tolerance of salt marsh species. She focused on the areas identified by participants in Workshop 2. Her approach was based on the availability of data. She tried to identify overlaps in salinity data, and decided upon four studies - Hamilton, WES, Macdonald and Winfield, and Smith and Goudzwaard. Based on information in these studies, 5 sites were selected: RM20 (Mott Island), RM22 (Grays Bay) , RM23 (Miller Sands), RM27 (Pillar Rock Island), and RM29 (Tronson Island).

The maximum change in salinity was predicted to be less than 0.5 ppt at any of these five sites. Rosy reminded the group that this is the predicted bottom salinity change, not the surface change, and is not directly reflective of intertidal or shallow subtidal sites.

Rosy indicated that for purposes of analysis, a list of vascular plant species was selected and classified into 3 separate groups. Group 1 was comprised of those species that overlap in distribution and are relatively abundant in Grays and Cathlamet Bays (ie., *Carex lyngbyei*, *Deschampsia caespitosa*, *Eleocharis palustris*). Group 2 is comprised of those species commonly distributed in low marsh habitats (ie., *Lileopsis occidentalis, Aster subspicatus, Juncus balticus, Juncus oxymeris, Lysichitum americanum, Potentilla pacifica*). Group 3 is comprised of unique species (*Sagittaria latifolia, Sium sauve*). Table IV.E on page 12 of her report shows the distribution of species form Groups 1-3 at the 5 selected sites.

Rosy then referred to several figures from her report:

Figure 1: Salinity tolerances reported for vascular plants in the Tidal-Fluvial Zone (Macdonald and Winfield). Of the vascular plants reported in the Macdonald and Winfield study, *Sagittaria latifolia*, *Sium sauve*, *Juncus oxymerus*, and *Lysichitum americanum* had the lowest salinity tolerance.

Figure 2: Salinity tolerances for vascular plants in the Tidal-Fluvial Zone (Hutchinson). The Hutchinson study showed the same result. Of the vascular plants reported, *Sagittaria latifolia*, *Sium sauve*, *Juncus oxymerus*, and *Lysichitum americanum* had the lowest salinity tolerance. Rosy indicated that she selected these four species for her impact determination, because each occurs with relative frequency in the estuary and has the capacity for further monitoring.

Figure 3: Salinity tolerances for vascular plants in the Tidal-Fluvial Zone and species distribution relative to maximum predicted salinity. Rosy stated that the x's on the chart indicate areas where species have been observed and recorded. The numbers under the site names indicate maximum predicted change in bottom salinity at these locations. Species observed outside of their tolerance range might indicate elevation or substrate changes. Rice and Mott Islands are low marsh habitats and species can survive in these areas if they can survive a 1 foot change in tide. Species tolerant of daily tidal changes in salinity are able to survive beyond their typical tolerance range.

Conclusion. Despite the lack of site specific data, Rosy concluded that there would be no expected impact to the most sensitive species (e.g., *Sagittaria latifolia*, *Sium sauve*, *Juncus oxymerus*, and *Lysichitum americanum*). Furthermore, Rosy concluded, no effect should be observed in species in Groups 1, 2, and 3, and *Sagittaria latifolia*, *Sium sauve*, and *Juncus oxymerus* could be indicator species for future monitoring.

Questions:

One individual asked why skunk cabbage (*Lysichitum americanum*) was present on Mott Island. Rosy indicated that skunk cabbage has been observed in the freshwater habitat of the island in high marsh habitat.

Lynne reemphasized that the 0.5 ppt predicted salinity change in the subtidal and intertidal areas is a prediction for bottom salinity, not surface salinity. Predicted changes to surface salinity are much smaller changes and would have a greater likely impact on plants in the area. Additional comments for Rosy included a suggestion to identify species of marsh plants that may gain advantage from salinity increases. Another participant voiced an opinion that elevation, not salinity, was the controlling factor for vegetation.

Rosy then reviewed her conclusions, which are summarized at the end of these notes.

3:00-4:30 Discussion Among Participants Regarding Potential Biological Impacts of Proposed Channel Deepening to the Columbia River

Deciding on an Approach

Several ideas were generated by agency participants as to how to close the meeting with a determination on biological impacts. COE participants were most interested in receiving a consensus statement from the agency participants as to potential biological impacts on the river. Opinions varied with respect to proceeding with a consensus on a global scale or individually, site by site. One participant felt that each site should be addressed individually in recognition of the individual attributes of each site. The majority of the participants, however, were of the opinion that a global approach would be sufficient, the thought being that total predicted salinity changes would be small and that salinity as a whole was not a major issue for the participants. From an impact perspective, outside influences such as river flow were more crucial areas of concern for the participants. Furthermore, most participants felt that each site was given a thorough examination by the biologists and that based on the presentations a consensus decision did not require individual attention. Following this discussion, all participants agreed that a global approach was sufficient.

Addressing Issues Beyond the Scope of this Study

Another discussion ensued as to issues of concern that might be strengthened in the final biological report. Some individuals expressed an interest in having the final report provide a list of issues that were considered by the COE, but which upon further consideration were determined to be of little or no concern for further investigation. Initially, it was offered that such a list could be provided in the COE report as further EIS questions that were beyond the scope of concern and inquiry for this project. It was eventually decided, however, that such a list was inappropriate for two reasons. First, such a list would be inevitably incomplete, and second, such an approach fails to credit the thoroughness of the studies and decisions that have taken place. It was further emphasized that the purpose of the public review process is to raise and address these issues. All participants were in agreement with this statement.

Reaching Consensus on a Concluding Statement for the Workshops

A final discussion ensued regarding the development of a consensus statement on biological impacts that would serve as a concluding statement for the workshop series. Several ideas were generated regarding the content of the statement. The following suggestions and sentiments were offered by individual participants:

- That there is a small impact from salinity that may be immeasurable.
- That there is no significant biological impact with respect to salinity from the proposed channel deepening.
- That the change in salinity will not have an impact on habitat and biology of the area.
- That there will be little or no impact to benthic invertebrates and to vascular plants.
- That there would be no identifiable impact.
- That the impacts could be characterized according to natural fluctuations on the river, using a comparative approach.
- That salinity is a non-issue with respect to potential construction of a deeper channel as presently proposed.

• That the predicted salinity changes and impacts to the biological community are within the realm of natural variability on the river.
• That the predicted amounts of salinity change are masked by the natural variability of the system.

Eventually all participants came to consensus and accepted as their own the following statement:

• No significant biological impact would result from salinity changes predicted for the proposed channel deepening.

Workshop Conclusions

With the intent of creating a set of conclusions for the workshop, the participants reviewed and made minor revisions to the conclusions of the contractors and accepted the following as their own:

Impacts to Benthic Invertebrates

• Small increases in bottom water salinity of less than 0.5 ppt at intertidal and shallow subtidal sites.
• Short-term increases in bottom water salinity of up to 2.45 ppt at channel sites.
• Changes of this magnitude could permit short, up-channel range extensions by salinity-dependent species (e.g., Eohaustorius estuarius, Corophium brevis).
• *Corophium salmonis* likely to remain the numerically dominant species at most sites, including channels.
• No expected impact on fish food resources.

Impacts to Vegetation

• No significant effect on species examined in the present analysis is expected to a result from 0.5 ppt maximum increase in salinity in the Columbia River estuary.
• Of the species selected for analysis, *Saggittaria latifolia*, *Sium sauve*, *Lysichitum americanum*, and *Juncus oxymerus* reflect the species with high sensitivity to changes in salinity.
• It is likely that factors other than salinity are affecting plant species distribution in the Columbia River estuary.
• Although species of *Sium sauve, Sagittaria latifolia* and *Juncus oxymerus* exhibit a higher degree of sensitivity relative to other species included in this analysis, these species often occur in habitats typified by salinities that exceed the individual species salinity tolerance and therefore are likely distributed along another (e.g., elevational, substrate) gradient.

Final Comment

Karl Eriksen concluded by thanking all the participants for contributing to and participating in the workshop process. It was agreed by all participants that there will be a 2 week review period for the minutes, after which they will be deemed accepted unless Karl is notified otherwise.

EXHIBIT D

COLUMBIA RIVER CHANNEL DEEPENING

REPORT OF THE INTERAGENCY WORKGROUP ON SALINITY INTRUSION

PREPARED BY
WOODWARD-CLYDE FEDERAL SERVICES

FINAL REPORT
JULY 1, 1996

COLUMBIA RIVER CHANNEL DEEPENING

REPORT OF THE INTERAGENCY WORKGROUP ON SALINITY INTRUSION

by

Woodward-Clyde Federal Services
111 SW Columbia, Suite 990
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for

U.S. Army Corps of Engineers
Portland District
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Final Report
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TABLE OF CONTENTS

List of Tables

List of Figures

1.0 INTRODUCTION

The Corps of Engineers Portland District (Corps) is conducting a feasibility study for the proposed deepening of the Columbia River main navigation channel. One of the major environmental concerns of the project is the potential effect that deepening could have on salinity patterns within the estuary and, in turn, on the distributions and abundances of estuarine organisms. In response to these concerns, the Corps convened a series of interagency workshops in which the participants were to identify specific concerns with regard to salinity changes in the estuary, specific geographic areas of concern, and potential indicator organisms of salinity stress. The goal of the workshop series was to reach consensus among the participating agencies regarding potential salinity impacts from deepening the Columbia River using existing data and tools. Technical support to the workshop participants was provided by the U.S. Army Corps of Engineers Waterways Experiment Station (CEWES) (hydraulic and salinity modeling) and Woodward-Clyde Federal Services (biological impacts). Workshops were led by a neutral facilitator from Environment International.

Workshops were held during July 1995 and January and April 1996. At the first workshop, the facilitator, Valerie Ann Lee, led a discussion of the proposed ground rules for the workshop process:

1. Participants will treat each other with respect and not interrupt during presentations.

2. Everyone should be given a fair opportunity to share their view with the participants.

3. The facilitator will ensure that ground rules are followed.

4. Because consistency is important in the process, each participating entity will make its best efforts to ensure that at least one person representing the agency is present at all workshop meetings.

5. Agencies with more than one representative at the workshops will designate one person to speak for the agency.

6. Agency representatives agree to keep decisionmakers within their agencies apprised of the developments in the workshops

7. Minutes will be recorded at each workshop and will be reviewed by the participants and adopted (with or without revision) at the start of each consecutive workshop.

8. The process will be open to input of technical information on salinity and the impacts of salinity intrusion.

The group was unable to agree on an acceptable version of the following proposed rule:

- Consensus shall be reached by unanimous agreement of all agencies present at a workshop

The following proposed rule was never addressed:

- Ground rules may be modified by unanimous consent of the participants

This final report for the workshop series describes the group's activities and findings. To some extent, it relies on the notes of the workshop proceedings, as recorded by Environment International. It also summarizes the findings presented in the technical reports prepared by CEWES (hydraulics and salinity), the Corps (salinity impacts on vascular aquatic plant assemblages), and Woodward-Clyde Federal Services (salinity impacts on benthic invertebrates).

2.0 AGENCIES AND PARTICIPANTS

The agencies and individuals who participated in the workshop series are shown in Table 2-1.

3.0 METHODS

The Corps technical goals for the workshop series were met through the following process:

Workshop 1

- Presentation of the proposed numerical salinity model by CEWES
- Development of consensus among the workshop participants regarding the computational mesh and boundary conditions to be used by the modelers
- Development of consensus regarding species of concern in the estuary

Workshop 2

- Presentation of the results of initial runs of the numerical salinity model
- Discussion of the results of the model among workshop participants

- Development of consensus regarding whether further model runs would be needed
- Presentation of known salinity tolerances for species of concern
- Development of consensus regarding criteria for determining whether impacts to species are significant

Workshop 2 or 3

Development of consensus regarding:

- Estimated changes in salinity
- Biological impacts from forecasted changes in salinity

At an additional meeting, held during August 1995, the workshop participants reviewed and approved a draft list of species of concern developed by the biological consultant and the Corps. Species that were chosen were known to occur at the freshwater end of the Columbia River estuary (Fox et al. 1984). The participants emphasized their interest in species which are important prey of salmonid fishes (e.g., the epibenthic amphipod *Corophium salmonis*).

The following sections describe the methods used for hydraulic and salinity modeling and the investigation of potential impacts to benthic macrofauna and vascular aquatic plants, respectively. Findings are summarized in Section 4.0 (Results and Discussion).

3.1 Hydraulic and Salinity Modeling

The Columbia River was modeled schematically, in a manner that reproduced the general qualitative behavior of the estuary as described in reports of the Columbia River Estuary Study Taskforce (CREST). The three-dimensional model was created by applying a computational mesh and a set of boundary conditions acceptable to the workshop participants to the computer code RMA 10-CEWES (Corps of Engineers Waterways Experiment Station, CEWES, 1996). The computational mesh (Figure 3-1) consisted of a large collection of points for which the physical equations of fluid motion and salt transport (coded into RMA 10-CEWES) were solved. The computational mesh and boundary conditions, as well as validation of the model, are described in more detail in CEWES (1996).

At the first interagency workshop, the participants were asked to define for CEWES the following parameters for use in the first two modeling runs:

- Existing channel depth

- Boundary conditions (i.e., ocean salinity, tidal periodicity, and freshwater discharge)

- Geographic areas of concern

Existing Channel Depth

Participants agreed that the first model run would represent base or existing conditions. In this run, CEWES would apply the February 1992 survey channel depths. The second run, representing plan conditions, would incorporate the February 1992 channel configuration except that any shallower areas within the navigation channel would be deepened to 48 feet. Any channel feature that was already 48 feet deep or deeper would be unaffected. The two model runs would use the same computational mesh and boundary conditions.

Boundary Conditions

Participants agreed that the model would be run using an ocean boundary salinity condition of 33 parts per thousand (ppt), based on data in The Columbia River Estuary: Atlas of Physical and Biological Characteristics (Fox et al. 1984). Approximately two neap-spring tidal cycles would be synthetically generated over the late summer and fall period of 1993. A freshwater discharge of 134,000 cubic feet per second (cfs) would be assumed, representing a typical late summer or early autumn (i.e., low flow period) value for total discharge from the Columbia River. This number represents the average discharge during the low-flow period for 1943 to 1957. A freshwater salinity of 0 ppt would also be assumed. A second model run would be performed using these same boundary conditions with the exception of a lower discharge rate, to be chosen by CEWES. The modelers chose a value of 120,000 cfs, so that the sensitivity of the model to a reduction in freshwater outflow could be determined.

Geographic Areas of Concern

Participants instructed CEWES to add elements (and nodes) to the computational mesh for Youngs Bay and Cathlamet Bays. Also, they instructed CEWES to model the effect of the islands located between River Miles (RM) 33 and 45. As a result, the channel was split in two (the navigation channel on the north side of the estuary and Prairie Channel along the southern shoreline) by adding four island units:

- Puget and Whites Islands

- Tenasillahe and Welch Islands

- Horseshoe, Brush, and Marsh Islands

- Russian, Seal, and Karlson Islands

Assumptions regarding the effects of depth and material type on flow were incorporated by applying higher friction coefficients to nodes over shallow areas than to those in the ship channel (Figure 3-2).

The workshop participants directed CEWES to develop expected changes in surface and bottom salinity at 19 specific points in the north channel, the ship channel, and Youngs and Cathlamet Bays (Figure 3-3). That is, at each nodal point, the model would produce two plots of surface and bottom salinities over time, one representing the existing channel conditions and one representing the plan conditions after deepening to 48 feet. The difference between these two conditions at each point would also be plotted. CEWES summarized and discussed these results at the second workshop.

At the conclusion of the second workshop, the participants determined that more information was needed on species assemblages and salinity conditions in shallow subtidal habitats in Cathlamet Bay. They directed CEWES to extract the same information for existing and plan conditions for intertidal and shallow subtidal areas. Sites were chosen based on the availability of existing data on benthic community structure. Based on further information, including the relatively large change in salinity predicted for the channel bottom, the biological consultant suggested that four more sites be evaluated. Thus, CEWES was directed to provide salinity data for a total of 10 sites between RM 20 and RM 30 (Figure 3-4).

3.2 Investigation of Impacts to Benthic Macroinvertebrates

The workshop participants made the assumption that sedentary organisms (i.e., benthic macroinvertebrates and vascular aquatic plants) would be more susceptible to short-term changes in salinity than mobile species such as fish. They therefore directed the biological consultant to focus research on benthic assemblages. The criterion for measuring impacts to species would be a comparison of the maximum expected salinity to known salinity tolerances.

The consultant evaluated potential impacts to benthic organisms at 10 sites incorporating 3 habitat types (Table 3-1). These sites are located within the Tidal-Fluvial Zone of the estuary (Simenstad et al. 1990), the large region between RM 20 and RM 30 that is characterized by relatively uniform, low salinity conditions (Figure 3-5). Small increases in salinity in the Tidal-Fluvial Zone are considered more likely to have biological effects than equivalent changes in either the Plume and Ocean or Estuarine Mixing Zone where daily salinity fluxes are relatively large.

The evaluation of potential impacts to benthic organisms was accomplished through the following steps:

1. Results of the hydrodynamic model were used to estimate both existing salinity ranges and expected increases in salinity at each of the selected study sites. The study sites represented three distinct habitat types (intertidal, shallow subtidal, and channel)

2. Published scientific data on species-specific salinity tolerance ranges of all benthic organisms identified to species at each study site were summarized (Figure 3-6)

3. Species that had salinity tolerance limits within or very close to the upper end of the salinity range predicted for the site were determined

4. Species identified as potentially sensitive to predicted increases in salinity were examined in more detail with respect to their habitat requirements, life histories, and distribution patterns

5. Community structure at each site was described in terms of taxonomic composition (species richness), total numerical abundance, relative numerical abundance, diversity (H) and equitability (E) with the objective of defining a sensitive species' role in an assemblage. Diversity and equitability are defined below.

6. Findings were summarized for the three habitat types studied: intertidal, shallow subtidal, and channel bottom

Diversity was calculated using the Shannon-Weiner function (Krebs 1978):

$$H = \sum_{i=1}^{s} (p_i)(\log_2 p_i)$$

where:

$$p_i = \frac{X_a}{n}$$

s = number of taxa
X_a = number of individuals of species *a* in the sample
n = total number of individuals of all species in the sample

Equitability (E) measures the proportional abundances of the various species in a sample (Krebs 1978). The value of E can range from 0.00 to 1.00. An E of 1.00 would indicate that all of the species in a sample were equally abundant.

$$E = \frac{H}{\log_2 s}$$

where:

H = Shannon-Weiner function (see above)
s = number of taxa in the sample

Results of this investigation are presented in detail in Woodward-Clyde Federal Services (1996). Findings are summarized in Section 4.0 (Results and Conclusions, below).

3.3 Investigation of Impacts to Vascular Aquatic Plants

Potential impacts to vascular aquatic plants at five locations in the Tidal-Fluvial Zone of the estuary were investigated (Mazaika 1996):

- Miller Sands
- Tronson Island
- Pillar Rock
- Rice Island
- Mott Island

These sites were chosen based on the availability of information on vascular aquatic plant distributions. Potential impacts were evaluated through the following steps:

1. Existing data on distributions of vascular aquatic plants in the Columbia River estuary were assembled (i.e., data from Macdonald 1984 and Smith and Goudzwaard 1993)

2. A list of 11 species for analysis of salinity tolerances was assembled based on relative abundances in the marsh communities of the Tidal-Fluvial zone of the estuary. The list included 2 relatively unique species (i.e., *Sagittaria latifolia* and *Sium sauve* which occur infrequently in the study area).

3. Salinity tolerances of vascular aquatic plants were inferred from observed distributions in estuaries throughout the Pacific northwest (including the Columbia River)

4. It was assumed that species considered tolerant or moderately tolerant (Hutchinson 1988) were not likely to be excluded from habitats in the Tidal-Fluvial Zone by salinity changes of the magnitude predicted by the model (i.e., less than 0.5 ppt)

5. The tolerances of species identified as "sensitive" or "very sensitive" to salinity were compared to the predicted maximum surface water salinity at each study site to determine whether any of these species would be excluded

Results of this investigation are presented in detail in CENPP (1996). Findings are summarized in Section 4.0, Results and Conclusions (below).

4.0 RESULTS AND DISCUSSION

4.1 Hydraulic and Salinity Modeling

Figure 4-1 shows a plot of surface and bottom salinities averaged over a 1200-hour simulation run for the channel between RM 0 to RM 40. This figure shows that the planned channel deepening would have little effect on the average surface salinity whereas average bottom salinity would be increased by less than 1 ppt. The same type of data was derived for the off-channel locations specified as areas of concern by the resource agencies and recommended by the biological consultant (Figure 3-3). In Figure 4-2, average top and bottom salinities at each site under both existing and plan conditions are shown in bar graphs. Differences of greater than 0.5 ppt are again shown to be restricted to the channel bottom.

CEWES also developed plots of bottom salinity under existing conditions and expected changes due to channel deepening at 10 sites between RM 20 and RM 30, as requested by the agencies and the biological consultant (shown in Figure 3-4). These plots are shown in Figures 4-3 through 4-22). In this case, predicted salinities are presented for each point in time over the 1200-hour simulation. The existing range and maximum increase in surface and bottom water salinity at each site are shown in Tables 4-1 and 4-2, respectively. Surface water salinity would increase by less than 0.15 ppt at all 10 sites. Bottom salinity would increase only 0.05 ppt at shallow subtidal station D9 but by as much as 2.45 ppt at channel station E3.

The difference in degree of salinity intrusion between surface and bottom waters of the estuary results from the vertical stratification of incoming and outgoing water bodies relative to salinity. This phenomenon is reproduced by the model. Because freshwater is less dense, the freshwater flowing downriver essentially floats on top of the incoming ocean water. The resulting longitudinal pressure gradient creates density currents which transport seawater landward along the bottom. The channel bottom is irregular with shallower shoals and deeper scours. If the shallower shoals were deepened, the higher salinity water on the bottom could be pushed farther upriver along the bottom by the incoming tide. The surface layer, however, would remain largely unaffected.

During neap tides, tidally-induced mixing is minimized, stratification is enhanced, and salinity intrudes further upstream along the bottom. During spring tides, the larger volume of water moving landward induces tidal mixing, reducing stratification and the degree of salinity intrusion. Thus, according to the Corps model, the new maximum salinities shown in Tables 4-1 and 4-2 would persist for up to 2 to 4 hours over a neap tidal cycle under the specified flow and tidal conditions. For vascular aquatic plants at elevations above mean low water, the period of inundation and thus of exposure to higher salinity would decrease with elevation in the intertidal zone.

Bottom isohalines for the existing channel configuration under the two modeled freshwater discharge rates (134,000 and 120,000 cfs) are compared in Figure 4-23. As shown, a 10 percent decrease in freshwater outflow would result in a much larger salinity change, especially away from the channel, than the proposed channel deepening (Figure 4-24).

4.2 Impacts to Benthic Macroinvertebrates

Results of the investigation of potential impacts to benthic invertebrates are described in detail in Woodward-Clyde Federal Services (WCFS) (1996) and are summarized here. As shown in Table 4-2, with the exception of two sites in the navigation channel, the maximum increase in bottom-water salinity at any of the selected study sites would be less than 0.5 ppt over existing conditions. Where salinity tolerances are known from bioassay experiments or life history data (Figure 3-6), the biological consultant concluded that there is no evidence that species would be excluded from existing habitats by short-term (2- to 4-hours over a neap tidal cycle) increases in bottom water salinity of less than 0.5 ppt.

Larger increases in salinity resulting from saltwater intrusion were predicted for two of the channel stations, S22 and S28. According to the model, a maximum, short-term increase in bottom water salinity of 2.45 ppt at site S22 would result in a maximum *in situ* salinity of 7.15 ppt for 2 to 4 hours over a neap tidal cycle. The smaller predicted increase of 0.85 ppt would result in a maximum short-term salinity of 2.5 ppt at site S28. Based on the information presented in Figure 3-6, none of the organisms identified to species at station S22 or S28 would be excluded from existing habitats by these short-term increases in bottom water salinity.

The analysis of benthic community structure at each of the study sites indicated that, in terms of numbers, benthic communities were typically dominated by one or two taxa. During the low-flow period, *Corophium salmonis, Corbicula fluminea*, oligochaetes, and midge larvae predominated at the intertidal sites. *Corophium salmonis* and oligochaetes dominated the fauna at most of the subtidal stations.

For samples collected during the low-flow period, diversity indices (H) ranged from 0.94 to 2.35 at intertidal sites and from 0.33 to 2.56 at subtidal sites (Table 4-3). Values in this range indicate very low to moderate species diversity. The lowest value occurred at one of the channel sites (S30) at the upstream end of the Tidal-Fluvial Zone. Equitability (E) was low (0.22 to 0.30) at both the intertidal and subtidal sites, reflecting a repeated pattern of dominance by one or two species. Typically, these species were *Corophium salmonis* and *Corbicula fluminea* (plus large numbers of unidentified oligochaetes), organisms with distributions extending from freshwater, well upstream of the estuary, down into the Mixing Zone. It is unlikely that the small changes in salinity predicted by the model from the planned channel deepening would have a significant impact on these abundant taxa or on overall community structure as measured by diversity and equitability.

The predicted increase in salinity along the navigation channel between RM 20 and RM 30 could result in upstream range extensions for species that are presently restricted to higher salinity habitats. Benthic organisms identified to species in subtidal habitats during the low-flow period and their distributions along the salinity gradient between S20 and S33.5 are shown in Figure 4-25. The number of species per station appeared to decline at stations with estimated *in situ* salinities less than 2 ppt. This suggests that the upstream distributions of some species may presently be limited by low salinities although other physical, chemical, or biological factors may also be involved. Most of the species shown in Figure 4-25 occurred only at shallow subtidal sites where bottom water salinities would increase by less than 0.5 ppt. Of those species occurring at channel stations, the sand dwelling amphipod *Eohaustorius estuarius* was relatively abundant at S22 but absent from the channel stations further upstream (i.e., S28 and S30). Salinity tolerance data for *E. estuarius* indicate that its lower limit is approximately 2 ppt (Figure 3-6). *Eohaustorius estuarius* has been shown to be relatively abundant on lower elevation intertidal sand flats and subtidal areas in the Mixing Zone of the estuary. If the upstream distribution of *E. estuarius* in the navigation channel is presently limited by low salinity, the predicted increase in bottom water salinity could allow it to extend its distribution somewhat further up the channel.

Corophium brevis, with a lower salinity tolerance limit of approximately 5 ppt (Figure 3-6), is another potential candidate for upstream extension of its distribution. *Corophium brevis* is typically found in the more saline portions of the estuary and was not present at any of the sites from the Tidal-Fluvial Zone. It is possible that other components of the Mixing Zone benthos could extend their distributions further up the channel but, unless these species were found at sites in the Tidal-Fluvial Zone, their salinity tolerance ranges were not identified.

The impact of upstream extensions of species distributions on the channel benthic community would probably be small. The number of species that are able to inhabit the current-swept channel environment is limited, as indicated by short taxonomic lists for the channel sites (WCFS 1996). Under existing conditions, *Corophium salmonis*, an opportunistic colonizer, is the numerically dominant component of the channel benthos during the low-flow period. Juveniles and adults periodically swim up into the water column and disperse, giving this species a competitive advantage over those with more limited dispersal mechanisms. *Corophium salmonis* is a numerically abundant component of the benthos at a number of locations in the Estuarine Mixing Zone where salinities are higher than those predicted by the model for channel sites in the Tidal-Fluvial Zone. The biological consultant suggested that it would be reasonable to assume that *C. salmonis* would remain abundant in the channel benthos even if channel deepening results in an upstream extension of species such as *C. brevis* and *Eohaustoris estuarius*.

The biological consultant considered the impact of potential upchannel extensions of the ranges of *Corophium brevis* and *Eohaustorius estuarius* on the food habits of estuarine fish resources. In a comprehensive study of the feeding habits of fishes in the Columbia River estuary by Bottom and Jones (1990), the annual average densities of fishes and epibenthic invertebrates followed similar trends: maximum densities on the tidal flats or in protected bays, intermediate values on the demersal slope and low values on the channel bottom. Stomach fullness varied along the same gradient; the index of feeding intensity (IFI) was highest in shallow, protected bays and was also high at channel bottom stations in the Estuarine-Mixing Zone. These results imply that the channel habitat in the Tidal-Fluvial Zone, where abundances of benthic organisms are low, is not an important feeding habitat for fish. Therefore, any potential up-channel range extension by *C. brevis* or *E. estuarius* into this zone would probably not significantly affect overall fish food relations in the estuary.

4.3 Impacts to Vascular Aquatic Plants

As shown in Table 4-2, the CEWES model predicted that the maximum increase in bottom-water salinity at any of the five study sites for aquatic plants would be less than 0.5 ppt. For intertidal elevations near or below mean low water, it was assumed that the duration of this change would be less than 2 to 4 hours over a neap tidal cycle. For higher elevations (i.e., approaching mean high water), the period of inundation and therefore of exposure to higher salinities would decrease.

Eleven species of aquatic plants were selected for analysis of salinity tolerances from data developed by Macdonald (1984). These authors conducted a cluster analysis using abundance data gathered at sites throughout the estuary. Nine of the 11 species are common and dominant in assemblages throughout the Tidal-Fluvial Zone of the estuary. Two are relatively unique (i.e., species that occur infrequently within the study area) (Table 4-4).

Representatives of this group have been observed at 5 of the sites in Cathlamet Bay for which CEWES modeled changes in salinity (Table 4-5).

Hutchinson (1988) summarized the salinity tolerances of 116 vascular plants. He established maximum limits of distribution in the field with respect to salinity for 79 of these, including the 11 selected for this analysis:

Rush *(Juncus balticus)* occurs in mud and brackish and freshwater meadows; salinity range of 0 to 27 ppt in estuaries throughout the Pacific northwest and northern California (0 to 11 ppt in the Columbia River estuary). Salt sensitivity rating "very tolerant".

Rush *(Juncus oxymerus)* occurs in marsh habitat; salinity range of 0 to 2 ppt in estuaries throughout the Pacific northwest and northern California (0 to 1 ppt in the Columbia River estuary). Salt sensitivity rating "sensitive".

Lyngby's sedge *(Carex lyngbyei)* occurs in intertidal marsh habitat; salinity range of 0 to 25 ppt in estuaries throughout the Pacific northwest and northern California (0 to 12 ppt in the Columbia River estuary). Salt sensitivity rating "tolerant".

Common spikerush *(Eleocharis palustris)* occurs in wetland habitat; salinity range of 0 to 12 ppt in estuaries throughout the Pacific northwest and northern California (0 to 4 ppt in the Columbia River estuary). Salt sensitivity rating "moderately tolerant".

Tufted hairgrass *(Deschampsia caespitosa)* occurs in high marsh habitat; salinity range of 0 to 25 ppt in estuaries throughout the Pacific northwest and northern California (2.5 to 11 ppt in the Columbia River estuary). Salt sensitivity rating "tolerant".

Lilaeopsis *(Lilaeopsis occidentalis)* occurs in muds of freshwater or brackish marsh habitats; salinity range of 0 to 20 ppt in estuaries throughout the Pacific northwest and northern California (5 to 16 ppt in the Columbia River estuary). Salt sensitivity rating "tolerant".

Skunk cabbage *(Lysichitum americanum)* occurs in coastal swamps or high marsh habitats; salinity range of 0 to 0.5 ppt the Columbia River estuary. Salt sensitivity rating "very sensitive".

Wapato *(Sagittaria latifolia)* occurs in ponds and muck in shallow freshwater marsh habitat; salinity range of 0 to 5 ppt in estuaries throughout the Pacific northwest and northern California (0 to 0.5 ppt in the Columbia River estuary). Salt sensitivity rating "sensitive".

Water parsnip *(Sium sauve)* occurs in freshwater and high marsh habitats; salinity range of 0 to 5 ppt in estuaries throughout the Pacific northwest and northern California (0 to 0.5 ppt in the Columbia River estuary). Salt sensitivity rating "sensitive".

Pacific silverweed *(Potentilla pacifica)* occurs in fresh and brackish high marsh habitat; salinity range of 0 to 20 ppt in estuaries throughout the Pacific northwest and northern California (0 to 12 ppt in the Columbia River estuary). Salt sensitivity rating "moderately tolerant".

Douglas aster *(Aster subspicatus)* occurs in high marsh habitat; salinity range of 0 to 15 ppt in estuaries throughout the Pacific northwest and northern California (0 to 12 ppt in the Columbia River estuary). Salt sensitivity rating "moderately tolerant".

As described in Section 3.3 (Investigation of Impacts to Vascular Aquatic Plants), it was assumed that species considered "tolerant" to "moderately tolerant" of salinity would not be excluded from habitats in the Tidal-Fluvial Zone based on the expected maximum short-term increase in salinity at intertidal and shallow subtidal sites (i.e., less than 0.5 ppt). This group included *Juncus balticus, Carex lyngbyei, Eleocharis palustris, Deschampsia caespitosa, Lilaeopsis occidentalis, Potentilla pacifica,* and *Aster subspicatus.* Species with relatively narrow ranges of tolerance included *Sagittaria latifolia, Sium sauve, Lysichitum americanum,* and *Juncus oxymerus. Lysichitum americanum* is considered "very sensitive" to salinity because it is typically found in high marsh habitats where the period of inundation is relatively brief (Thomas 1983).

The salinity tolerances of the 11 plant species studied, the short-term maximum bottom-water salinity predicted by the CEWES model for the 5 study sites, and the distributions of the species among the sites are shown in Figure 4-26. As expected, the seven species considered tolerant or moderately tolerant of salinity have tolerance ranges greater than those to which the model predicted they would be exposed after channel deepening. The tolerance ranges of the four "sensitive" species (*Sagittaria latifolia, Sium sauve, Juncus oxymerus,* and *Lysichitum americanum*) are narrower. However, each of these species currently occurs at a site where the maximum existing salinity predicted by the model is outside its "tolerance range". Thus, factors other than salinity, such as substrate type and period of inundation, must strongly influence the distributions of vascular aquatic plants. It was concluded that there is no evidence that any of the 11 species of aquatic plants studied would be excluded from existing habitats by a short-term (up to 2- to 4-hours over a neap tidal cycle) maximum increase in salinity of less than 0.5 ppt.

It is recommended that *Sagittaria latifolia, Sium sauve,* and *Juncus oxymerus* are potentially useful indicator species for monitoring potential effects of increased salinity after channel deepening. Each of these species was assumed to be relatively sensitive to salinity based on observed distributions in Pacific coast estuaries.

5.0 CONCLUSIONS OF THE WORKSHOP PARTICIPANTS

The results of the investigations on potential impacts to benthic invertebrates and vascular aquatic plants were presented at the third interagency workshop. A final discussion ensued regarding the development of a consensus statement on biological impacts that would serve as a concluding statement for the workshop series. Individual participants offered suggestions that:

- There is a small impact from salinity that may be immeasurable
- The predicted amounts of salinity change are masked by the natural variability of the system
- There is no significant biological impact with respect to salinity from the proposed channel deepening
- The change in salinity will not have an impact on habitat and biology of the area
- There will be little or no impact to benthic invertebrates and to vascular plants
- There would be no identifiable impact
- The impacts could be characterized according to natural fluctuations on the river, using a comparative approach
- Salinity is a nonissue with respect to potential construction of a deeper channel as presently proposed
- The predicted salinity changes and impacts to the biological community are within the realm of natural variability on the river

All participants came to consensus and accepted as their own the following statement:

- No significant biological impact would result from salinity changes predicted for the proposed channel deepening

With the intent of creating a set of conclusions for the workshop, the participants reviewed and made minor revisions to the conclusions researchers. Consensus was achieved on the following:

<u>Impacts to Benthic Macroinvertebrates</u>

- Small increases in bottom water salinity of less than 0.5 ppt due to planned channel deepening would be predicted at intertidal and shallow subtidal sites
- Short-term increases in bottom water salinity of up to 2.45 ppt due to planned channel deepening would be predicted at channel sites
- Changes of this magnitude could permit short, upchannel range extensions by salinity-dependent species (e.g., *Eohaustorius estuarius* and *Corophium brevis*)
- *Corophium salmonis* would be likely to remain the numerically dominant species at most sites, including channels
- No impact on fish food resources would be expected

<u>Impacts to Vascular Aquatic Plants</u>

- No significant effect on species examined in the present analysis is expected to result from a 0.5 ppt maximum increase in salinity in the Columbia River estuary
- Of the species selected for the analysis, *Sagittaria latifolia, Sium sauve, Lysichitum americanum,* and *Juncus oxymerus* reflect the species with the high sensitivity to changes in salinity
- It is likely that factors other than salinity are affecting plant species distribution in the Columbia River estuary
- Although species of *Sium sauve, Sagittaria latifolia* and *Juncus oxymerus* exhibit a higher degree of sensitivity relative to other species included in this analysis, these species often occur in habitats typified by salinities that exceed the individual species salinity tolerance and therefore are likely distributed along another (e.g., elevational/inundation, substrate) gradient

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Table 2-1
Agencies and Individuals Participating in the Workshop Series

AGENCY	PARTICIPANT
Bonneville Power Administration	Tom Vogel
CREST	Peter Britz
Oregon Department of Environmental Quality	Bill Young
Oregon Department of Fish and Wildlife	Don Bennett
Ports of Portland and Vancouver	Danil Hancock, Hartman Associates
U.S. Fish & Wildlife Service	Kathi Larson
U.S. Environmental Protection Agency	John Malek
U.S. Army Corps - Portland District	Karl Erikson and Kim Larson
Washington Department of Fish and Wildlife	Ken Mohoric
Washington Department of Ecology	Rick Vining

Table 3-1
Habitat Types Represented by Benthic Macroinvertebrate Sampling Sites

INTERTIDAL SITES	SHALLOW SUBTIDAL SITES	CHANNEL SITES
Rice Island	Mott Island	E3
Miller Sands	Rice Island	E4
Pillar Rock Island	Miller Sands	Km46
	Minaker Island	
	Pillar Rock Island	
	Tronson Island	
	D9	

Table 4-1
Estimated Existing Salinity Ranges and Maximum Increases in Surface Water Salinity

SITE #	SITE NAME	EXISTING RANGE (ppt)	MAXIMUM INCREASE (ppt)	NEW MAXIMUM (ppt)
S20	Mott Is.	1.4-5.9	0.13	6.03
S21	Rice Is.	0.2-5.4	0.12	5.52
S23	Miller Sands	0.5-3.3	0.08	3.38
S27	Pillar Rock Is.	0.2-2.1	0.07	2.17
S29	Tronson Is.	0.2-1.2	0.04	1.24

Table 4-2
Estimated Existing Salinity Ranges and Maximum Increases in Bottom Water Salinity

SITE #	SITE NAME	DEPTH (ft)	EXISTING RANGE (ppt)	MAXIMUM INCREASE (ppt)	NEW MAXIMUM (ppt)
S20	Mott Is.	20	2.3-7.5	0.44	7.94
S21	Rice Is.	12	1.4-6.4	0.28	6.68
S22	E3	50	1.0-4.7	2.45	7.15
S23	Miller Sands	15	0.7-3.5	0.26	3.76
S25	Minaker Is.	15	0.9-2.8	0.18	2.98
S27	Pillar Rock Is.	15	0.1-2.0	0.17	2.17
S28	Km46	33	0.1-1.6	0.85	2.45
S29	Tronson Is.	15	0.3-1.2	0.08	1.28
S30	E4	50	0.0-0.9	0.38	1.28
S33.5	D9	6	0.0-0.7	0.05	0.75

Table 4-3
Shannon-Weiner Diversity (H) and Equitability (E) for the August/September (Low-Flow) Period

RMile	INTERTIDAL STATIONS Study Site	Year	H	E	Mean Abun.	± SE	Dominant Taxon	p_i
21	S21 (Rice Island)	1988	1.61	0.13	11,946	5,162	*Corophium salmonis*	0.62
		1989	2.02	0.22	487	168	*Corbicula manilensis*	0.30
							Oligochaeta	0.39
		1991	1.74	0.16	2,388	1,940	*Corophium salmonis*	0.65
23	S23 (Miller Sands)	1975	0.94	0.07	6,940	1,336	*Oligochaeta*	0.81
							Corophium salmonis	0.14
		1976	1.55	0.13	3,472	278	*Oligochaeta*	0.54
							Corophium salmonis	0.34
		1988	2.35	0.16	30,817	9,239	*Oligochaeta*	0.40
							Corophium salmonis	0.37
		1889	1.67	0.12	14,176	5,758	*Corophium salmonis*	0.58
							Oligochaeta	0.30
		1991	1.8	0.13	22,135	*	*Oligochaeta*	0.50
							Corophium salmonis	0.26
		1992	2.33	0.15	60,795	8,416	*Oligochaeta*	0.51
							Chironomid larvae	0.23
27	S27 (Pillar Rock Island)	1988	1.91	0.13	20,131	5,616	*Oligochaeta*	0.45
							Corophium salmonis	0.39
		1989	1.83	0.13	24,633	9,317	*Oligochaeta*	0.57
							Corophium salmonis	0.24

* No standard error calculated where n=1 sample

(continued)

Table 4-3 (cont.)

RMile	*SUBTIDAL STATIONS* *Study Site*	*Year*	*H*	*E*	*Mean Abun.*	*± SE*	*Dominant Taxon*	p_i
20	S20 (Mott Island)	1984	1.44	0.08	231,393	13,247	*Coullana canadensis*	0.73
21	S21 (Rice Island)	1991	0.84	0.05	44,298	5,315	*Corophium salmonis*	0.88
22	S22 (E3)	1991	2.25	0.21	1,333	*	*Corophium salmonis*	0.34
							Nematoda	0.33
							Eohaustorius estuarius	0.19
23	S23 (Miller Sands)	1984	2.26	0.16	36,538	6,771	*Corophium salmonis*	0.70
		1988	0.95	0.06	90,751	*	*Corophium salmonis*	0.78
							Oligochaeta	0.18
25	S25 (Minaker Island)	1984	2.56	0.17	35,331	4,428	*Nematoda*	0.40
							Corophium salmonis	0.22
27	S27 (Pillar Rock Island)							
	subtidal - restoration area	1992	1.48	0.11	15,926	3,310	*Corophium salmonis*	0.51
							Ceratopogonidae	0.39
	subtidal - control area	1992	1.89	0.13	47,267	4,769	*Corophium salmonis*	0.59
							Oligochaeta	0.08
28	S28 (Km46)	1988	1.61	0.14	3,643	*	*Corophium salmonis*	0.61
							Heleidae	0.25
		1989	0.95	0.09	2,140	*	*Corophium salmonis*	0.84
29	S29 (Tronson Island)	1991	1.67	0.10	99,333	*	*Oligochaeta*	0.61
							Nematoda	0.27
30	S30 (E4)	1991	0.33	0.03	5,633	*	*Corophium salmonis*	0.96
33.5	S33.5 (D9)	1991	1.23	0.10	5,867	*	*Corophium salmonis*	0.77

Table 4-4
Vascular Aquatic Plant Associations Selected for Analysis of Salinity Tolerance

CLUSTER	ASSOCIATION	DOMINANT VEGETATION
1	Ubiquitous in Cathlamet Bay	*Carex lyngbyei* *Deschampsia caespitosa* *Eleocharis palustris*
2	Ubiquitous in low marsh habitats throughout the estuary	*Lileopsis occidentalis* *Aster subspicatus* *Juncus balticus* *Juncus oxymerus* *Lysichitum americanum* *Potentilla pacifica*
3	Unique species	*Sagittaria latifolia* *Sium sauve*

Table 4-5
Distributions of Vascular Aquatic Plant Species at Study Sites in the Tidal Fluvial Zone of the Columbia River Estuary[1]

SPECIES	RICE ISLAND	MOTT ISLAND	MILLER SANDS	TRONSON ISLAND	PILLAR ISLAND
Juncus balticus	X		X		
Juncus oxymerus	X	X	X	X	
Carex lyngbyei	X	X	X	X	X
Eleocharis palustris	X	X	X	X	X
Deschampsia caespitosa	X	X	X	X	X
Lilaeopsis occidentalis	X	X		X	X
Lysichitum americanum		X		X	
Sagittaria latifolia	X	X			
Sium sauve	X	X			
Potentilla pacifica	X	X		X	
Aster subspicatus	X	X			

[1] Data from Macdonald (1984) and Smith and Goudzwaard (1993)

Figure 3-1
Grid System Used in the Hydraulic Model
Mouth to River Mile 50

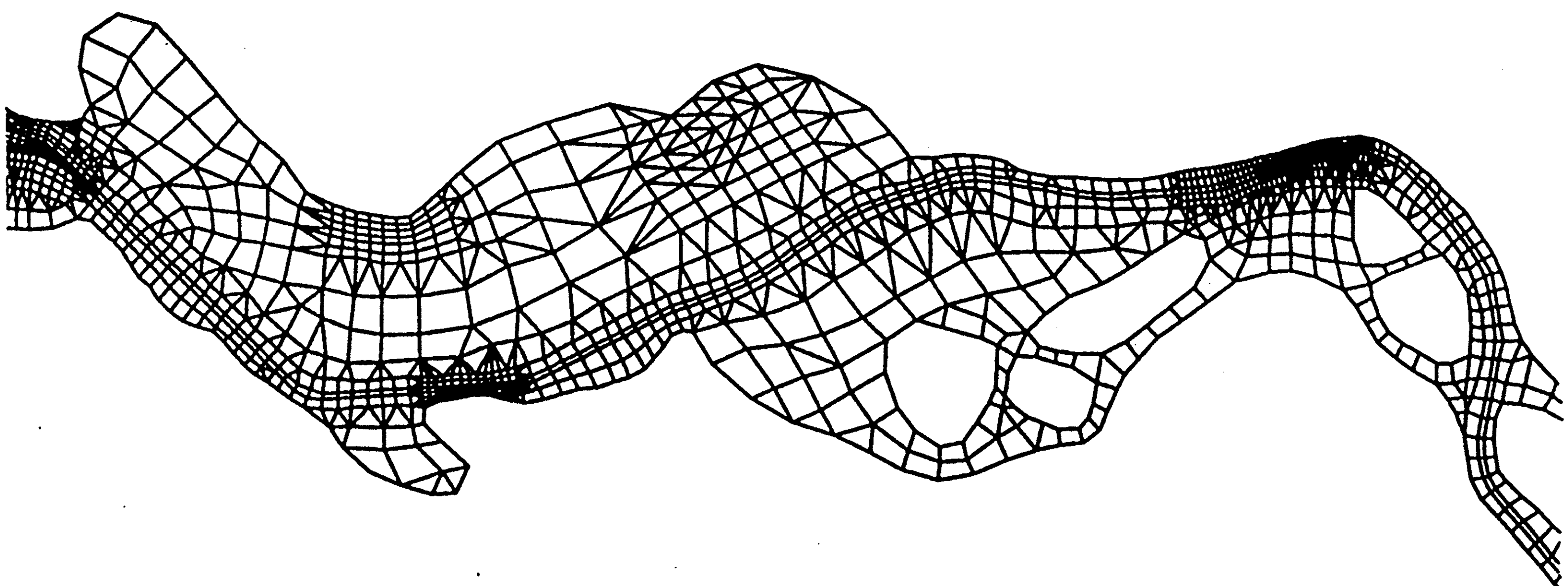


Figure 3-2
Material Boundaries Used in the Hydraulic Model

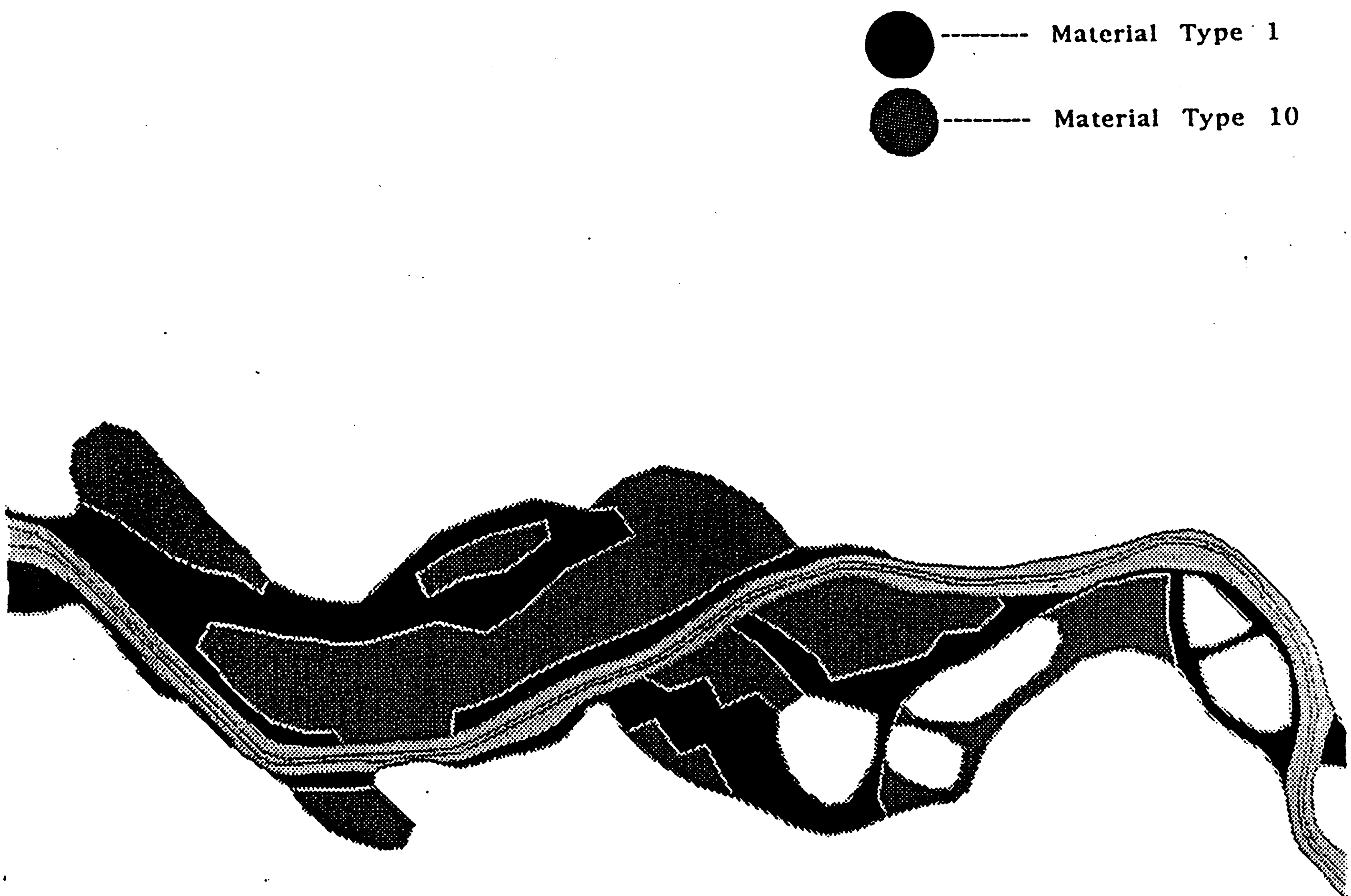


Figure 3-3
Salinity Locations in Columbia River Estuary

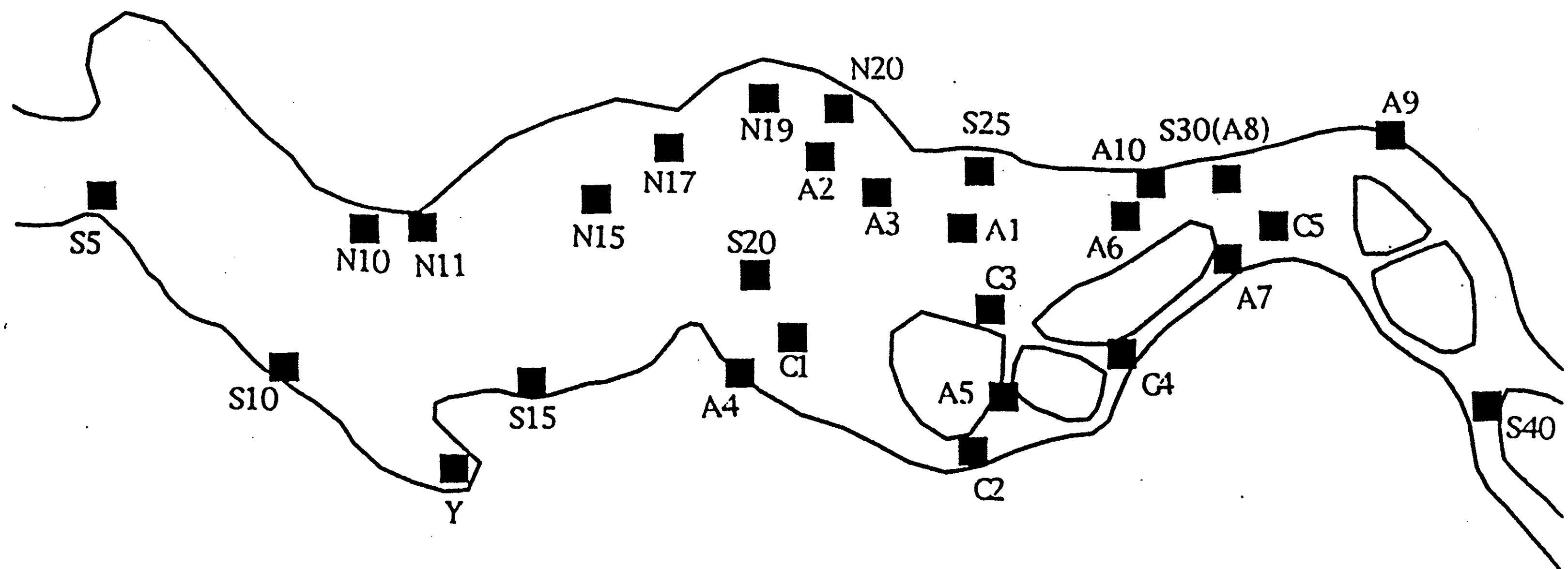


Figure 3-4
Locations of Benthic Invertebrate Sampling Sites and Nodes for Salinity Modeling

SITE NUMBER	SALINITY NODE	SITE NAME
S20	A4	Mott Island
S21	A2	Rice Island
S22	A3	E3
S23	A1	Miller Sands
S25	A5	Minaker Island
S27	A6	Pillar Rock Island
S28	A10	Km46
S29	A7	Tronson Island
S30	A8	E4
S33.5	A9	D9

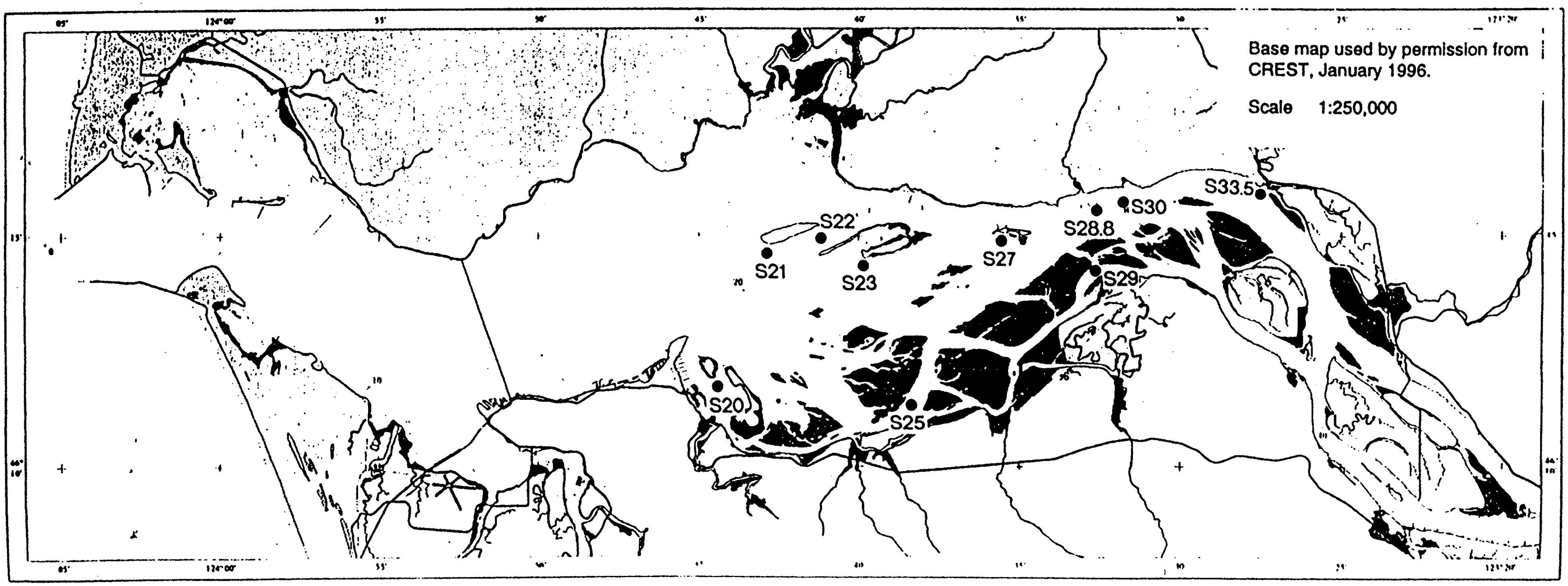
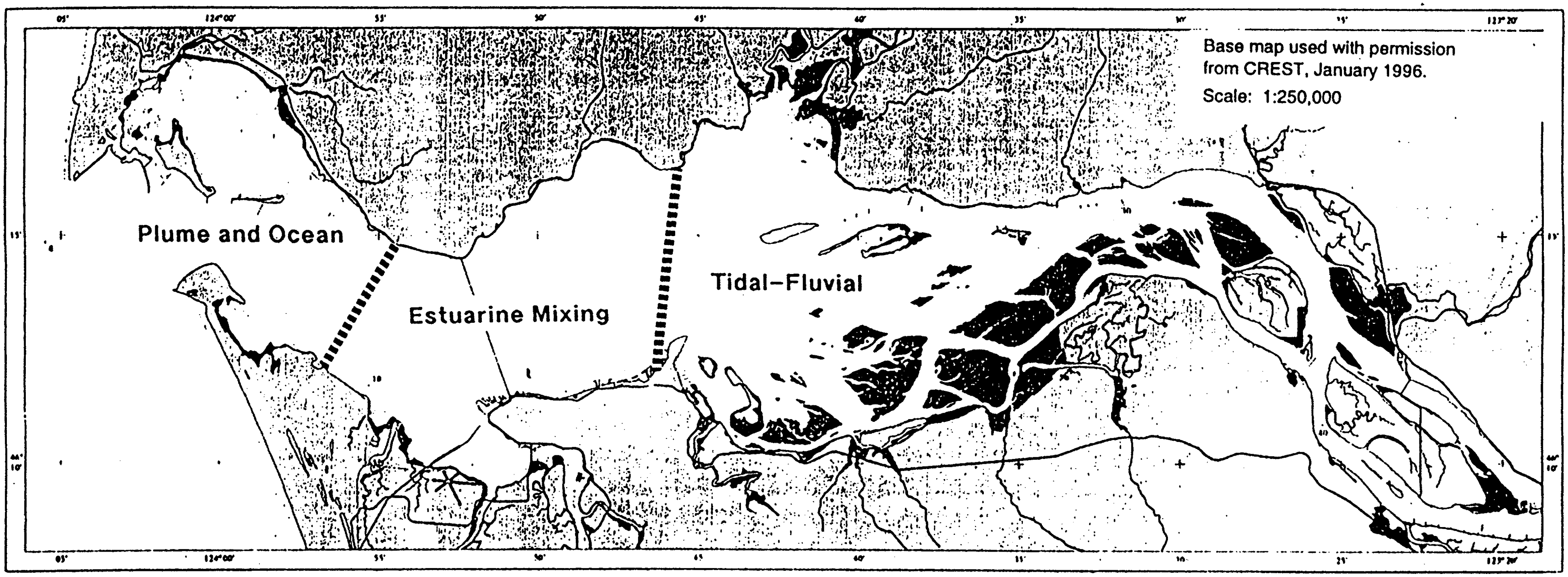
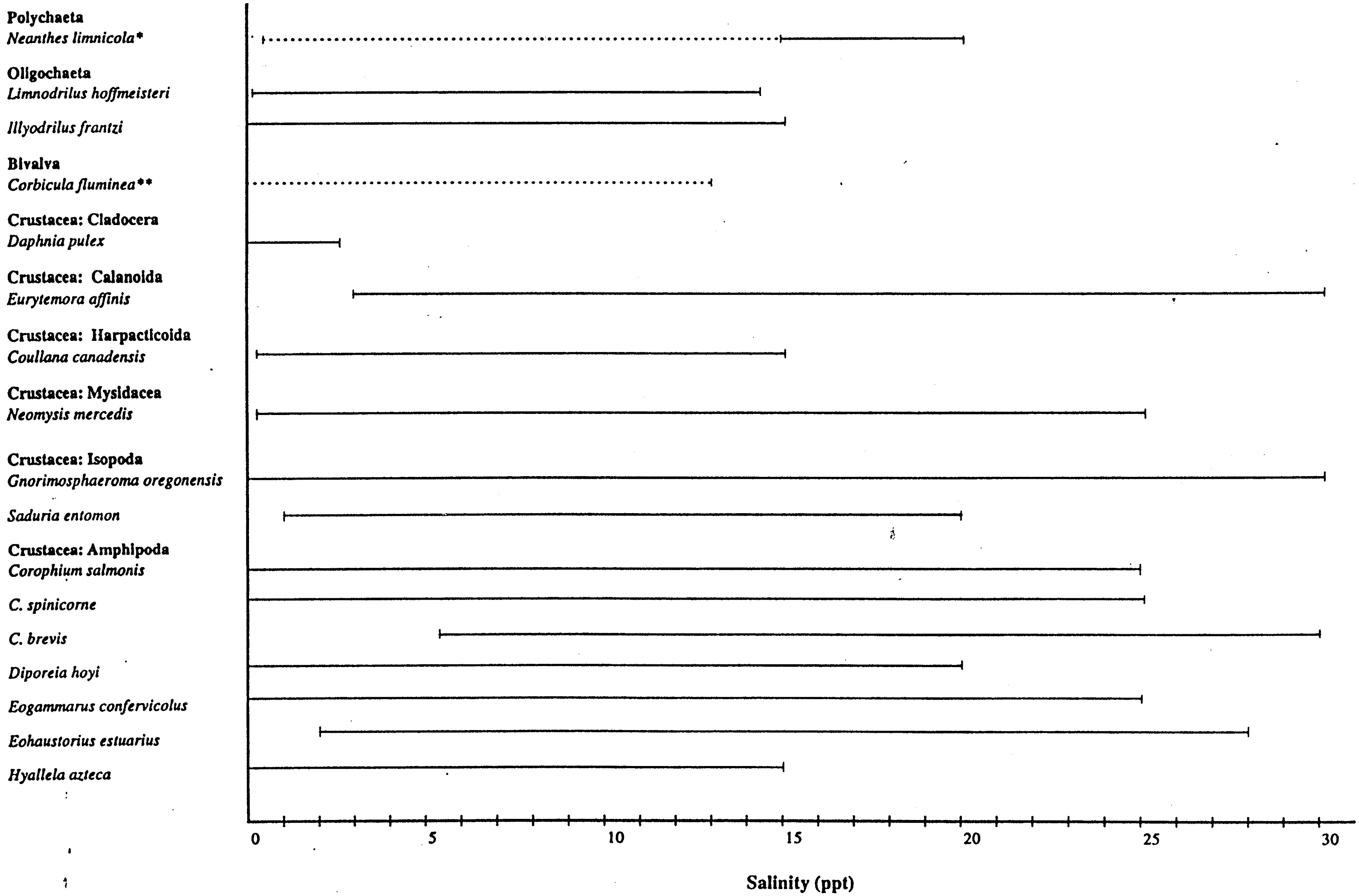


Figure 3-5
Columbia River Estuary Salinity Zones



From Simenstad et al. 1990

Figure 3-6
Salinity Tolerances of Benthic Macroinvertebrates



* Lower end of salinity tolerance range extended due to observations of *Hobsonia florida* at sites with *in situ* salinities down to 0.0 to 0.1 ppt.
**Observed salinity tolerance range in the field (Pennak 1989)

k9523\phaseii\salfig4

Figure 4-1
Comparison of Existing and Plan Salinities
Ship Channel Values, 1200-h Average

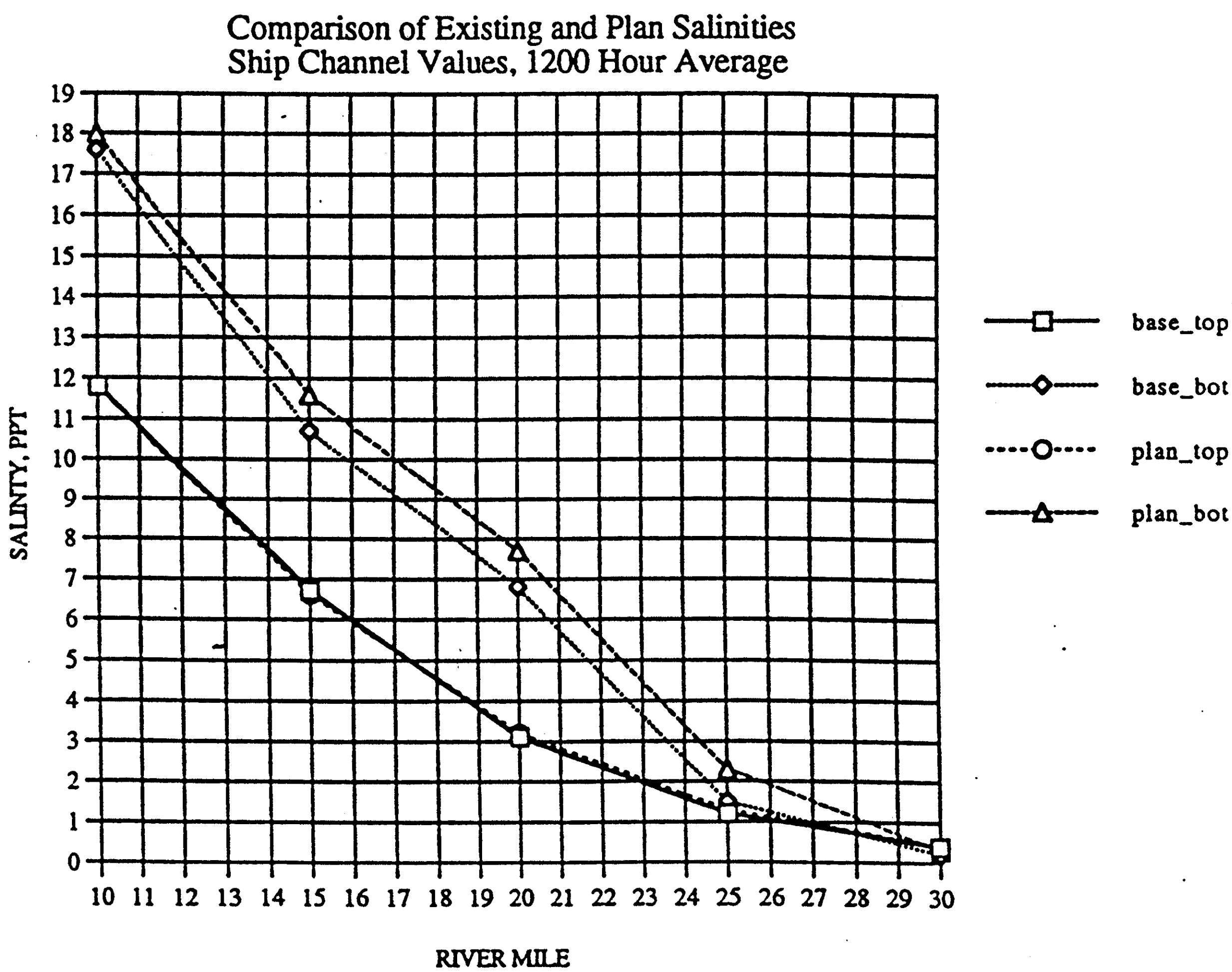


Figure 4-2
Comparison of Existing and Plan Salinities
North Channel, Grays, Cathlamet, and Youngs Bay

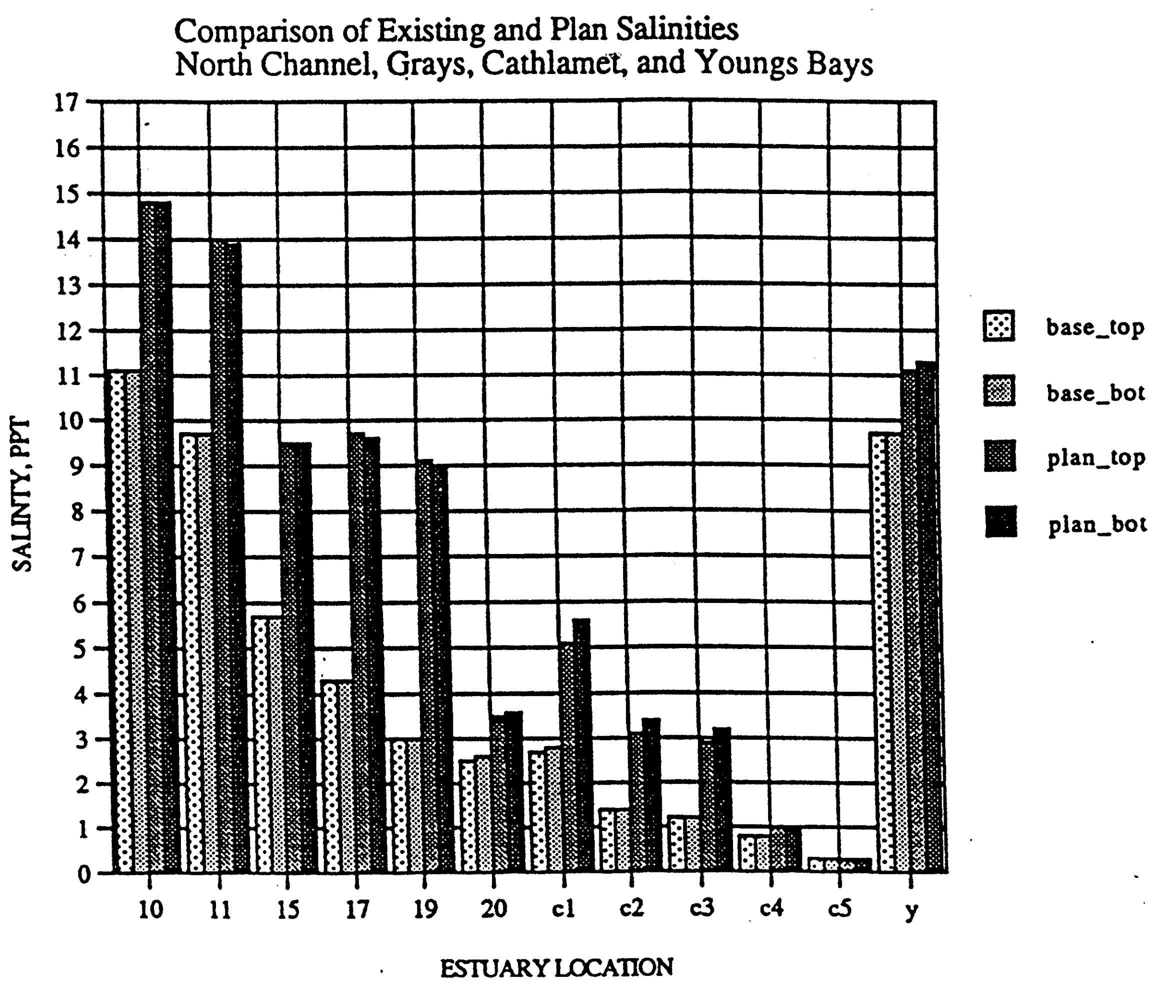


Figure 4-3
Bottom-Water Salinity at Node A1 (Site S23), Cathlamet Bay
Existing Channel Configuration

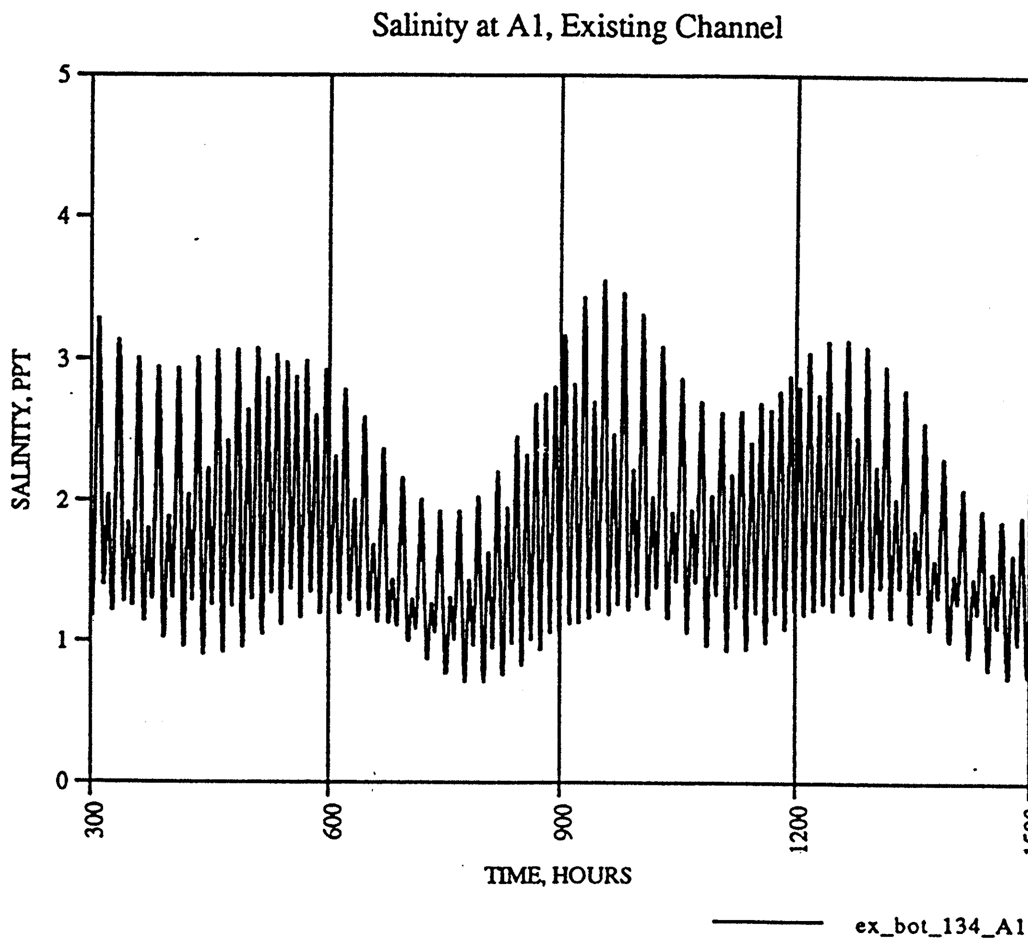


Figure 4-4
Bottom-Water Salinity at Node A2 (Site S21), Cathlamet Bay
Existing Channel Configuration

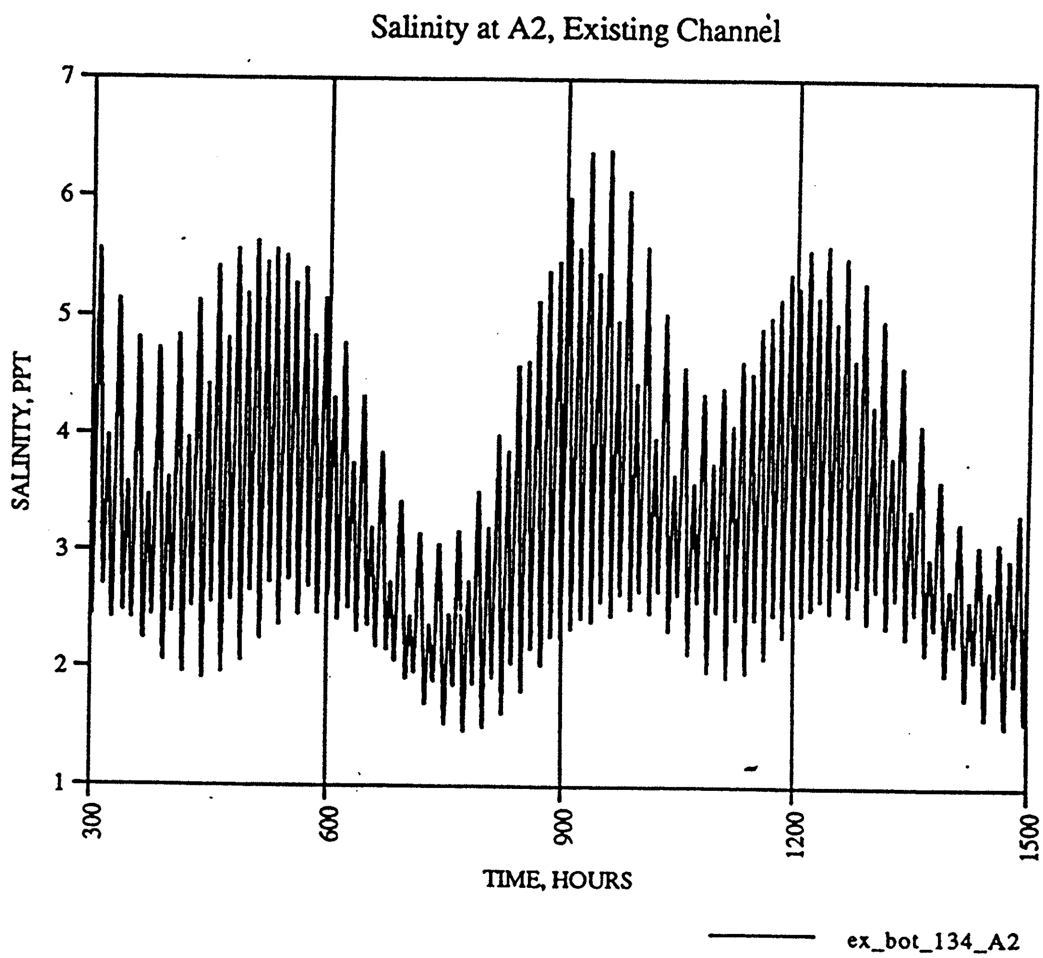


Figure 4-5
Bottom-Water Salinity at Node A3 (Site S22), Cathlamet Bay
Existing Channel Configuration

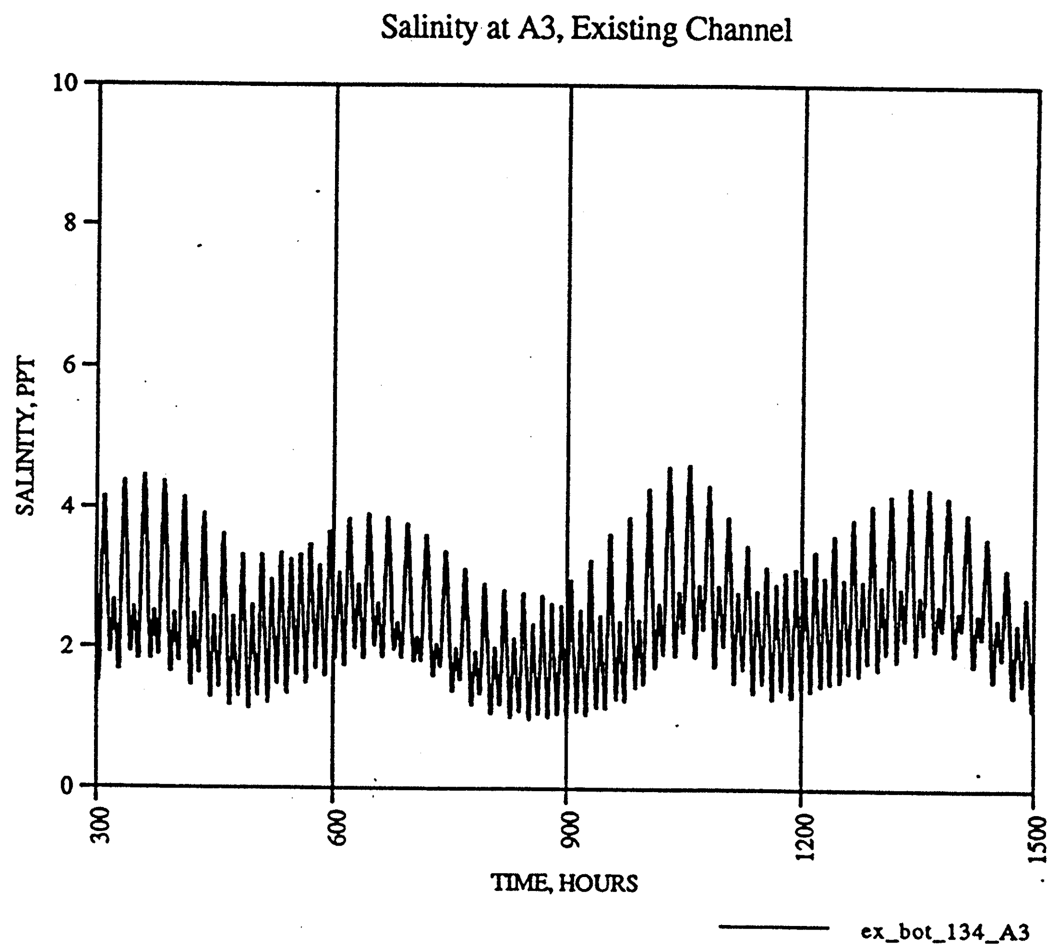


Figure 4-6
Bottom-Water Salinity at Node A4 (Site S20), Cathlamet Bay
Existing Channel Configuration

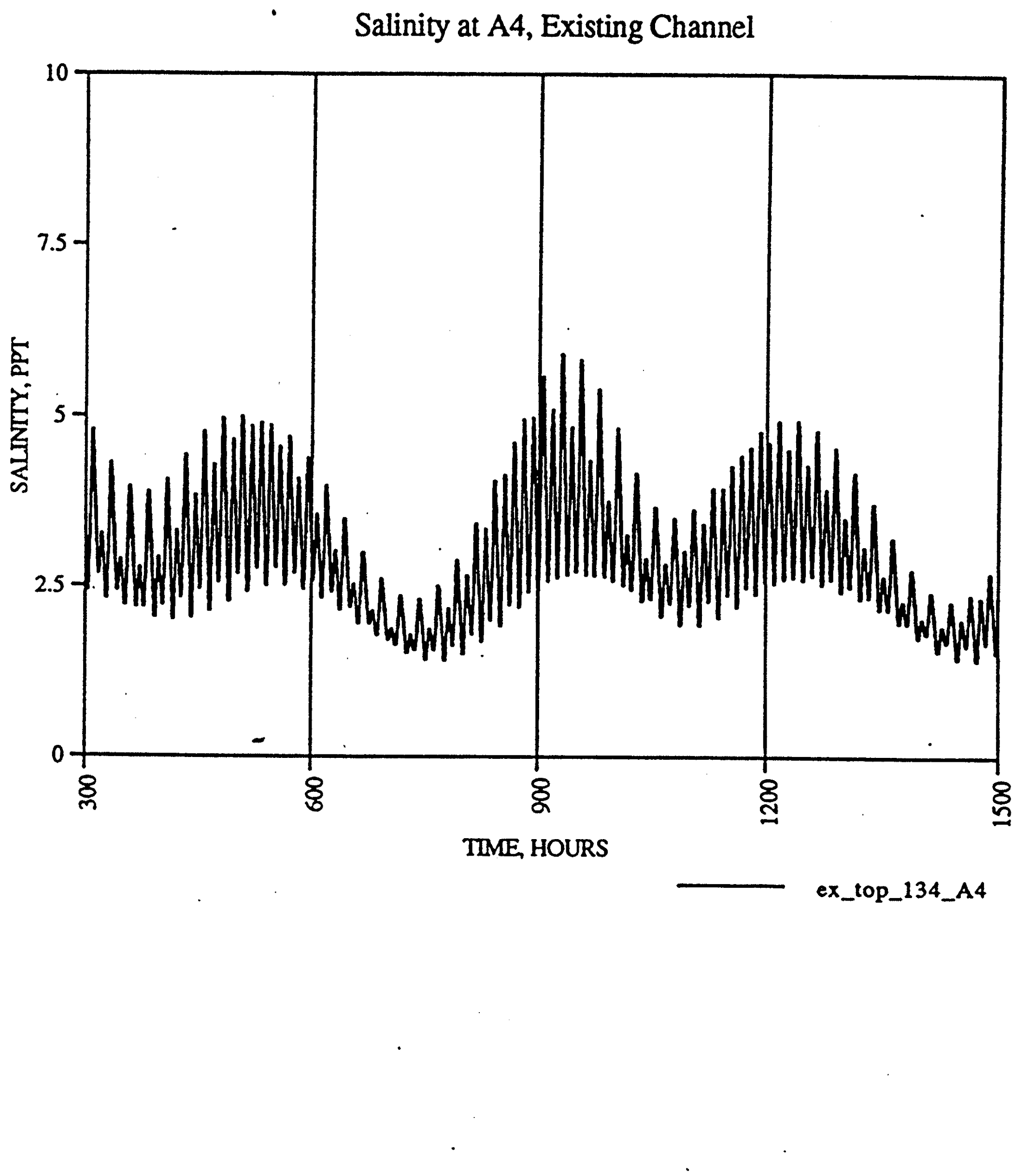


Figure 4-7
Bottom-Water Salinity at Node A5 (Site S25), Cathlamet Bay
Existing Channel Configuration

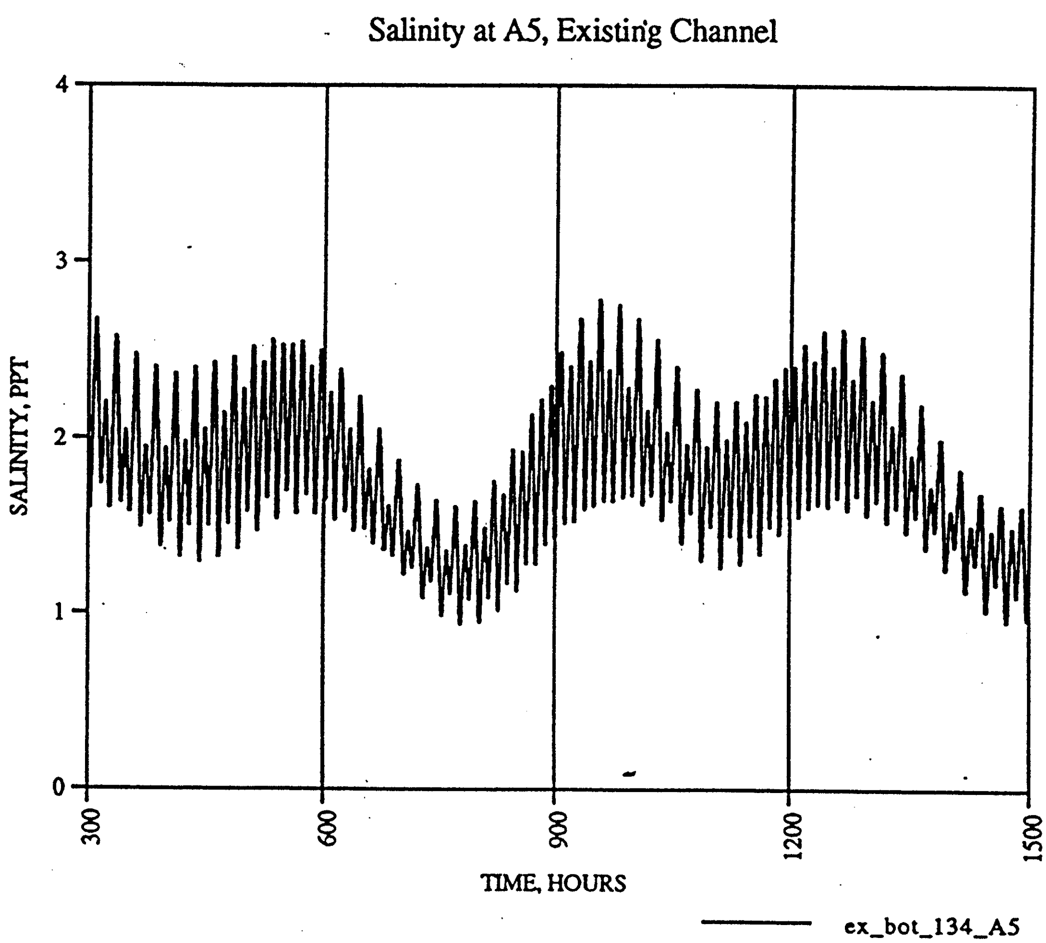


Figure 4-8
Bottom-Water Salinity at Node A6 (Site S27), Cathlamet Bay
Existing Channel Configuration

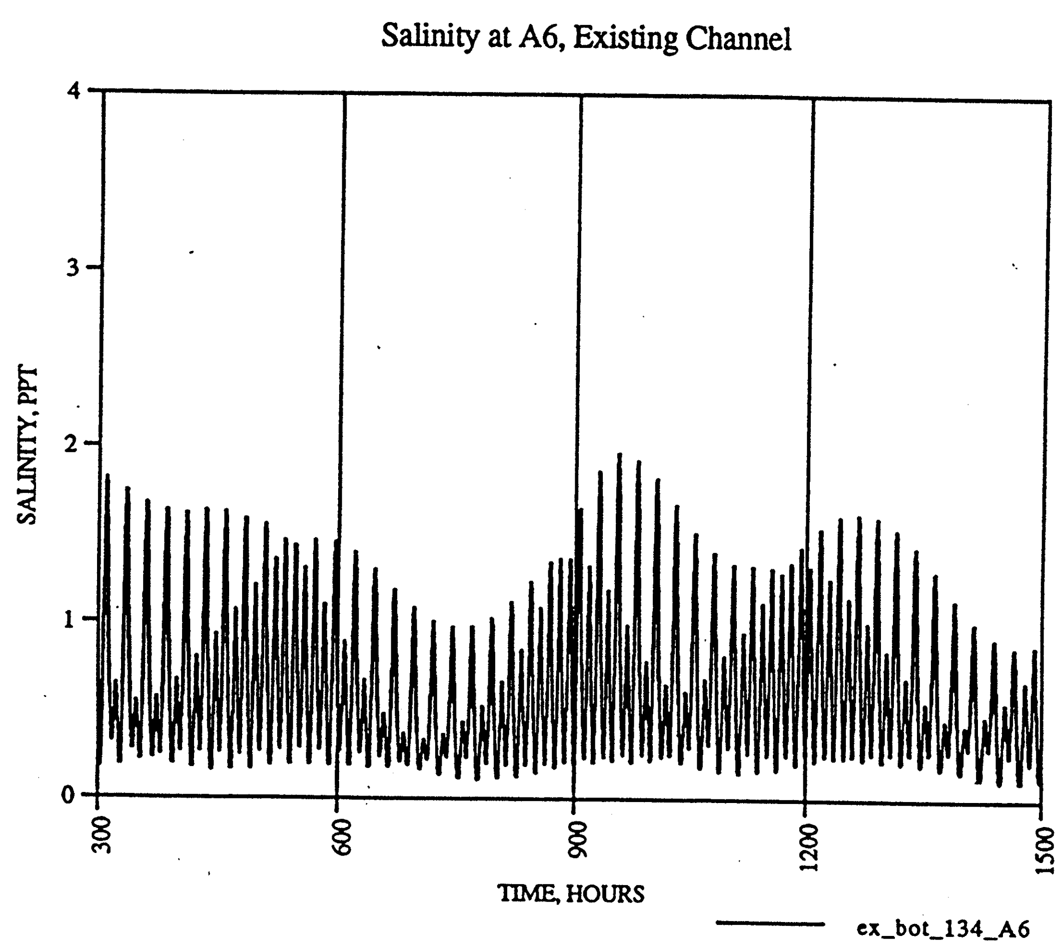


Figure 4-9
Bottom-Water Salinity at Node A7 (Site S29), Cathlamet Bay
Existing Channel Configuration

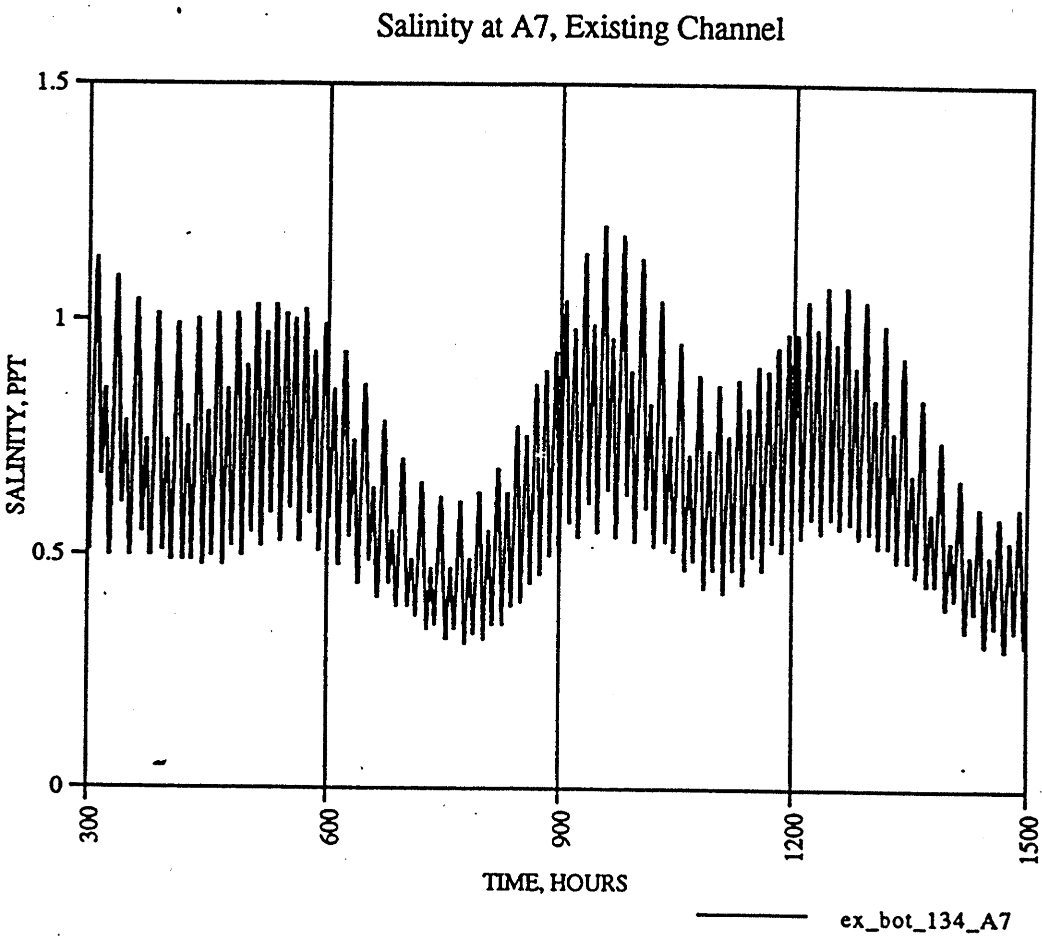


Figure 4-10
Bottom-Water Salinity at Node A8 (Site S30), Cathlamet Bay
Existing Channel Configuration

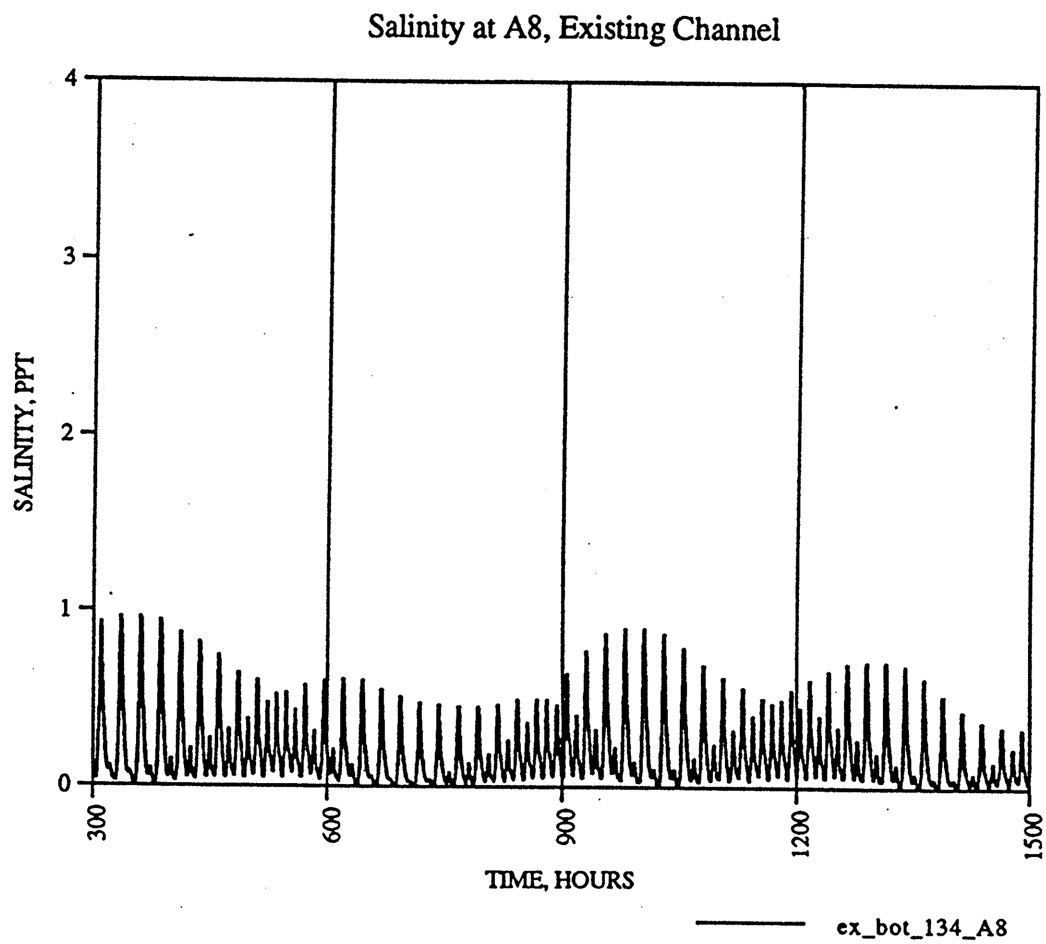


Figure 4-11
Bottom-Water Salinity at Node A9 (Site S33.5), Cathlamet Bay
Existing Channel Configuration

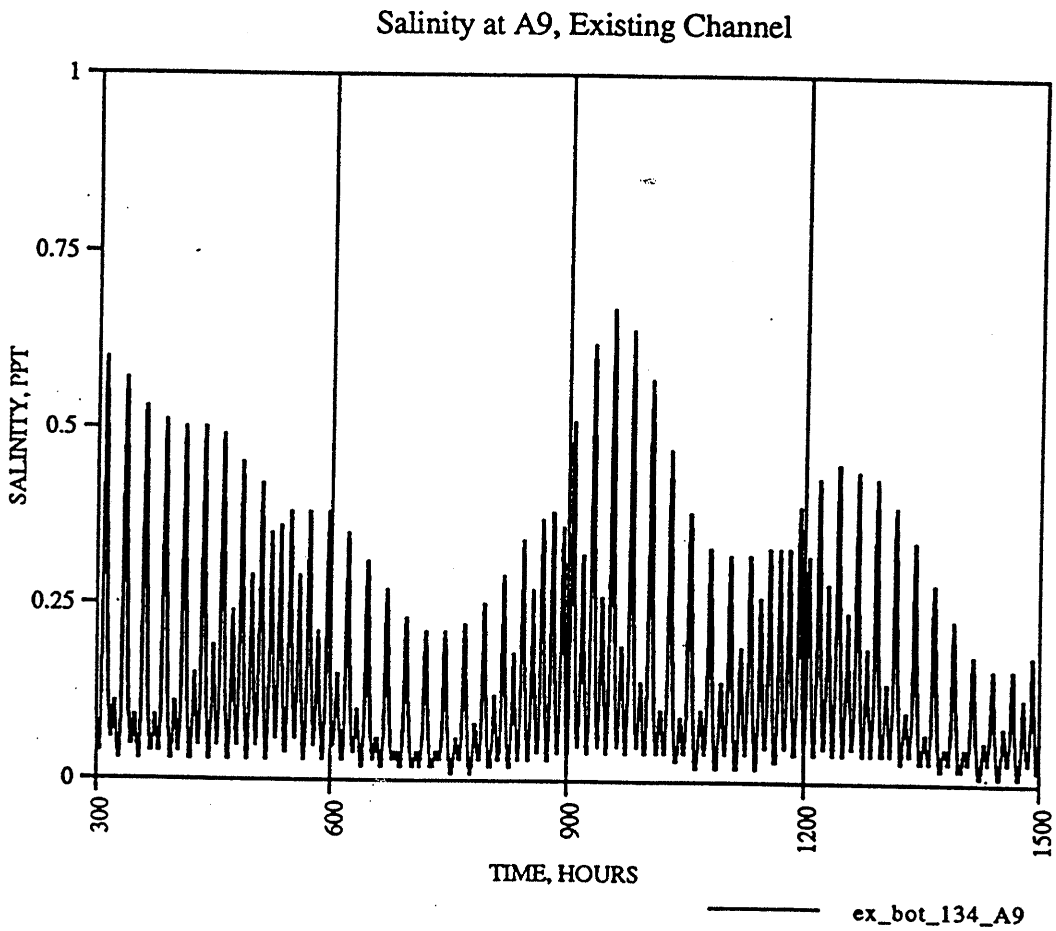


Figure 4-12
Bottom-Water Salinity at Node A10 (Site 28), Cathlamet Bay
Existing Channel Configuration

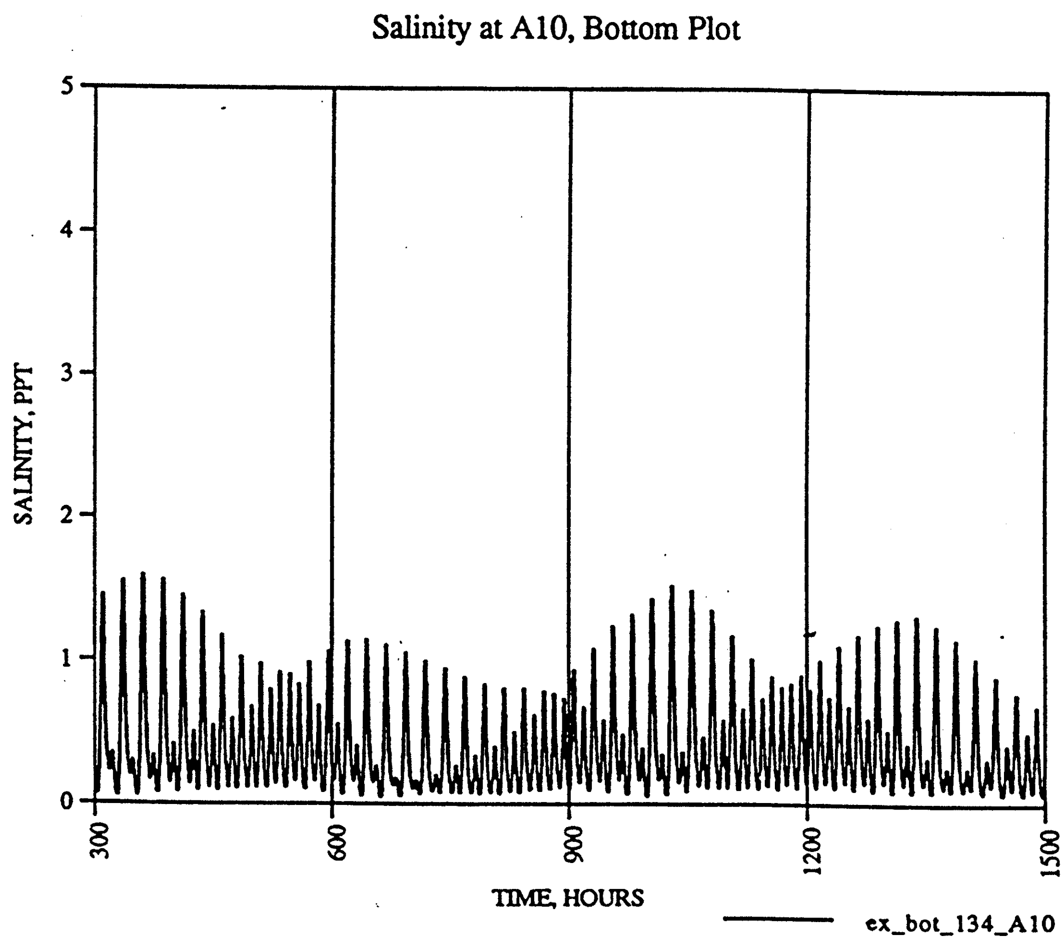


Figure 4-13
Difference in Bottom-Water Salinity at Node A1 (Site S23), Cathlamet Bay Plan Channel Configuration

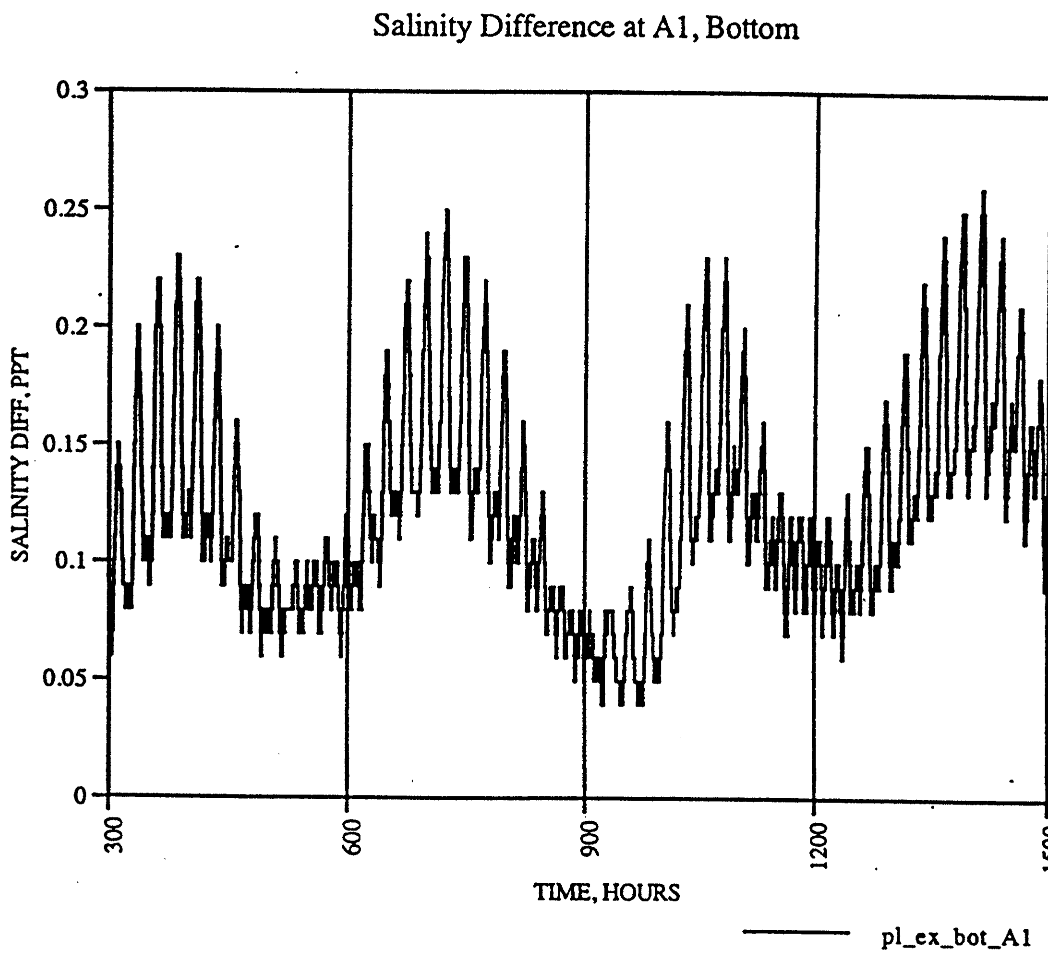


Figure 4-14
Difference in Bottom-Water Salinity at Node A2 (Site S21), Cathlamet Bay Plan Channel Configuration

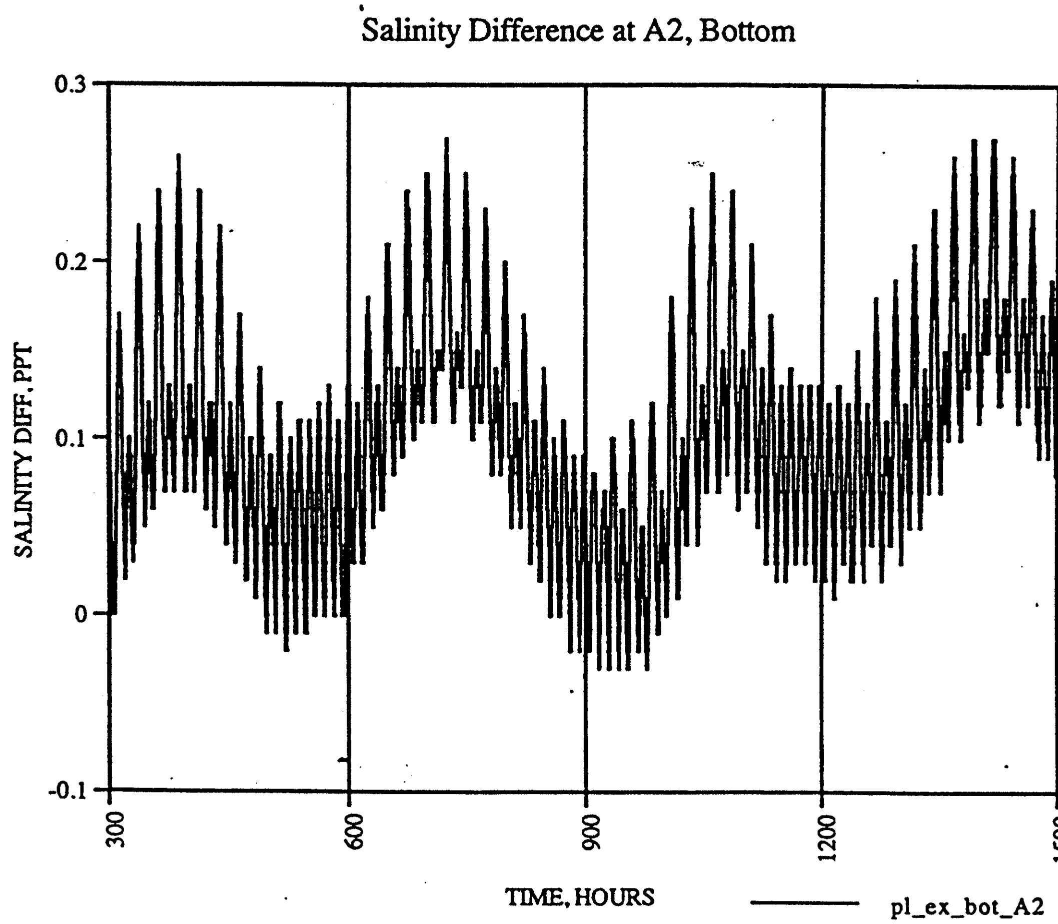


Figure 4-15
Difference in Bottom-Water Salinity at Node A3 (Site S22), Cathlamet Bay Plan Channel Configuration

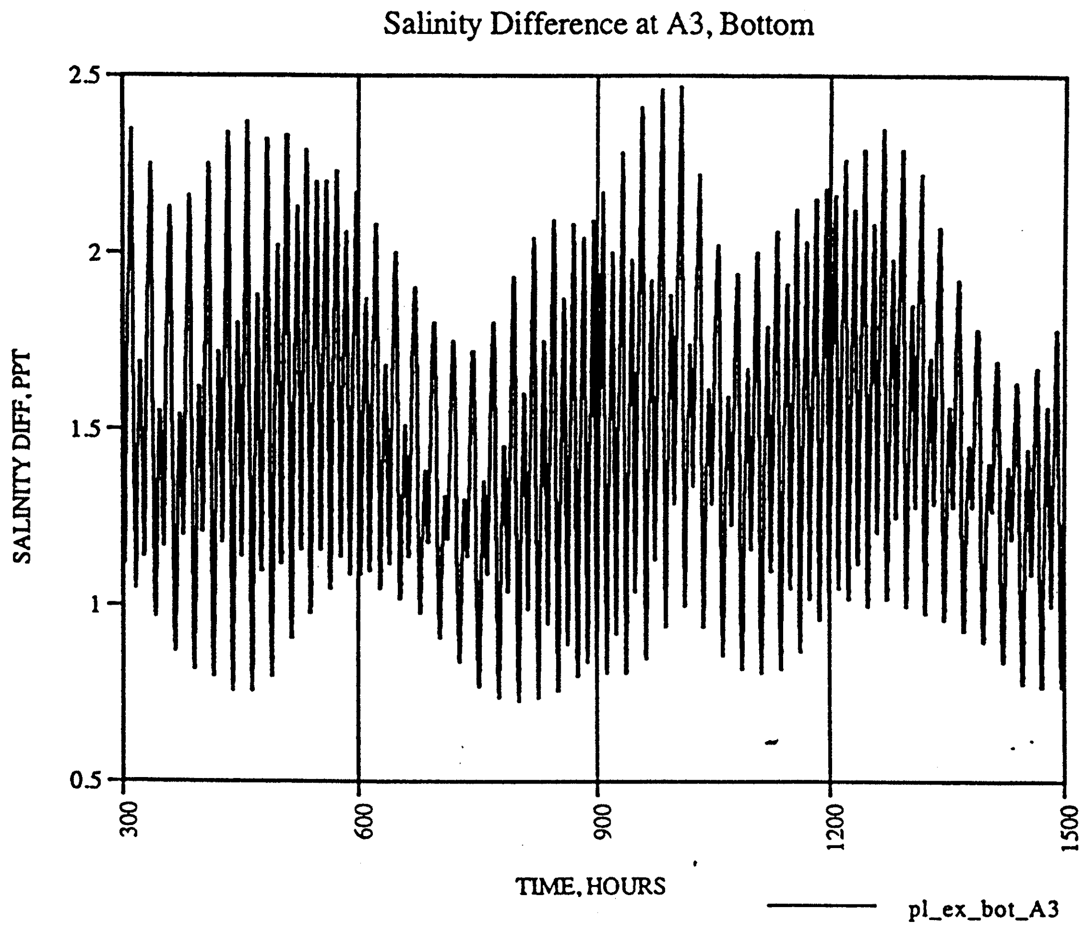


Figure 4-17
Difference in Bottom-Water Salinity at Node A5 (Site S25), Cathlamet Bay Plan Channel Configuration

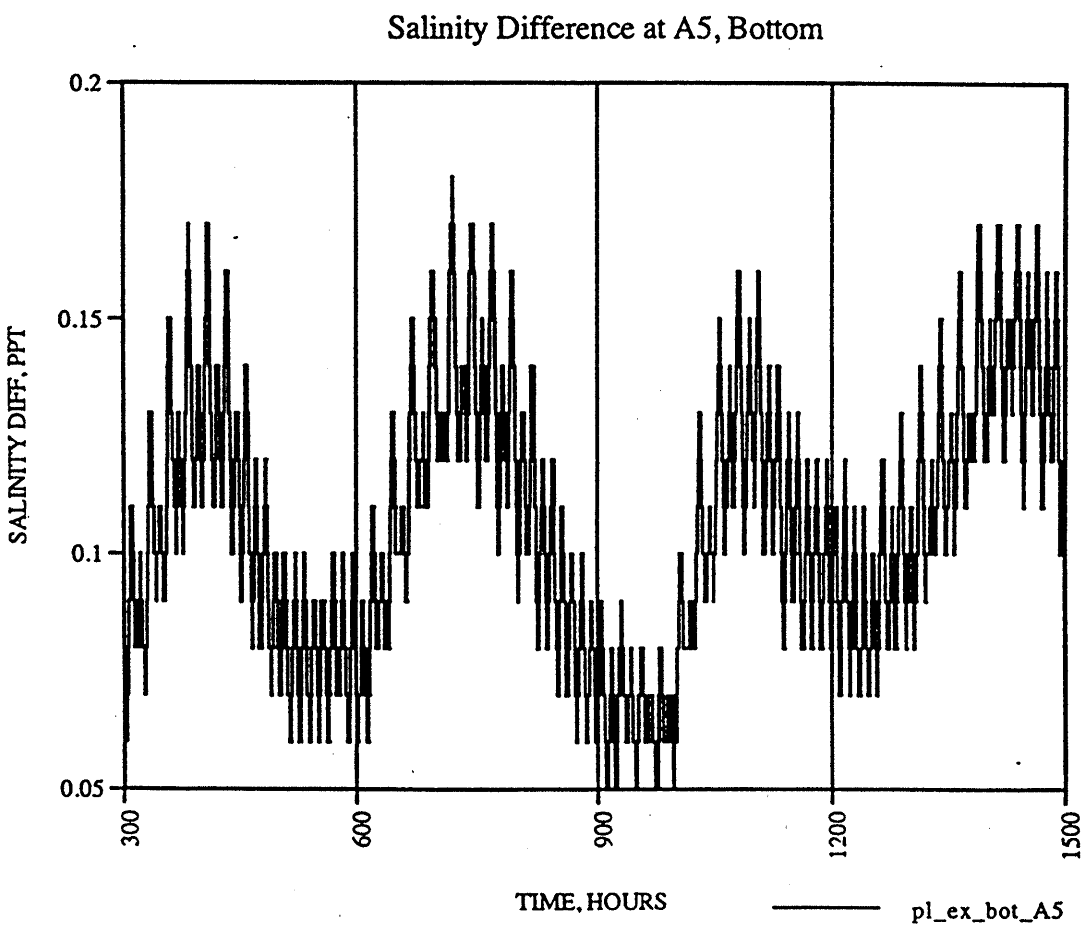


Figure 4-18
Difference in Bottom-Water Salinity at Node A6 (Site S27), Cathlamet Bay Plan Channel Configuration

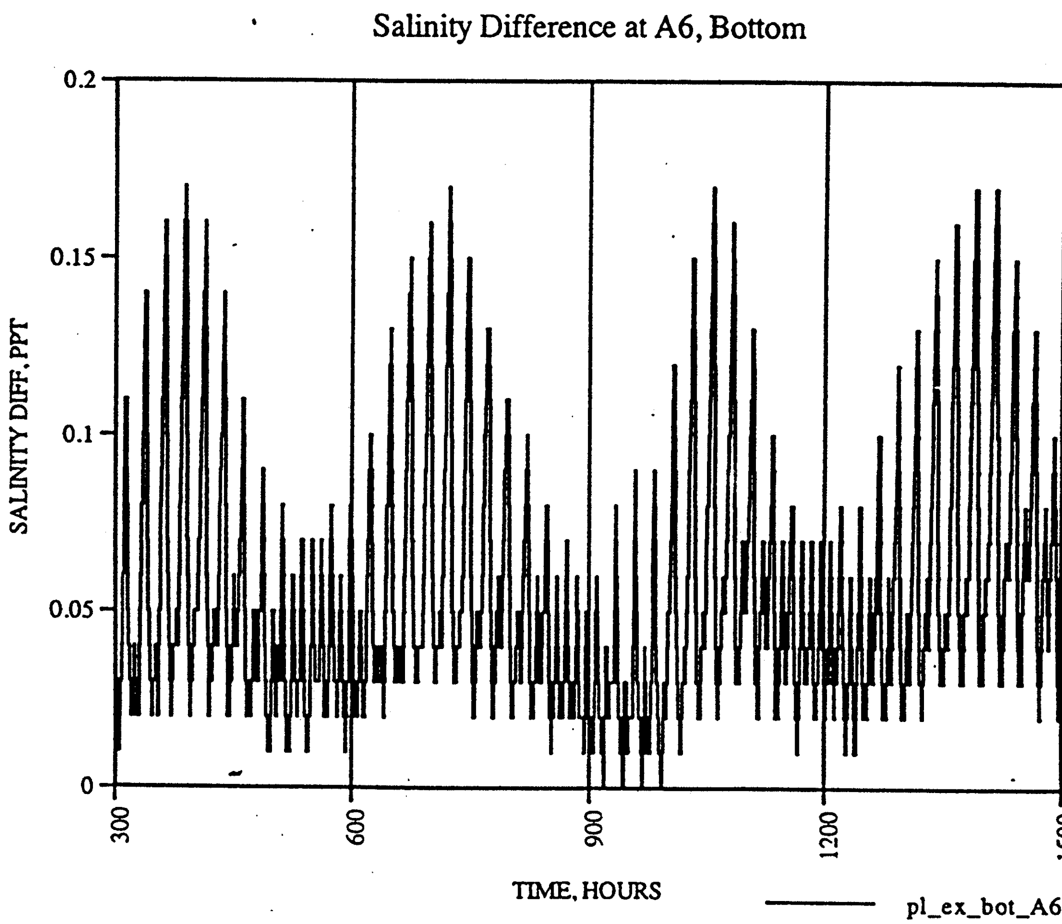


Figure 4-19
Difference in Bottom-Water Salinity at Node A7 (Site S29), Cathlamet Bay Plan Channel Configuration

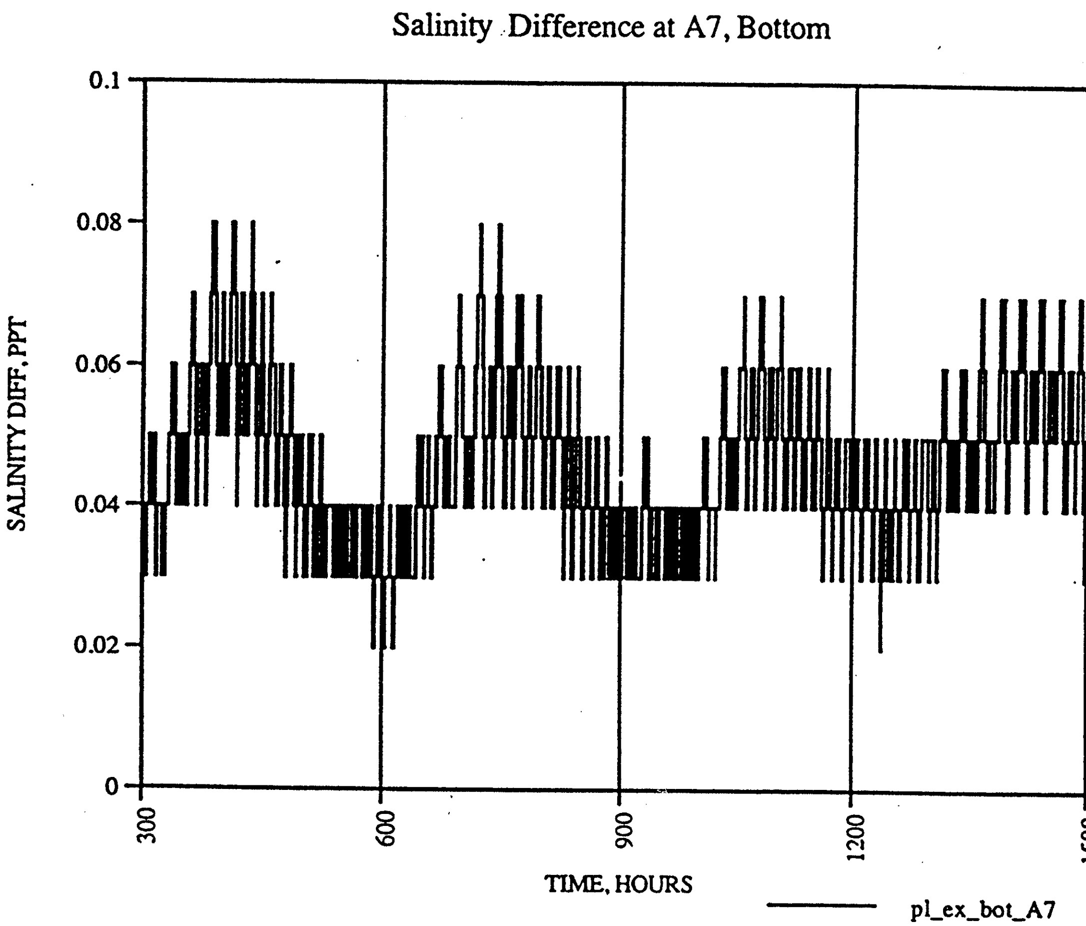


Figure 4-20
Difference in Bottom-Water Salinity at Node A8 (Site S30), Cathlamet Bay Plan Channel Configuration

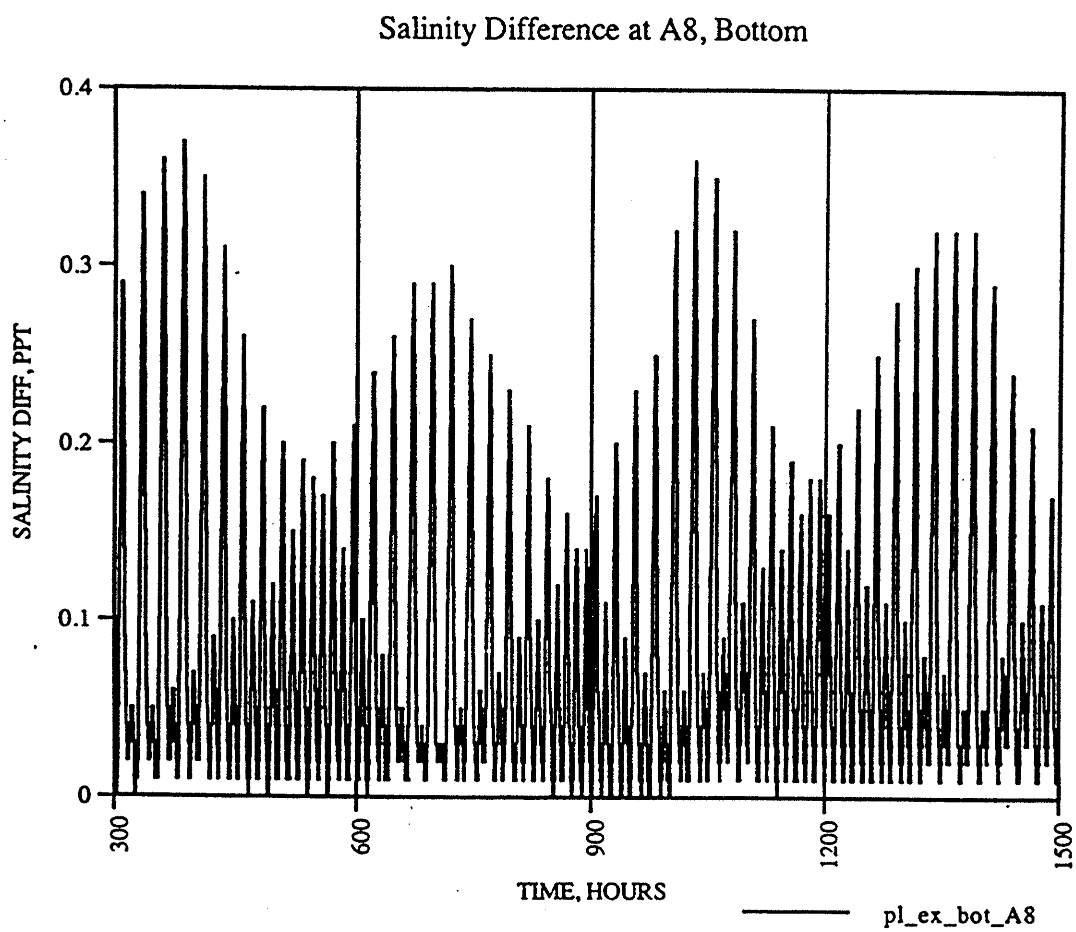


Figure 4-21
Difference in Bottom-Water Salinity at Node A9 (Site S33.5), Cathlamet Bay Plan Channel Configuration

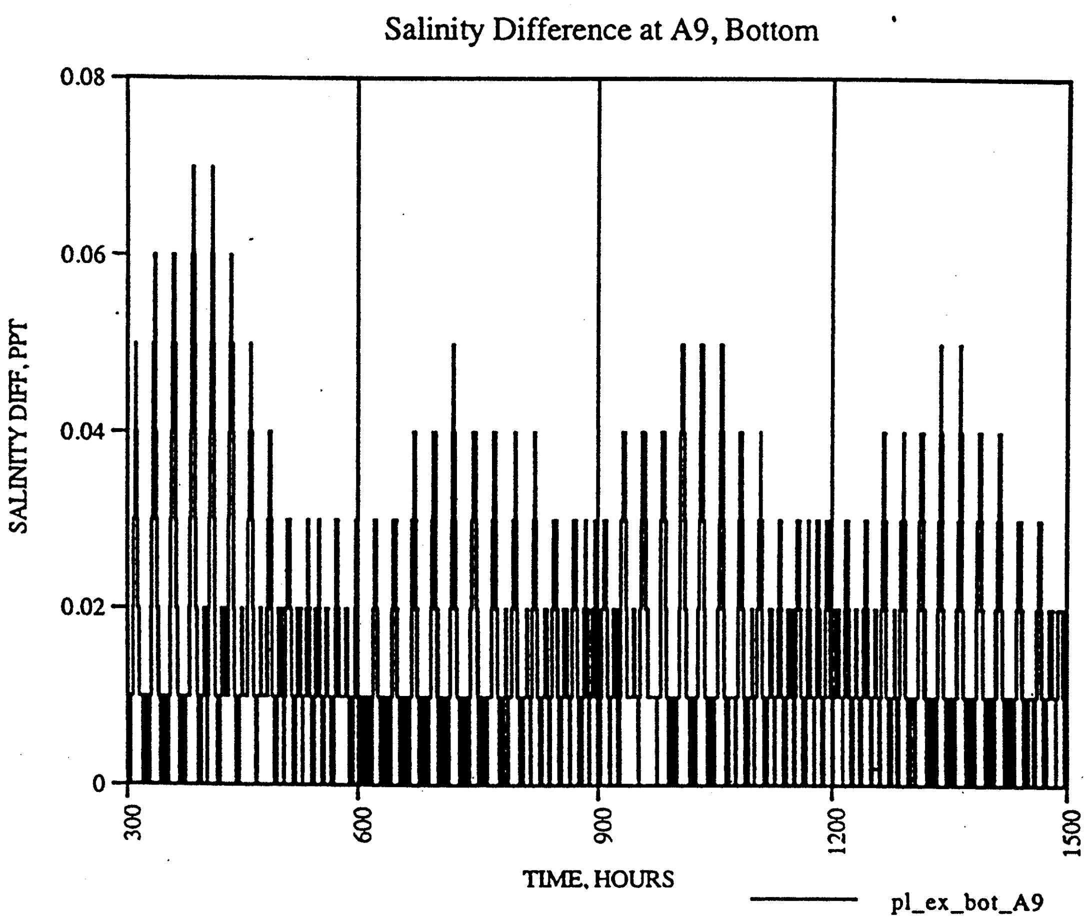


Figure 4-22
Difference in Bottom-Water Salinity at Node A10 (Site S28), Cathlamet Bay Plan Channel Configuration

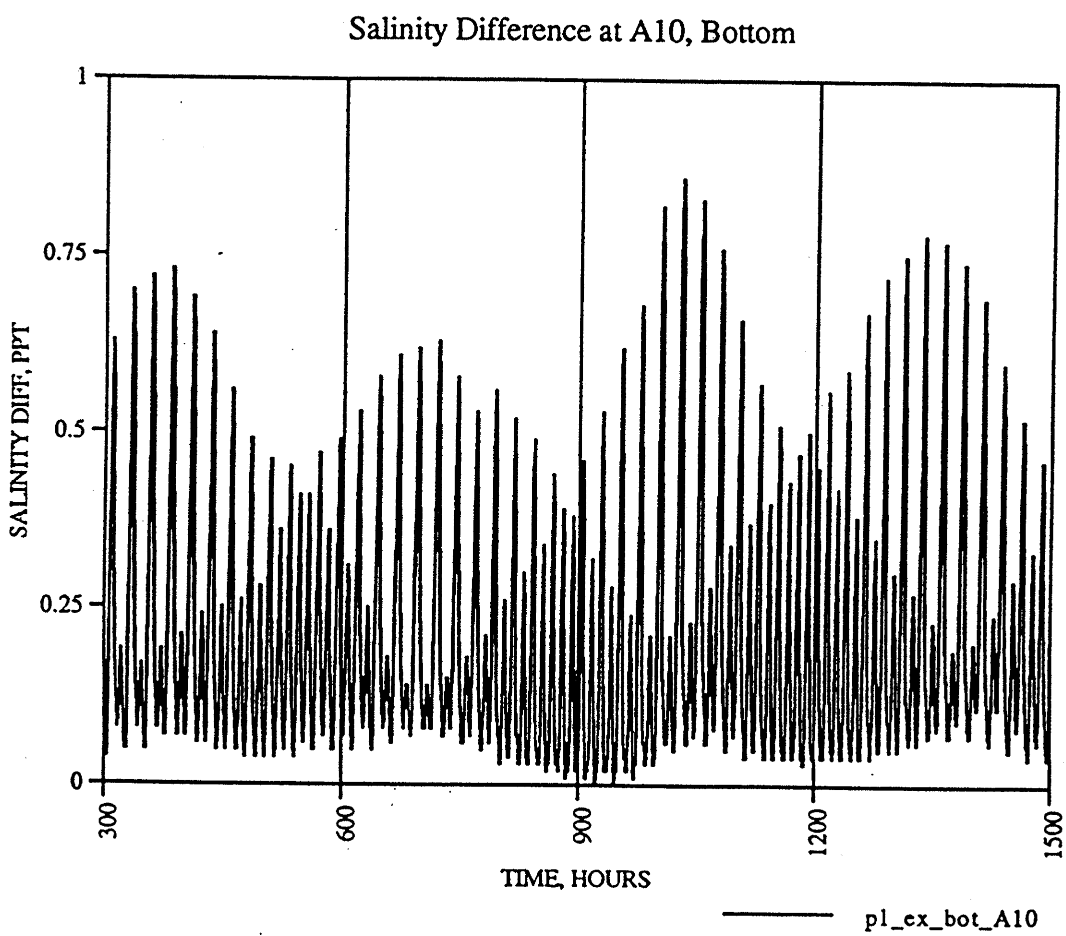


Figure 4-23
Bottom-Water Isohalines for the Existing Channel Configuration
Under Two Modeled Freshwater Discharge Rates
(134,000 and 120,000 cfs) (Hour 1030)

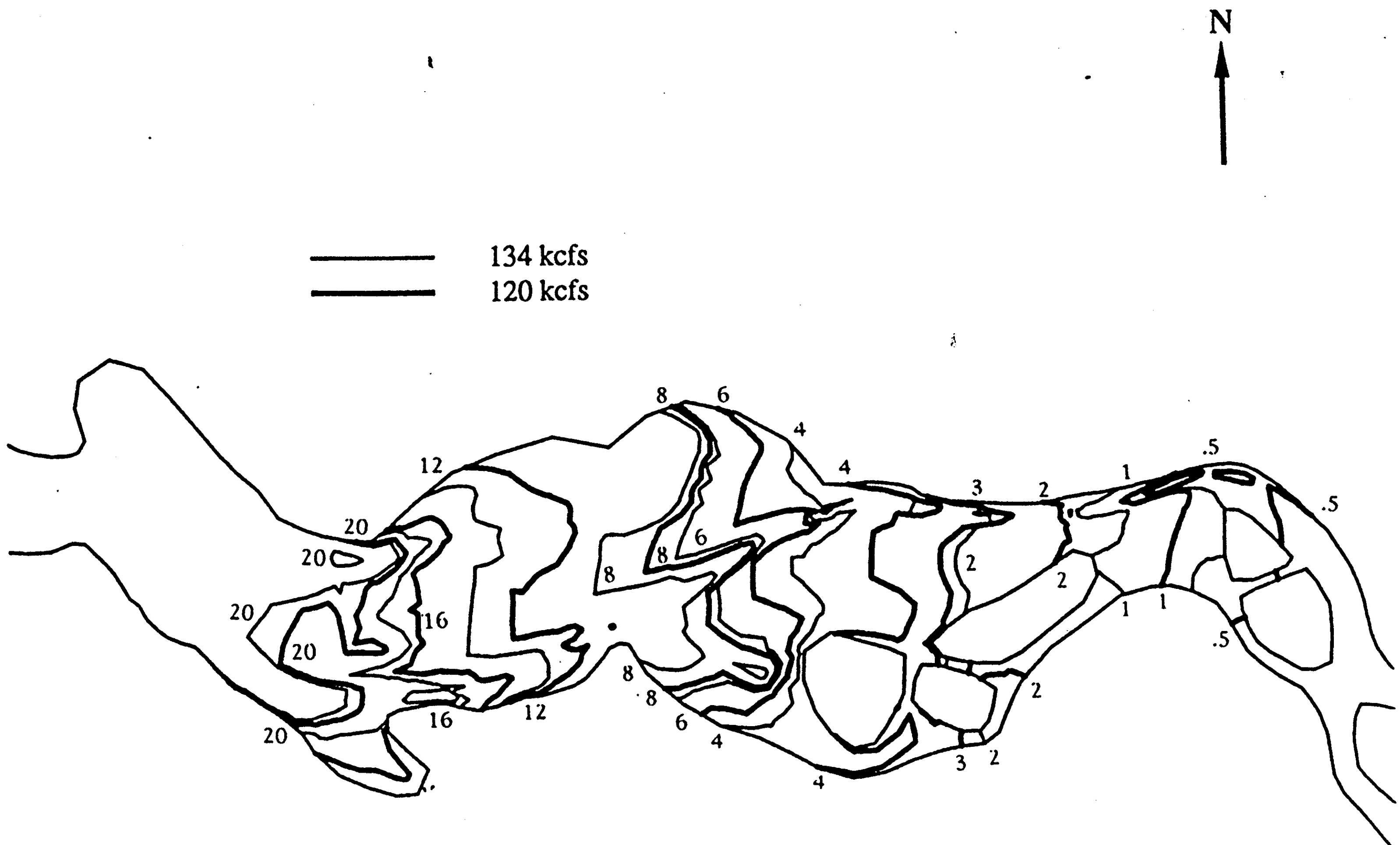


Figure 4-24
Bottom-Water Isohalines for the
Existing Versus Plan Channel Configurations
(134,000 cfs) (Hour 1030)

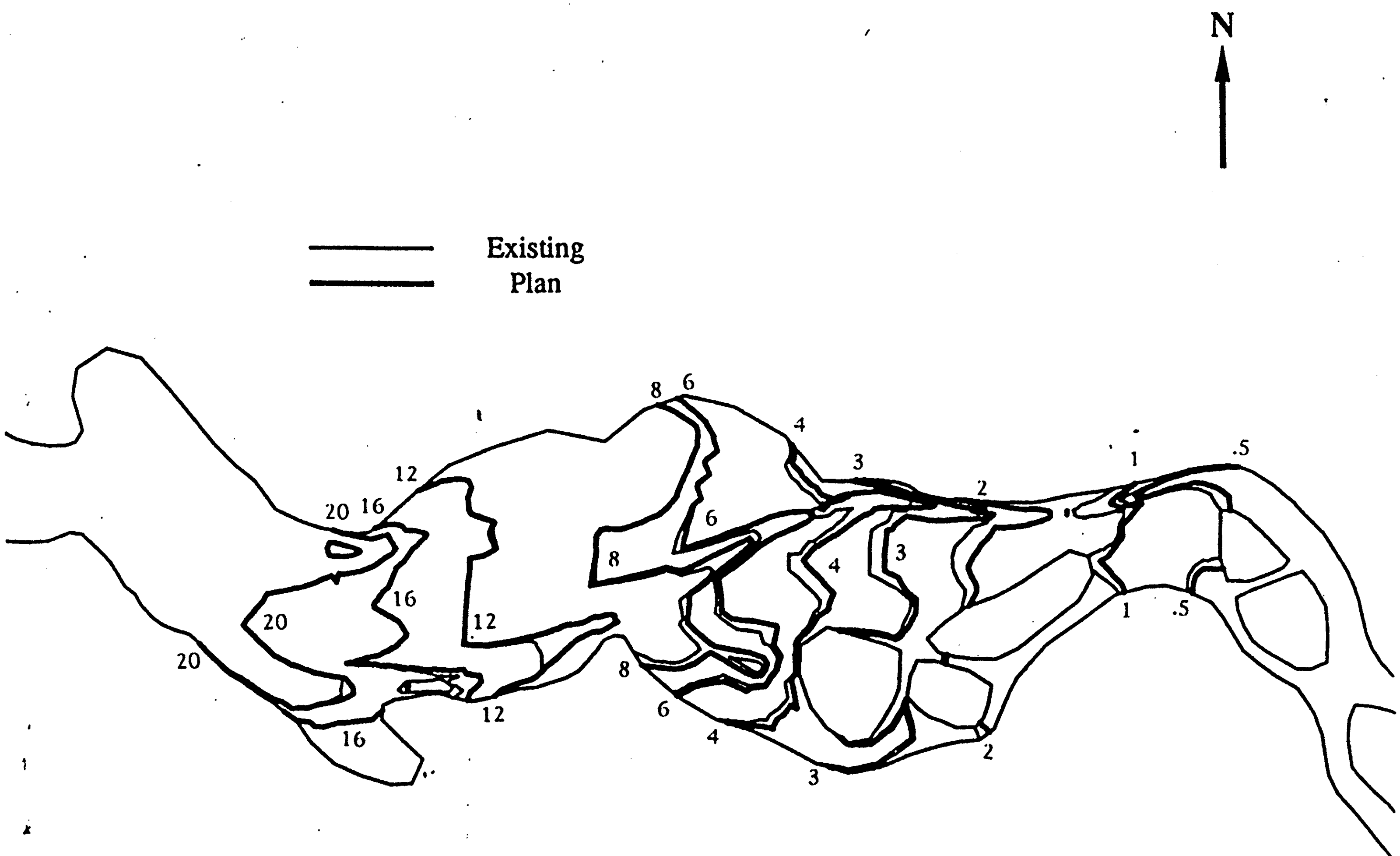
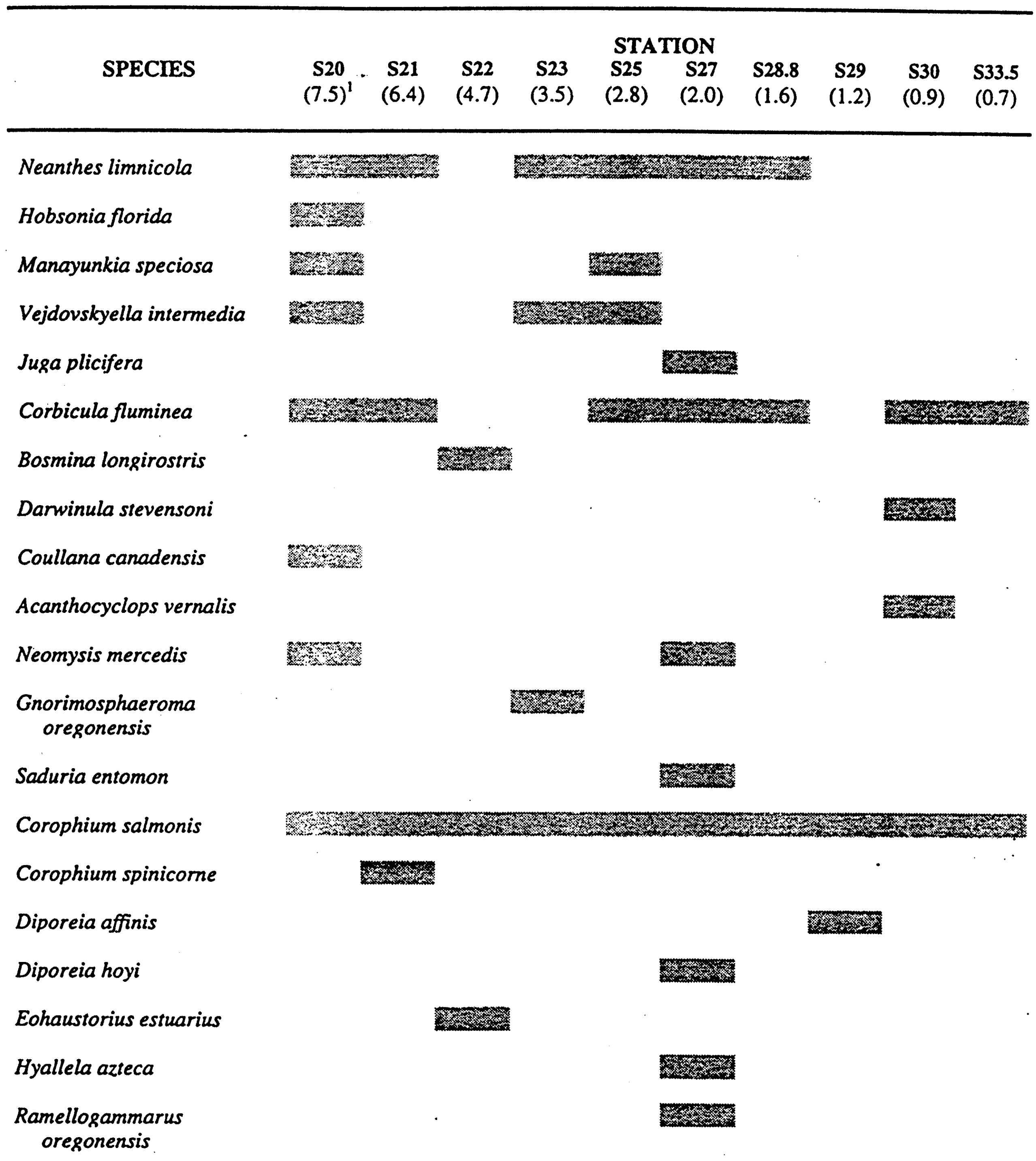
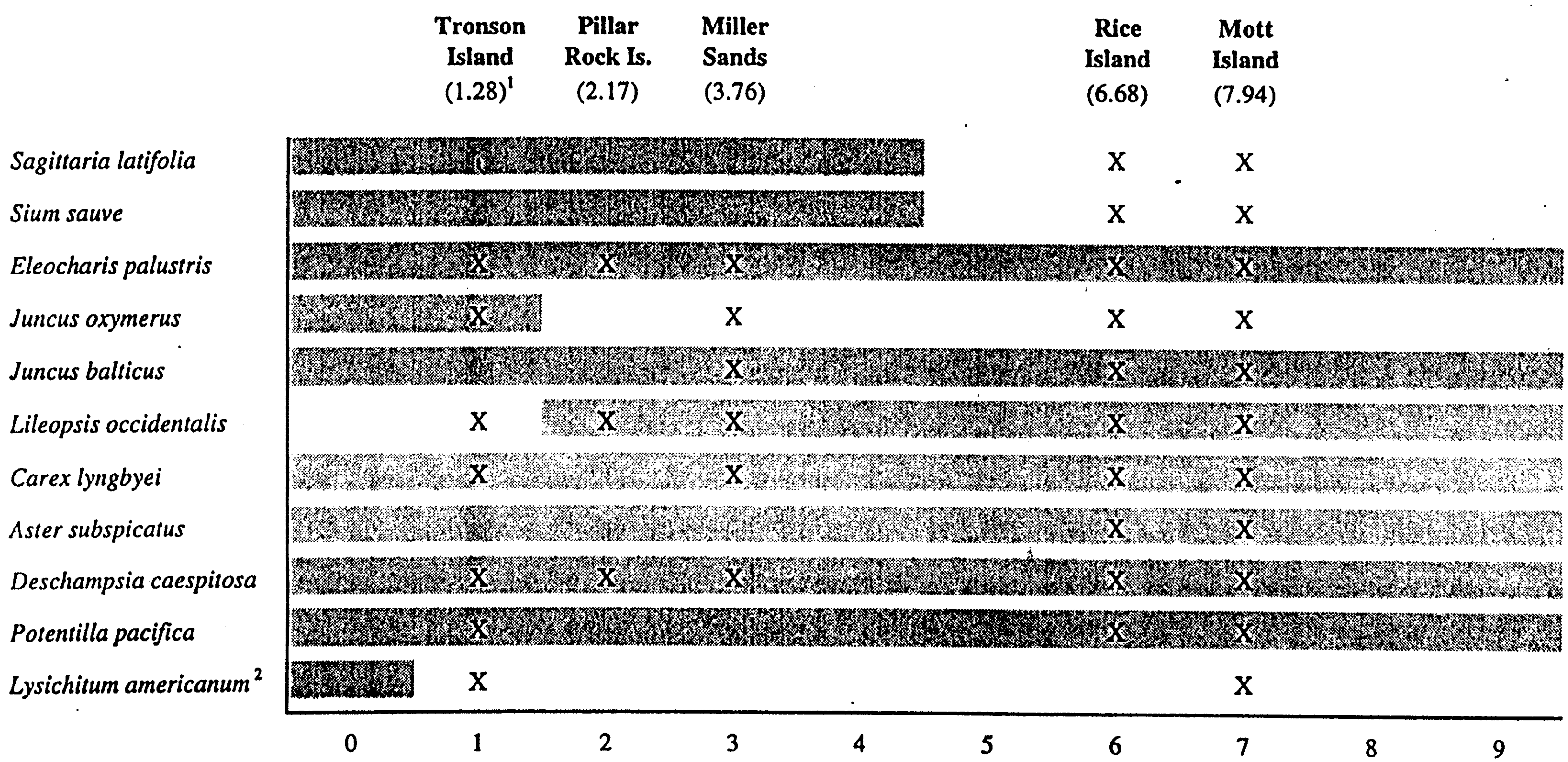


Figure 4-25
Benthic Invertebrates at Subtidal Sites During the Low-Flow Period



[1] Numbers in parentheses are maximum existing salinities (ppt) predicted under modeled low flow and tidal condtions.

Figure 4-26
Salinity Tolerances of Vascular Aquatic Plants in West Coast Estuaries



[1] Short-term maximum bottom-water salinity at this site as predicted by the hydraulic model
[2] Information on the salinity tolerance range of this species in Pacific coast estuaries available from the Columbia River only

EXHIBIT E

COLUMBIA RIVER ESUTARY
SALINITY STUDY

PREPARED BY
US ARMY CORPS OF ENGINEERS
WATERWAYS EXPERIMENT STATION

AUGUST 23, 1996

CEWES-HW-E (1110-2-1403b) 23 August 1996
MEMORANDUM FOR RECORD
SUBJECT: Columbia River Estuary Salinity Study

I. Introduction

1. At the request of the U. S. Army Engineer District, Portland (NPP), the U. S. Army Engineer Waterways Experiment Station (WES) performed a study designed to model the response of the salinity in the Columbia River Estuary to proposed deepening of the Columbia River Ship Channel. The purpose of the modeling effort was to gauge the general response of the salinity of the estuarine system to deepening. The response of the salinity was then to be used in the assessment of potential biological impacts to determine if further, more detailed modeling of salinity was warranted. The general results of the salinity modeling effort were that the salinity increases in the estuary were small. These small increases were primarily restricted to the near bottom areas of the system in the dredged ship channel, and salinity increases in the off channel areas were smaller. Figure 13 shows the average salinities for the base (undeepened) and the plan (three feet deeper) conditions in and on the bottom and surface (top) of the ship channel as a function of river mile.

II. Modeling

2. The Columbia River was modeled schematically with verification consisting of reproducing the general qualitative behavior of the estuary when compared to data extracted from reports of the Columbia River Estuary Study Taskforce (CREST) (Ref. 1 and 2). The three dimensional (3D) model was made up of a computational mesh, boundary conditions, and the computer code RMA10-WES. The computational mesh consists of a large collection of points in the estuarine system for which the physical equations of fluid motion and salt transport coded into RMA10-WES are solved using the boundary conditions established for the system.

3. The boundary of the computational mesh is shown in Figure 1. The computational mesh for the area from the mouth of the Columbia River to Puget Island is shown in Figure 2. The computational mesh is a discretized representation of the geometry and bathymetry of the estuary developed from National Oceanic and Atmospheric Administration (NOAA) navigation charts and the NPP February 1992 navigation channel survey. The system is modeled from offshore in the Pacific Ocean up to the Bonneville Dam. The computational mesh consists of 20,562 nodes, each with x, y, and z coordinate values so that the geometric characteristics of the system are represented. The computational mesh also consists of 9279 elements, or polygons, that are bordered by the nodes and for which local system characteristics, such as bottom roughness, can be assigned to enable the estuary to be better represented. These local system characteristics are assigned by designating the material type of the surface element in question. Contiguous elements, each with similar properties, can then be modeled so as to capture the physics of different regions in the system. For example, Figure 3 shows the material type regions used in these experiments.

Material types, indicated as color coded in Figure 3, represent the schematic modeling of the off channel areas as either relatively shallow regions with higher friction flows (material 10), or deeper areas with relatively freer flows (material 1). Thus, the large scale physiographic features of the system are modeled. Figure 3 also shows the material type representation of the dredged ship channel (material 3), the channel side slopes (material 4), and the ocean (materials 6 and 7). Materials 2, 5, 8, and 9 were not directly relevant to the lower estuary. The mesh shown in Figure 2 shows the grid in plan view; the full 3D calculation includes nodes and elements that are projected below this plan view. The ship channel was modeled two elements deep in the vertical, providing five second order calculational nodes in the vertical, from the opening and continuing up river to near Portland; most of the remainder of the system in this region was modeled one element deep, providing three second order calculational nodes in the vertical. With a typical channel depth of 44 feet in the base conditions, the two element modeling results in a resolution of 11 feet. Because the RMA10-WES code uses a finite element realization of the physics of the estuarine system with quadratic basis functions this resolution is comparable to about 3 to 4 feet resolution with a linear representation of the depth profile.

4. The boundary conditions consist of the applied ocean tide and salinity enforced on portions of the ocean boundary, and the fresh water inflow provided at the Bonneville Dam boundary. The tide was synthetically generated for the late summer and fall period of 1993. See Figure 4. This tide reproduces well the conditions off the ocean entrance to the Columbia River. The ocean boundary salinity was chosen as 33 parts per thousand (ppt). The fresh water inflow at the Bonneville dam was chosen as 134,000 cubic feet per second (cfs). This flow was chosen as a typical late summer or early autumn low flow value for total flow down the lower Columbia River. A still lower flow, 120,000 cfs, was also used so that the sensitivity of the calculation to fresh water inflow could be determined.

5. RMA10-WES, as mentioned above, is a finite element hydrodynamic and salinity transport computer code within which the physics of fluid motion and salt transport relevant to estuarine systems are modeled. The code uses the geometrical information in the computational mesh and the boundary and initial value conditions of the physical variables (water surface elevation, water velocity, salinity) as input to solve equations that encapsulate the physics of the system (Reynolds form of the Navier-Stokes equation of fluid motion, and convection-diffusion equation for the salt). The solutions are created so as to produce conditions in the estuary: the water surface elevation, velocity, and salinity at every node (surface nodes for water surface elevation) in the mesh for every half hour time step in the calculation. RMA10-WES has been successfully applied to various estuaries nationwide. Examples include the Cape Fear River, NC, San Francisco Bay, and Galveston Bay, TX (Ref. 3).

III. Model Validation

6. Validation of the model consisted of comparing the calculated results with data extracted from CREST publications concerning the tides and salinities of

the estuary. Figure 5 shows a comparison of the average tide range in the estuary as a function of river mile. The solid line is data extracted from a CREST report (Ref. 1), and the dashed line is the result of averaging the tide ranges occurring in a 1500 hours long tidal series produced by calculations using a computational mesh representative of the existing, or base, channel conditions in the estuary. Examination of calculated tide ranges for 300 hour periods reveals variation of about 0.5 foot around the 1500 hour average, bracketing the CREST data (see Figure 6). The tide ranges produced by the model are thus seen to be in good general agreement with the CREST data.

7. Figure 7 shows a comparison of the calculated surface and bottom salinities, averaged over hours 300 to 1500, with surface and bottom salinities extracted from the CREST Atlas (Ref 2.). The calculation was performed for the 134,000 cfs fresh water inflow. (The first 300 hours of the calculation were not used due to the long relaxation time of the initial salinity conditions assumed for the estuary in the calculation.) The apparently low value of the CREST bottom value ("ATLAS BOT" in Figure 7) at river mile 0 is due to the resolution limits of the Atlas: the bottom salinity is given in ranges, except near the river mouth, making estimation of the salinity at the mouth difficult. The value shown is that of the last isohaline line shown in the data and, thus, is a deliberate underestimation. In general the match between the CREST data and the model is good, especially near the bottom in the upper portion of the salt influenced portion of the estuary between river miles 20 and 30. The CREST salinity data was taken during real fresh water flow conditions which were varying, and appear to have included, at least in the period immediately preceding the time of data collection, lower flows. Figure 8 shows a comparison of model and CREST data for this lower, 120,000 cfs, flow. The bulk of the bottom averaged salinities compare well. As will be seen later in the comparisons between the base and plan channels, the surface salinity conditions are little affected by any changes in channel depth. If the surface and bottom salinities shown in Figures 7 and 8 are averaged and plotted versus river mile, Figure 9 results. Figure 9 indicates that the general behavior of the average salinity in the river is reproduced well by the model.

8. Qualitatively, Figures 7 and 8 show that the model reproduces the feature of stratification that is expected to be present in estuaries such as the Columbia River. Though the model is not as stratified as the CREST data indicate the estuary to be, the model clearly demonstrates the phenomenon of stratification to a significant degree and reproduces all the important behaviors of estuarine systems. In addition to the behaviors of the tide range and of the stratification of salinity, Figure 10 shows in more detail the way the stratified salinity and the tide interact at river mile 20. Note that during neap tide periods the stratification of the salt is enhanced, whereas during spring tide events the stratification is decreased, as expected.

9. This model of the Columbia River Estuary was intended to be a tool that will allow the general response of estuary salinity to a deepening of the controlling depth of the ship channel to be gauged. The validation arguments presented above indicate that the model reproduces the qualitative and quantitative

behaviors of the estuary closely enough to be used to gauge the approximate effect of deepening the ship channel on salinity.

IV. Results

10. Experiments were performed with two different channel depths to determine the response of the modeled system salinity. The base, or existing, conditions are those channel conditions in the February 1992 survey. Since the February 1992 survey, the channel in the vicinity of river mile 16, between Astoria and Tongue Point (Astoria Range), was deepened from the survey depth of 41 feet (MLLW) to 45 feet. The proposed deepening in Astoria Range represents the greatest deepening in the proposed channel deepening project, and the above mentioned deepening to 45 feet represents more than half of this proposed eventual deepening. The shallower, predeepened channel depth (41 feet), was used in the base conditions to provide a conservative estimate of salinity changes in the system due to proposed channel deepening. The plan conditions are the February 1992 conditions with the exception that no channel depth is less that 48 feet. The controlling depth of 48 feet was inserted into the geometry of the computational mesh by deepening the shoals; any channel feature that was already 48 feet deep or deeper was unaffected. The experiments were conducted using identical boundary condition files, so that the only difference between the base-plan comparison pairs was the channel depth.

11. Figures 11 and 12 show plots of surface and bottom salinities averaged over a 1200 hour period from river mile 0 to 40 for, respectively, the 134,000 cfs and the 120,000 cfs fresh water flow conditions. Figures 13 and 14 are enlargements of the mile 10 to 30 portion of Figures 11 and 12, respectively. Examination of these plots reveals that the channel deepening had little effect on the averaged surface salinity, whereas the averaged bottom salinity was generally increased by less that 1 ppt. (Note that the surface salinity plots for base and plan lie essentially on top of one another in Figures 11 to 14.) Site A3 (see paragraph 12), in the channel between river miles 20 and 25, increased by 1.5 ppt on the bottom. The plots from the two flows are very similar: the effect of the decreasing the flow from 134,000 cfs to 120,000 cfs is to increase the average salinities about 1 ppt (surface) to 1.5 ppt (bottom) at most. Salinity values for Figures 11,13,16, and 18 are tabulated in Table 1.

12. Figure 15 shows the locations of other sites in the estuary where averaged salinity values were calculated. Location sets S, N, C, and Y indicate, respectively, locations in the south (ship) channel, the north channel, Cathlamet Bay, and Youngs Bay. The set designated by A indicates additional estuary locations requested by NPP. The numeric suffix on the S and N locations, only, indicates a river mile location. The S locations are represented in Figures 11 to 14, the N, C, and Y locations are represented in Figures 16 and 17, and the A locations are represented in Figure 18. Figures 16-18 use bar graphs of the averaged salinities at these (mostly) off-channel sites since the sites are not strung along a common transect. As with the case of data represented in Figures

11 to 14, examination of Figures 16 to 18 shows that only modest changes in salinity occur when the channel is deepened.

13. More specifically, salinity changes at the surface of the system are predicted to be essentially negligible. The most significant changes occur in the channel, at the bottom, between river miles 10 and 30, as shown in Figures 11 to 14. As discussed in paragraph 8, the model is stratified, and it is this stratification that is responsible for the relative difference in response to the deepening of the surface and bottom salinities. Since salt water is heavier that freshwater, the freshwater flowing down river will essentially float on top of the heavier ocean salt water, thus yielding the stratified salinity structure of the estuarine system. Density currents due to the longitudinal pressure gradients arising from these density differences between salt and freshwater also act to transport the bottom salt water landward. During neap tides, when tidally induced mixing is minimized, this stratification is enhanced, whereas during spring tides, with larger tides causing greater mixing, the stratification is minimized (see Figure 10). The river bottom in the channel is irregular, with shallower shoals and deeper scours. When the shallower shoals are deepened, the higher salinity water on the bottom behind the shoals (seaward of the shoals) can be more easily pushed farther up river along the bottom by the incoming tide. The surface layer, however, remains largely unaffected.

14. Thus, the salinity of an area will be related to its proximity to the deep water of the ship channel. Sites such as A1 and A2, A4 to A7, A9, N20, C4 and C5, and Y are shallow and sample the top layers of the water column (see Table 1). Since this portion of the water column is less affected by the salinity changes, the salinity at these locations is not affected significantly, even at the bottom of the water column. Sites A3 and A8 (same as S30) are in the ship channel. Sites C1 to C3 are in deeper water and are connected directly through a side channel to a portion of the deepened ship channel. Since the connection is direct and the ship channel bottom salinity in this location is one of the most sensitive to channel deepening, bottom salinities at sites C1 to C3 are also affected. North channel locations such N10 to N19, however, are not affected even though they are deep since their own bottom topography is not changed and they are not near the south ship channel.

15. Close inspection of the salinities of sites A6 and A8 to A10 reveals that these stations are saltier on the surface that the bottom in some surface and bottom salinity pairs. Though this phenomenon is physically possible, it is difficult to determine its origin in this study given its limited scope. These anomalies are likely numerical artifacts which, due to their small size and the schematic nature of the modeling effort, are not significant and do not compromise the general conclusion that salinity changes in the system can be expected to be small and located primarily on the bottom in the ship channel.

16. To get an idea of the instantaneous effect on salinity of deepening the ship channel, consider Figure 19, which shows bottom isohalines of the base (existing) and plan channel configuration experiments for a time that represents

approximately the largest salinity difference of the calculation. Again, the differences are confined to channel and near channel locations. The effect of deepening the shoal in the Astoria Range between tongue point and Astoria is obvious.

17. Figure 20 shows a comparison of bottom isohalines for the existing channel configuration with varying freshwater inflows. Figure 21 is included to clarify the isohaline values of Figure 20. This plot shows that a 10 % decrease in fresh water leads to much larger salinity changes in the system, especially in the off channel areas, than the proposed channel deepening.

V Conclusions

18. A 3D hydrodynamic and salinity model suitable for gauging the approximate response of the lower Columbia River Estuary salinity to a proposed channel deepening was developed and validated.

19. Experiments using this model demonstrated that deepening the controlling depth of the lower Columbia River Estuary navigation depth to 48 feet results in a change in the average salinity of the 10 to 30 river mile region of less than 1 to 1.5 ppt in and near the channel at the bottom. The surface of the estuary and off channel regions are affected, on average, by smaller changes. Instantaneous salinities are of the same order of magnitude as the averages. Variations in fresh water inflow have the potential to have a much greater impact on the salinity of the estuary, especially in the off channel areas, than the proposed channel deepening.

20. Acknowledgments: This work was performed with the able assistance of Dr. R. C. (Charlie) Berger, Mr. Jay Hardy, and Ms. Cassandra Gaines.

R. T. McAdory, Jr., PhD
Chief, Estuaries Branch

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3. Berger, R. C., Martin, W. D., McAdory, R. T., Schmidt, J. H., 1993. "Galveston Bay 3D Model Study Channel Deepening Circulation and Salinity Results," Hydraulic Engineering '93, Vol. 2, pp 2318-2322.

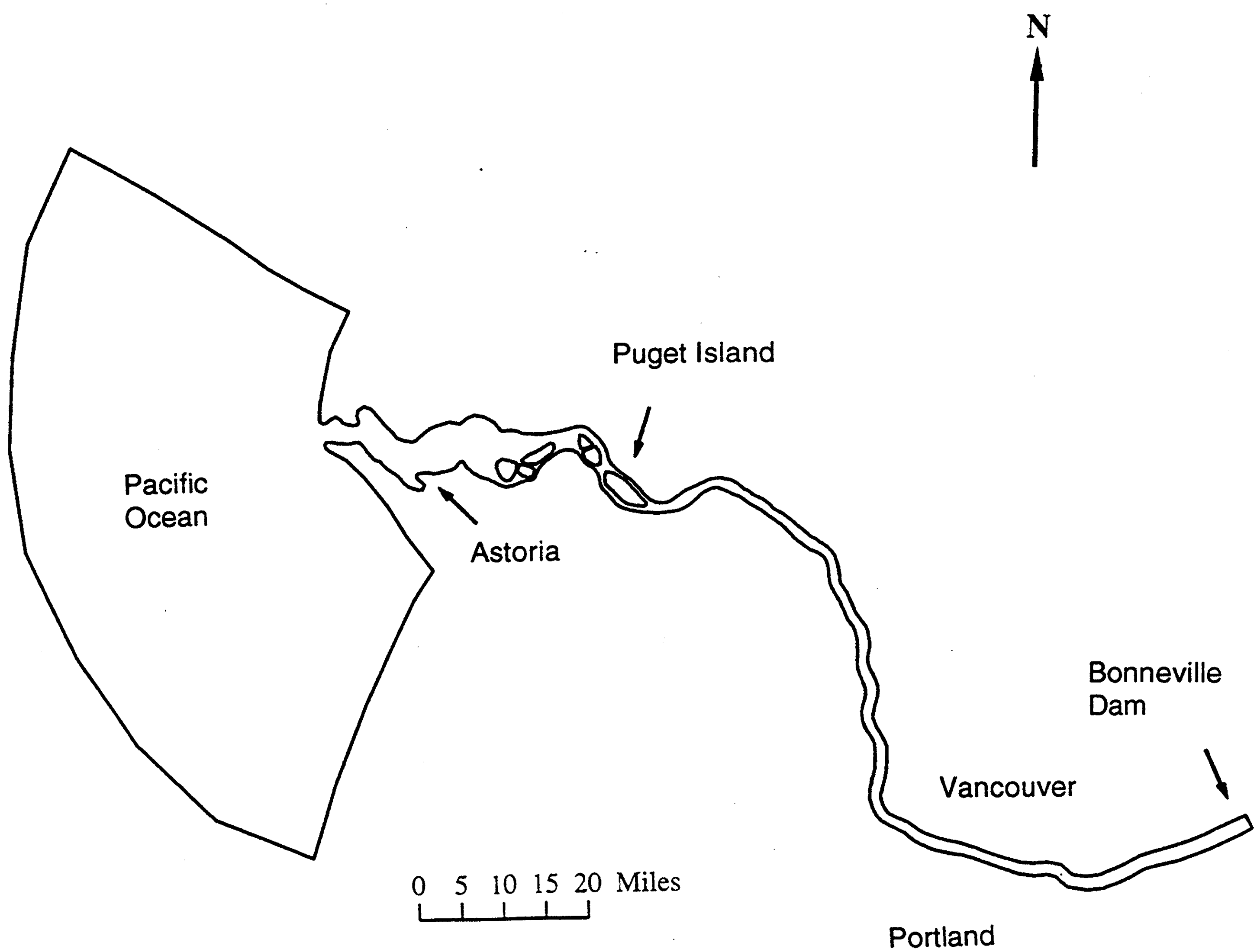

Figure 1. Computational mesh boundary and project location and vicinity

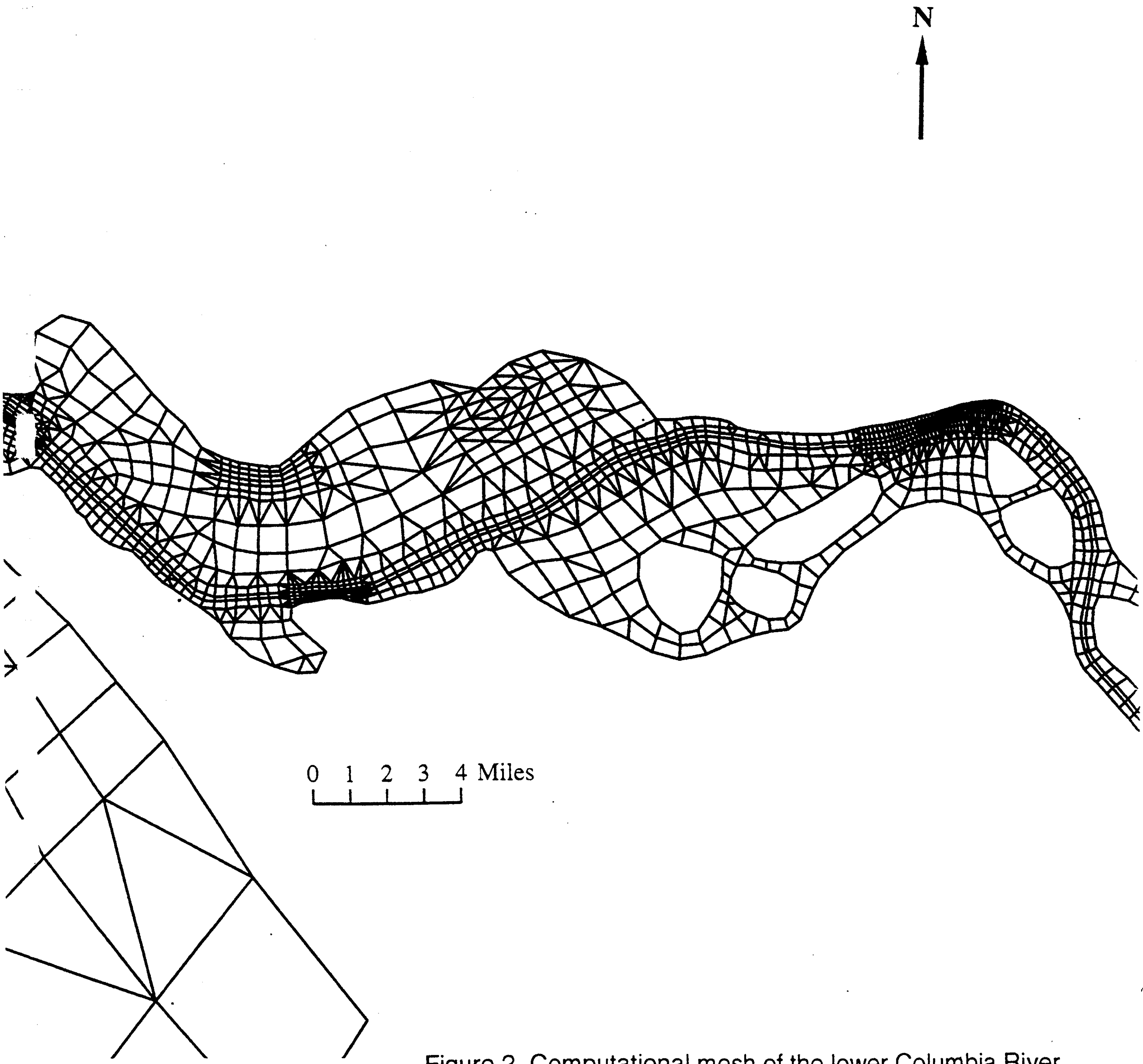

Figure 2. Computational mesh of the lower Columbia River

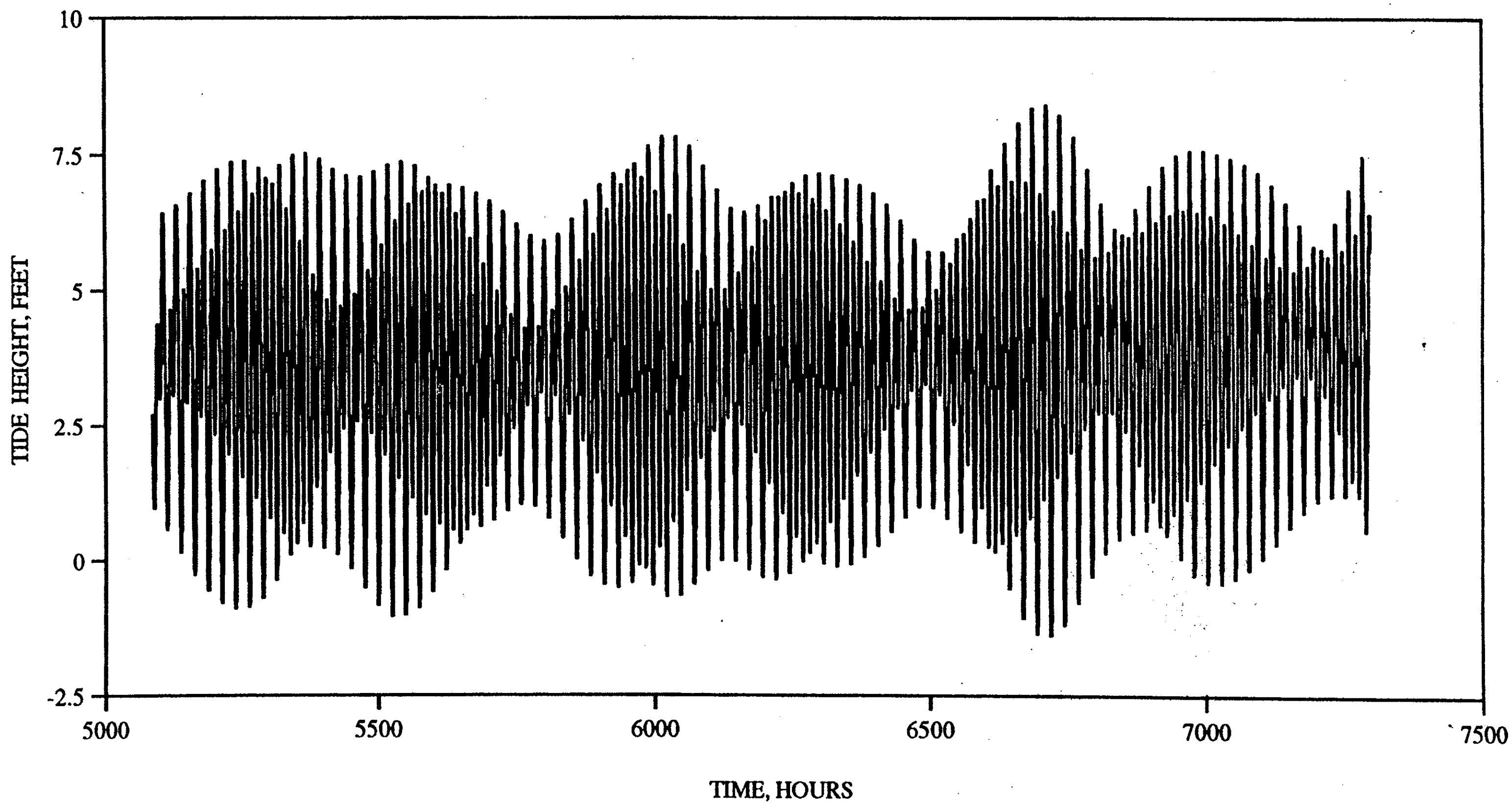

Figure 4. Synthetically generated tide near the mouth of Columbia River, late summer and fall 1993

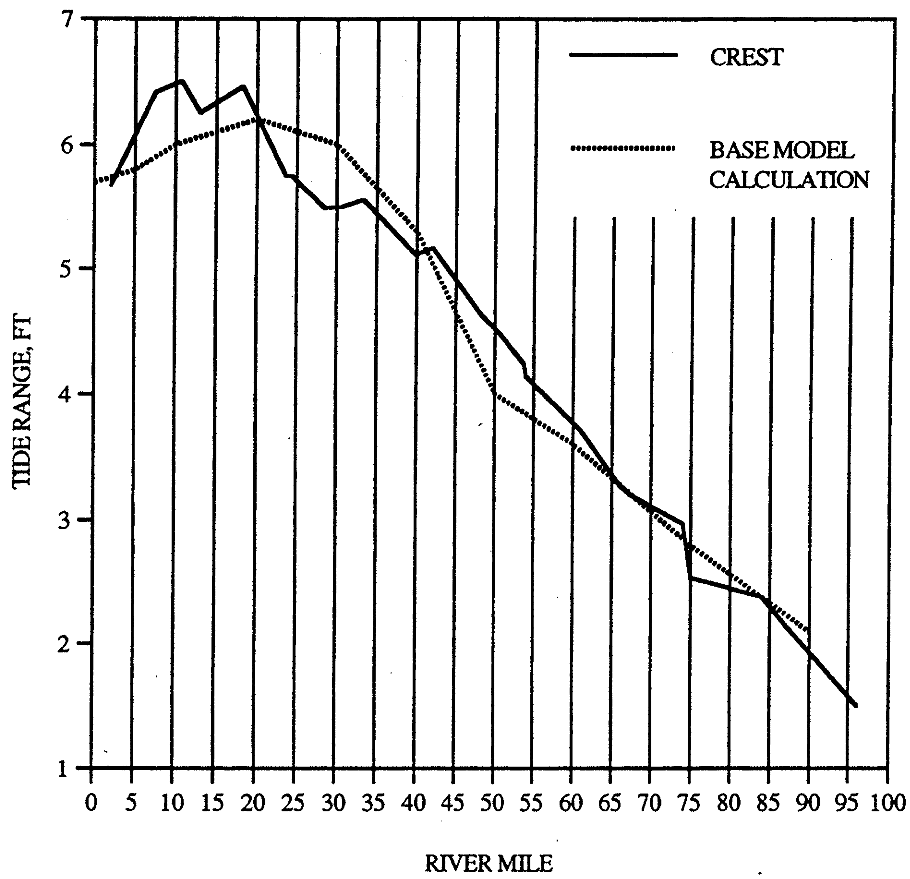

Figure 5. Average tide ranges in Columbia River estuary from CREST data and 1,500 hour calculation period

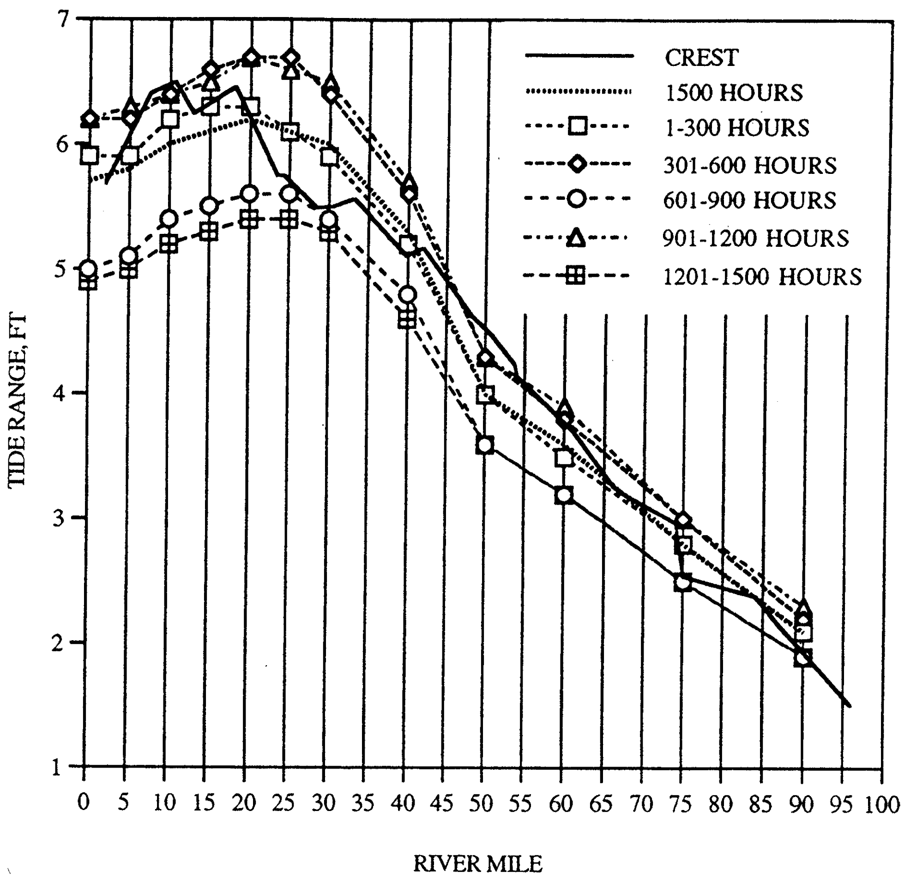

Figure 6. Average tide ranges in Columbia River estuary from CREST data, 1,500 hour calculation, and 300 hour calculation periods

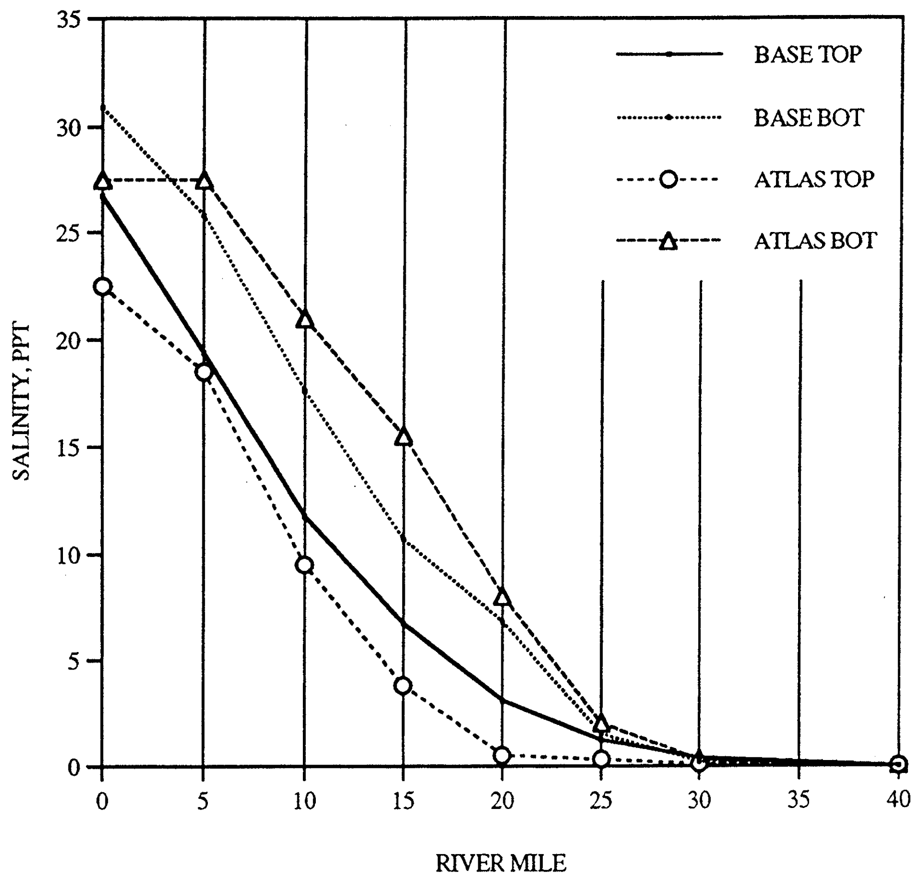

Figure 7. Columbia River surface and bottom mean salinities from the CREST ATLAS and calculated base conditions with 134,000 cfs inflow

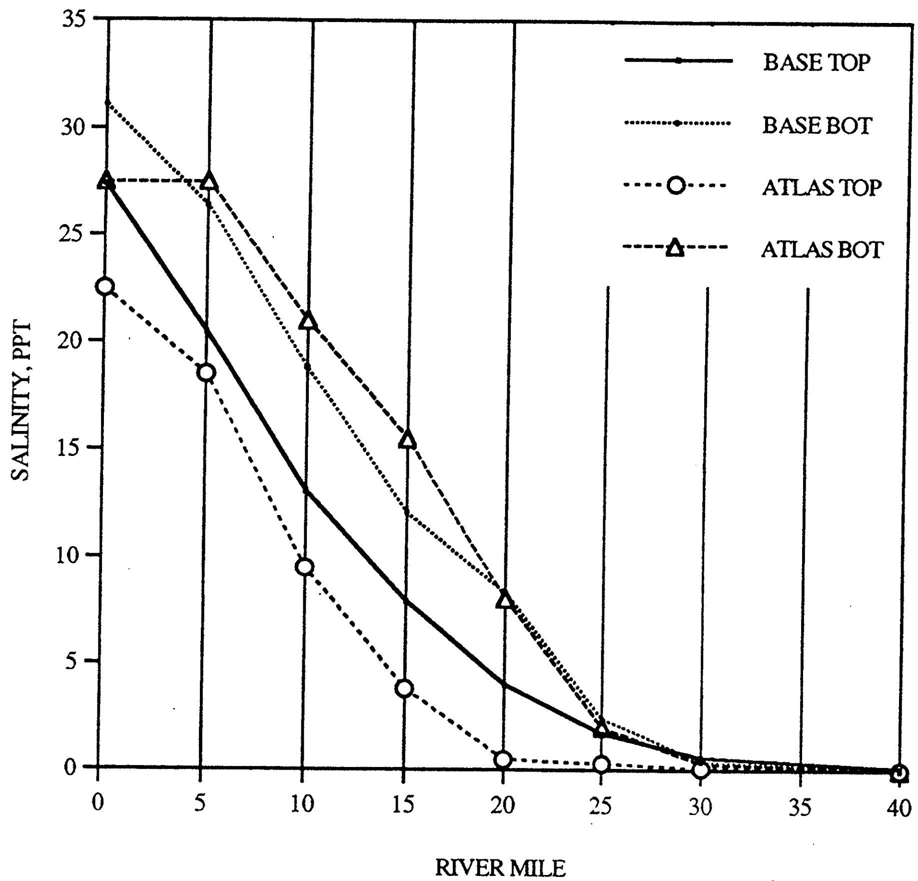

Figure 8. Columbia River surface and bottom mean salinities from the CREST ATLAS and calculated base conditions with 120,000 cfs inflow

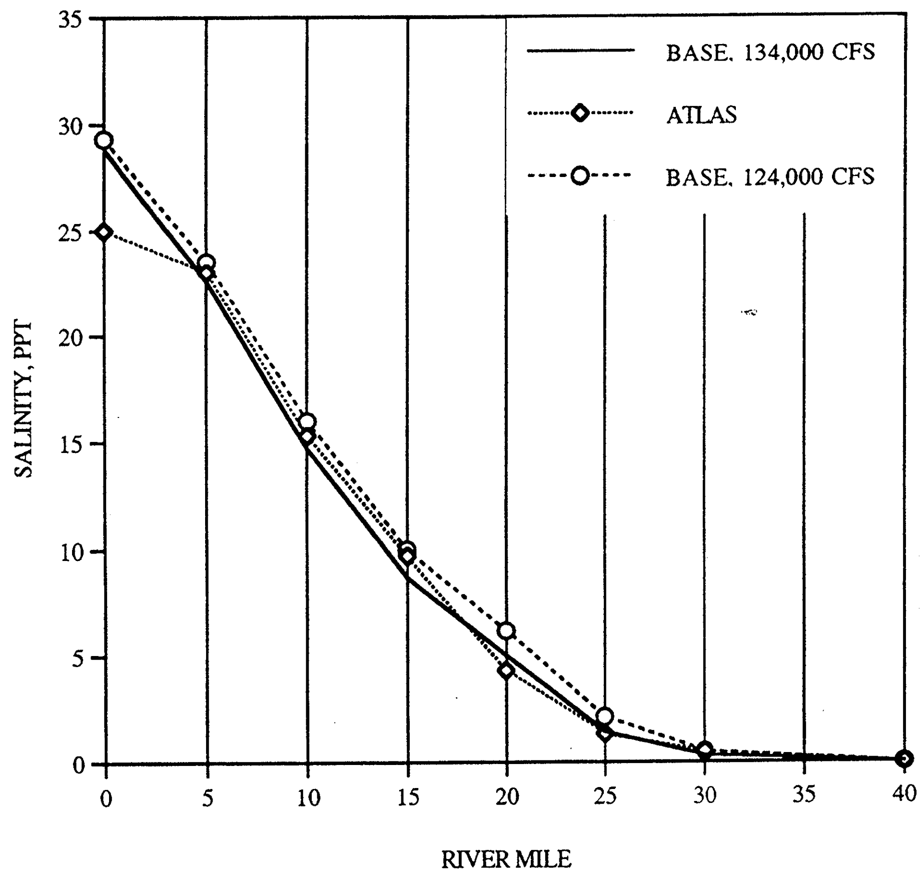

Figure 9. Columbia River surface and bottom mean salinities from the CREST ATLAS and calculated base conditions for 134,000 cfs and 120,000 cfs inflows

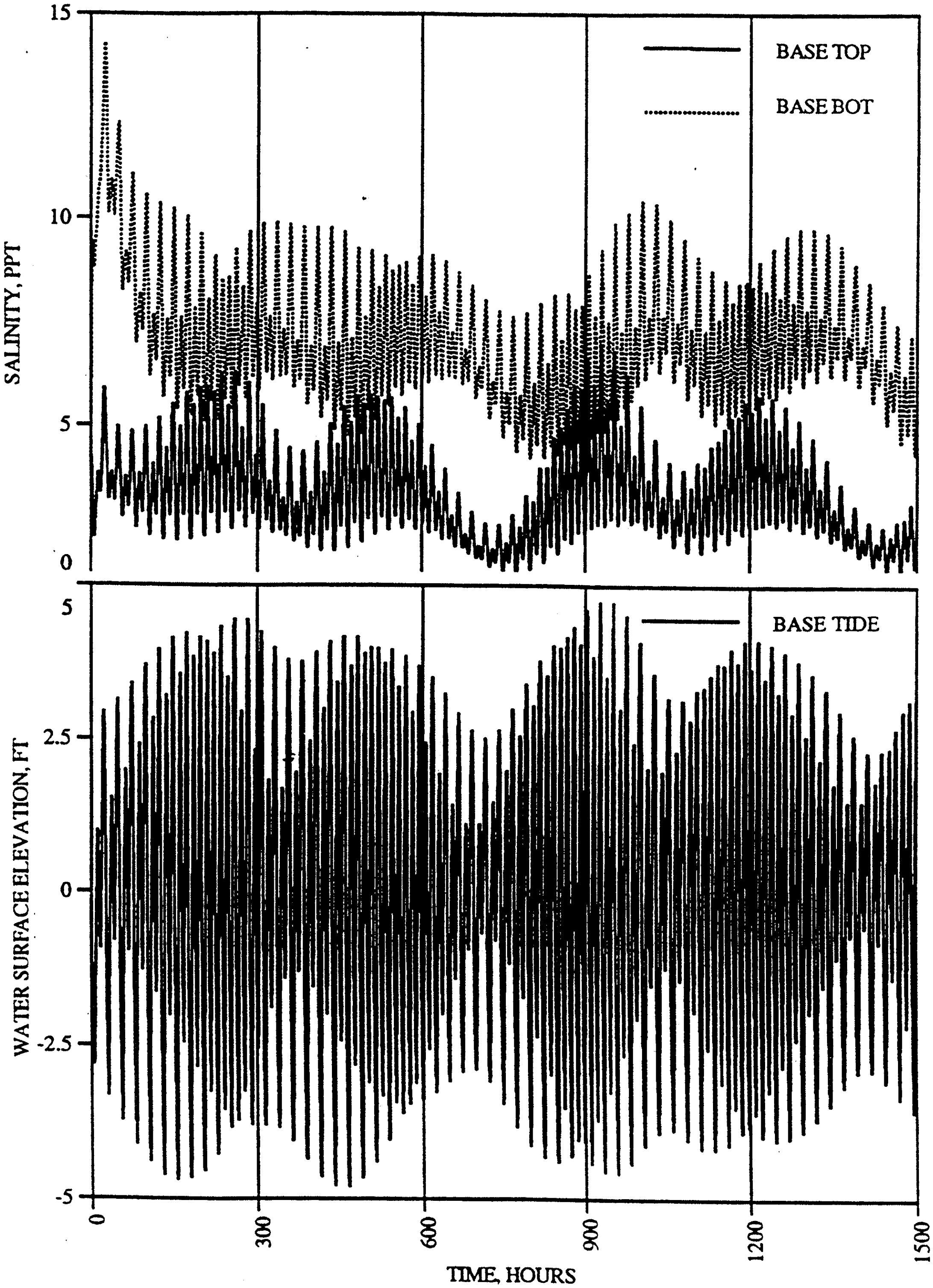

Figure 10. Upper plot shows surface and bottom salinity in the base channel at Columbia River mile 20; lower plot shows tide level (average tide level removed) at the same level

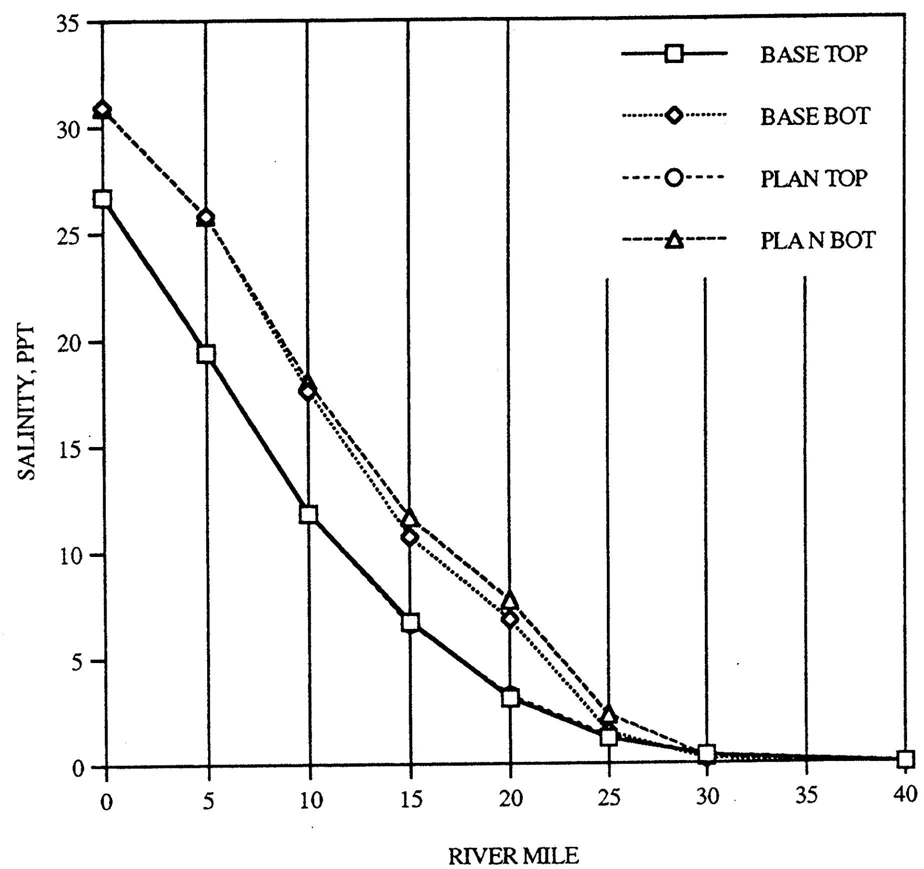

Figure 11. Comparison of existing and plan salinity in the Columbia River ship channel, 1,200 hour average, 134,000 cfs inflow

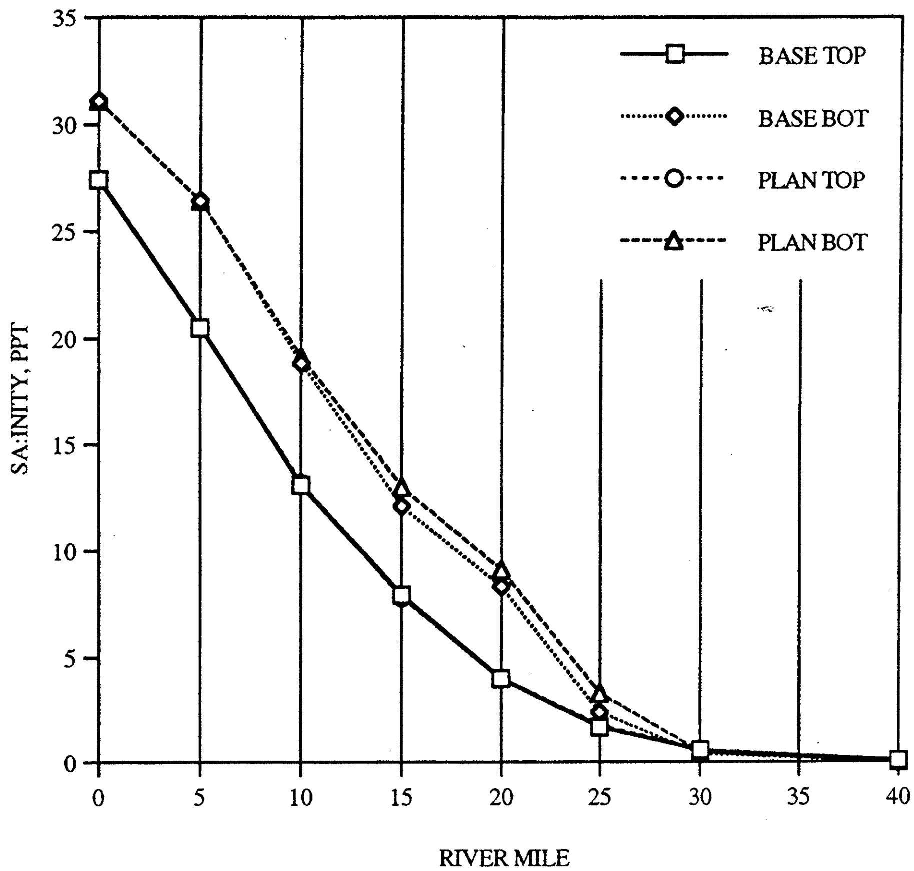

Figure 12. Comparison of existing and plan salinity in the Columbia River ship channel, 1,200 hour average, 120,000 cfs inflow

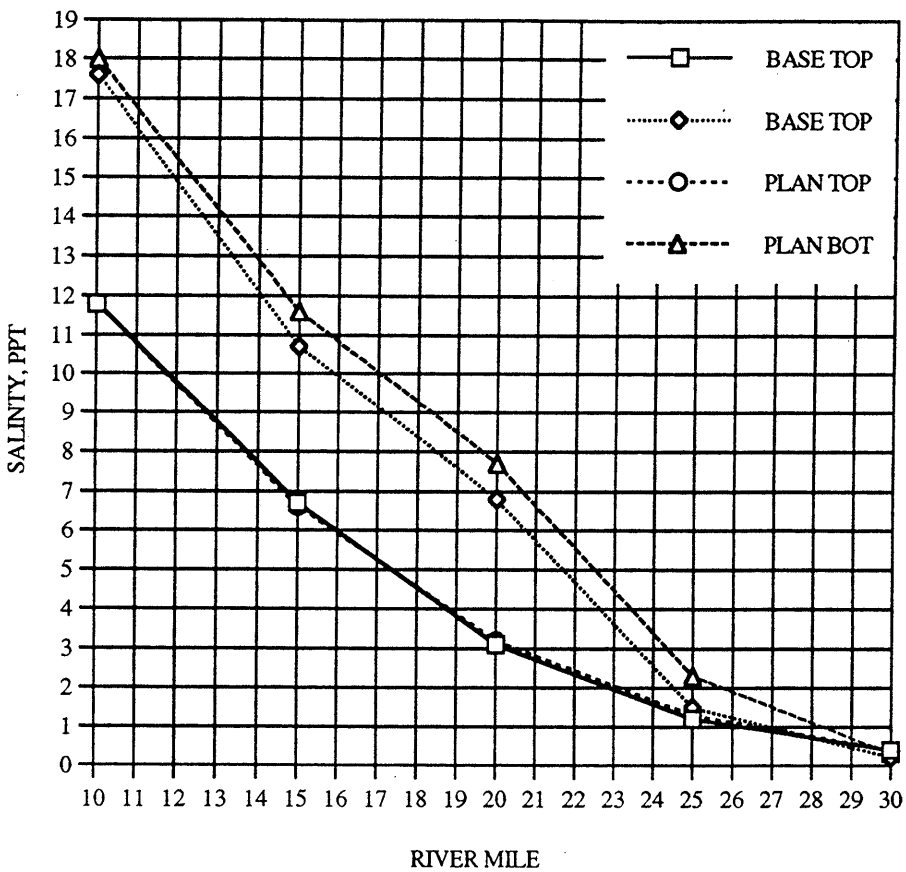

Figure 13. Comparison of existing and plan salinity in the Columbia River ship channel, 1,200 hour average, 134,000 cfs inflow, river miles 10 to 30

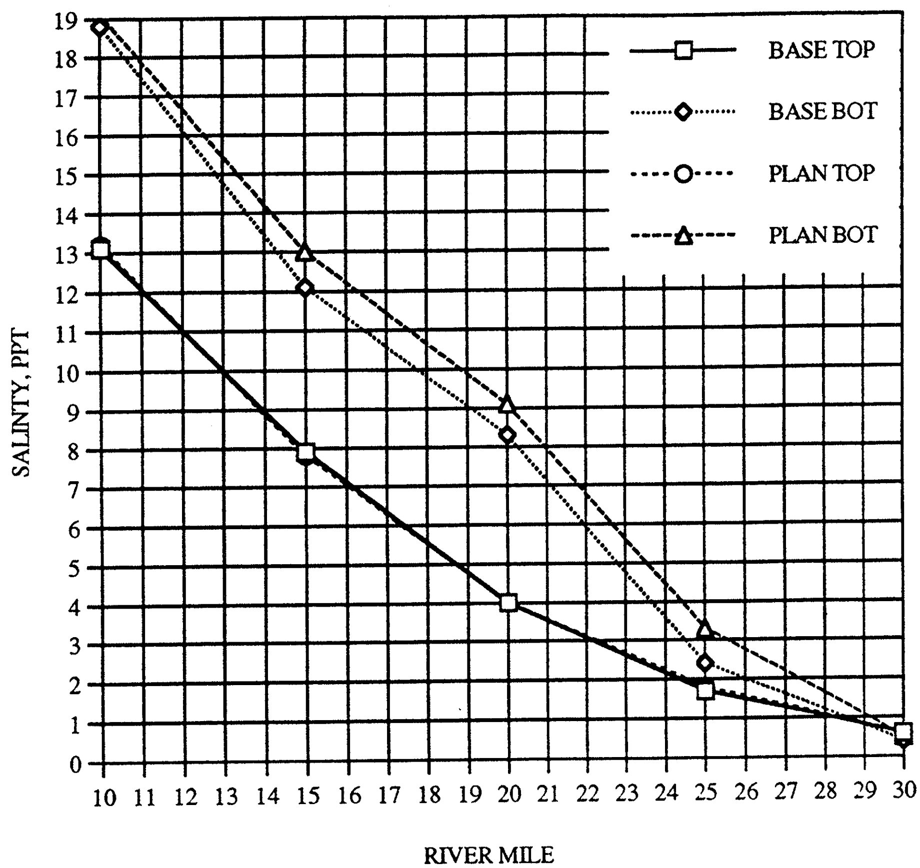

Figure 14. Comparison of existing and plan salinity in the Columbia River ship channel, 1,200 hour average, 120,000 cfs inflow, river miles 10 to 30

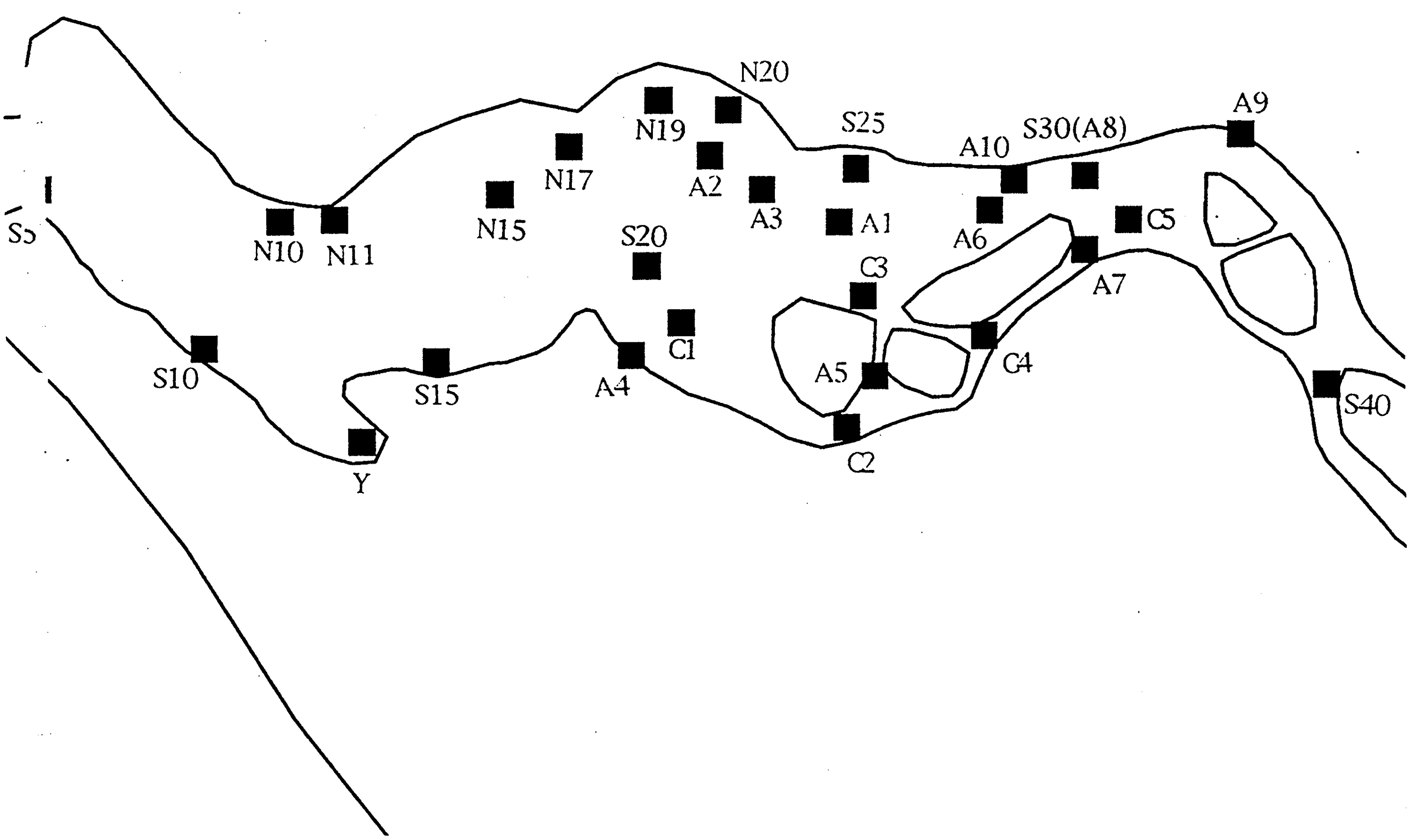

Figure 15. Sites where averaged salinity values were calculated

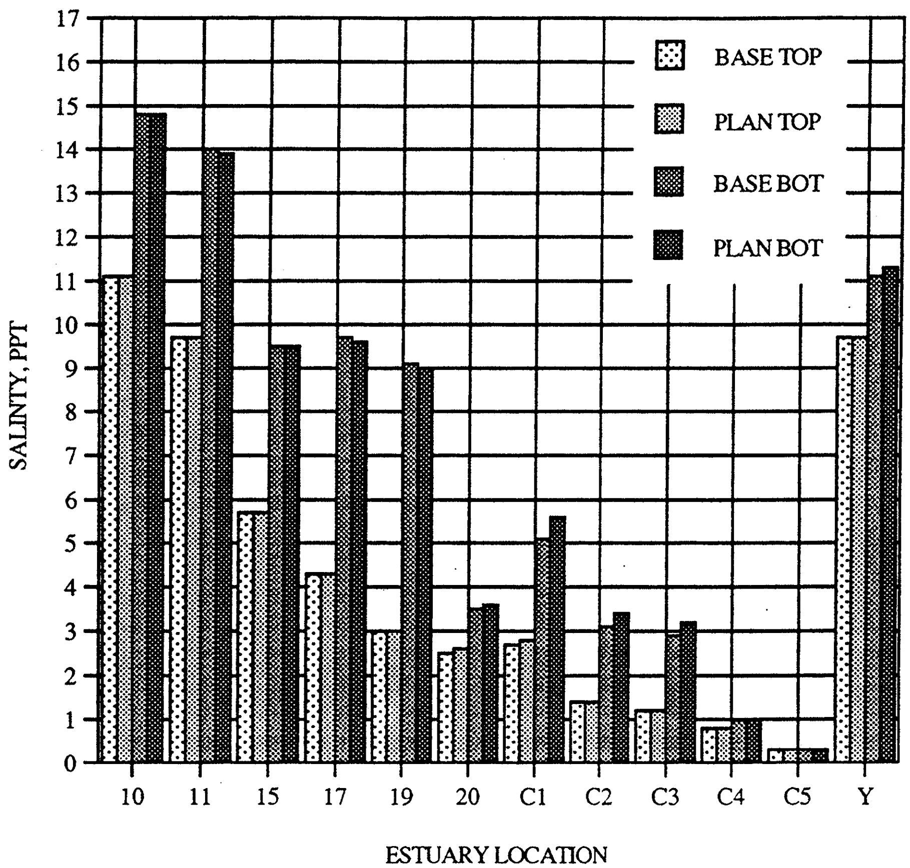

Figure 16. Comparison of base and plan salinities for Columbia River north channel, Grays, Cathlamet, and Youngs Bays, 1,200 hour average, with 134,000 cfs inflow

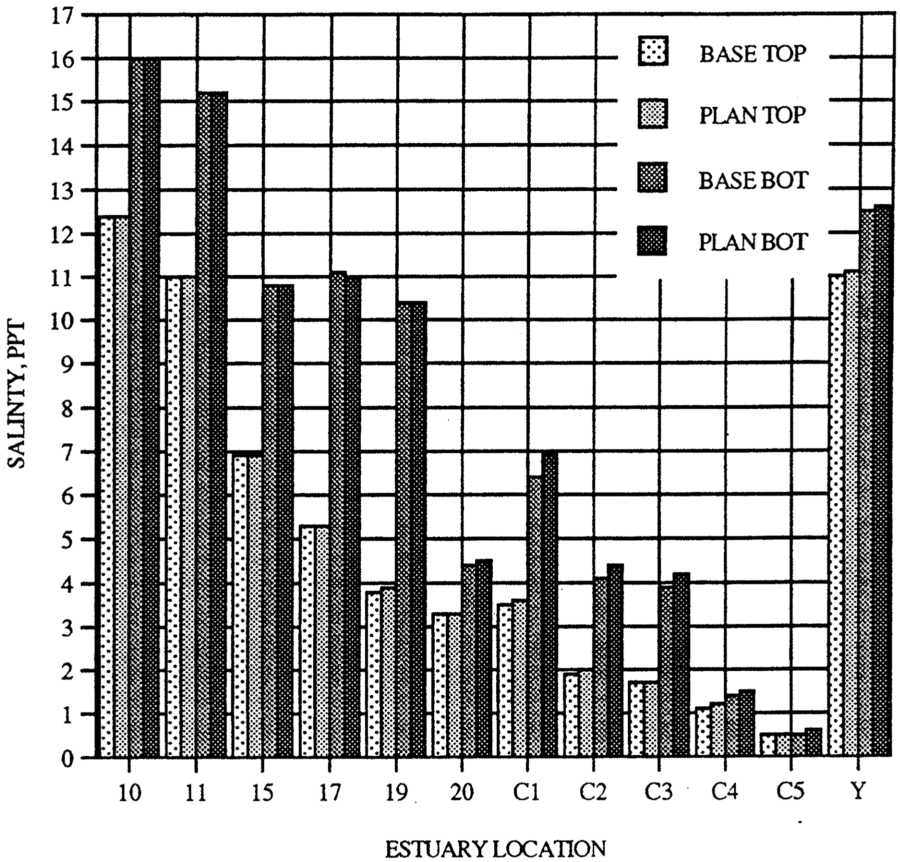

Figure 17. Comparison of base and plan salinities for Columbia River north channel, Grays, Cathlamet, and Youngs Bays, 1,200 hour average, with 120,000 cfs inflow

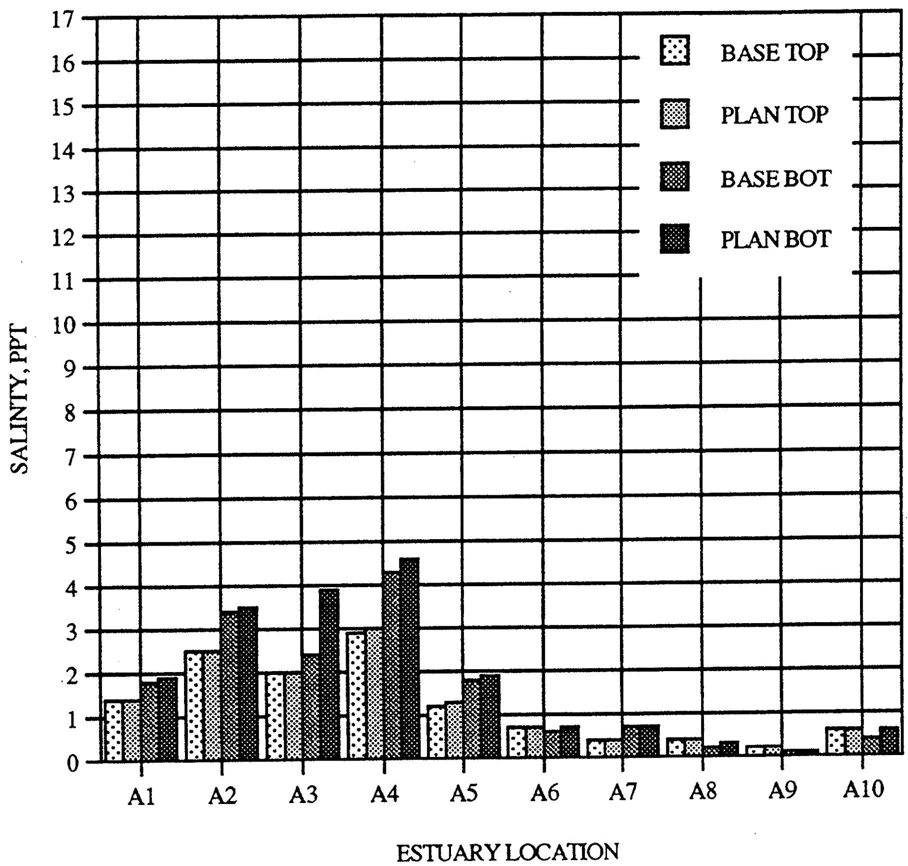

Figure 18. Comparison of base and plan salinities for Columbia River at locations A1 to A10, 1,200 hour average, with 134,000 cfs inflow

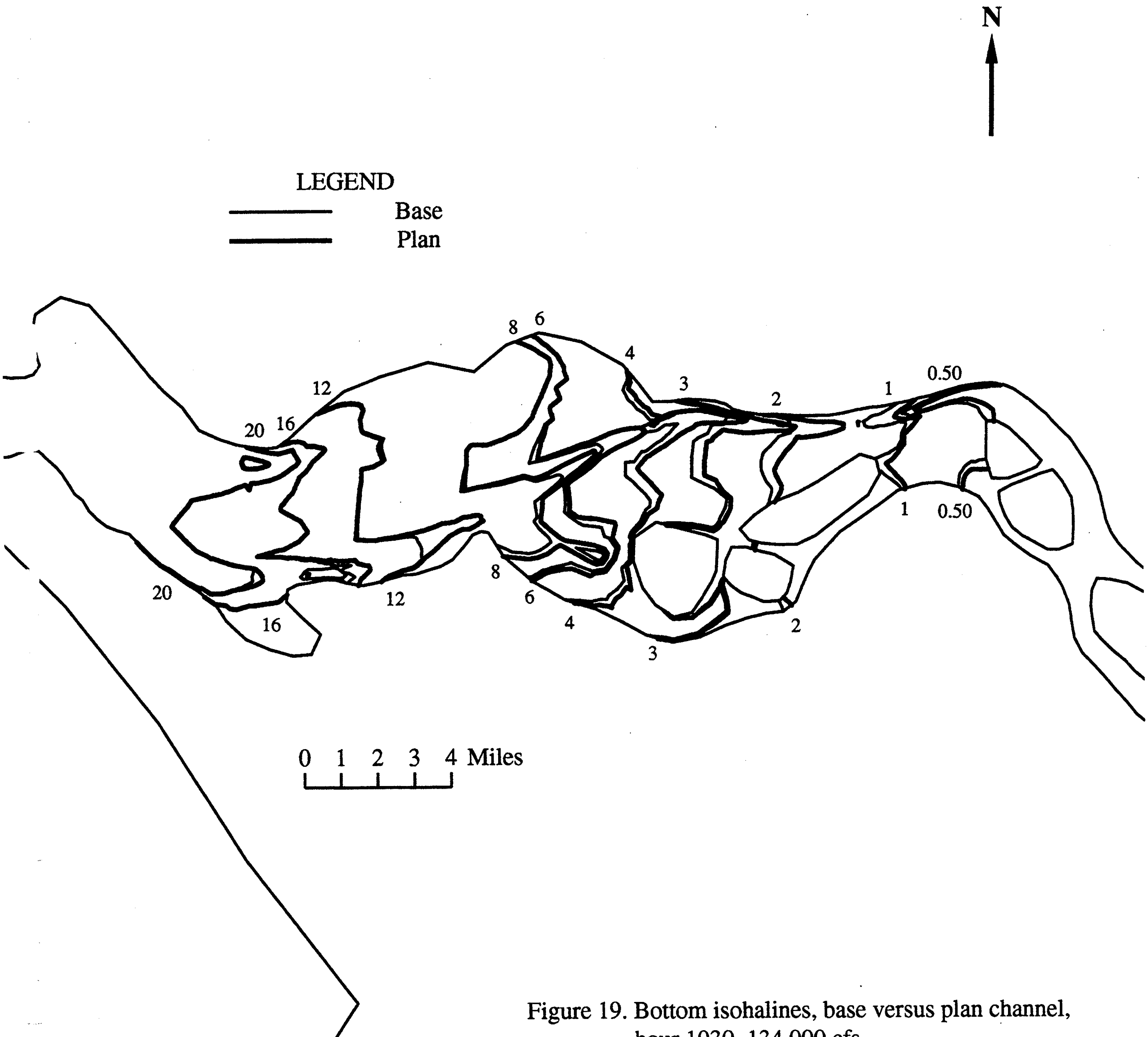

Figure 19. Bottom isohalines, base versus plan channel, hour 1030, 134,000 cfs

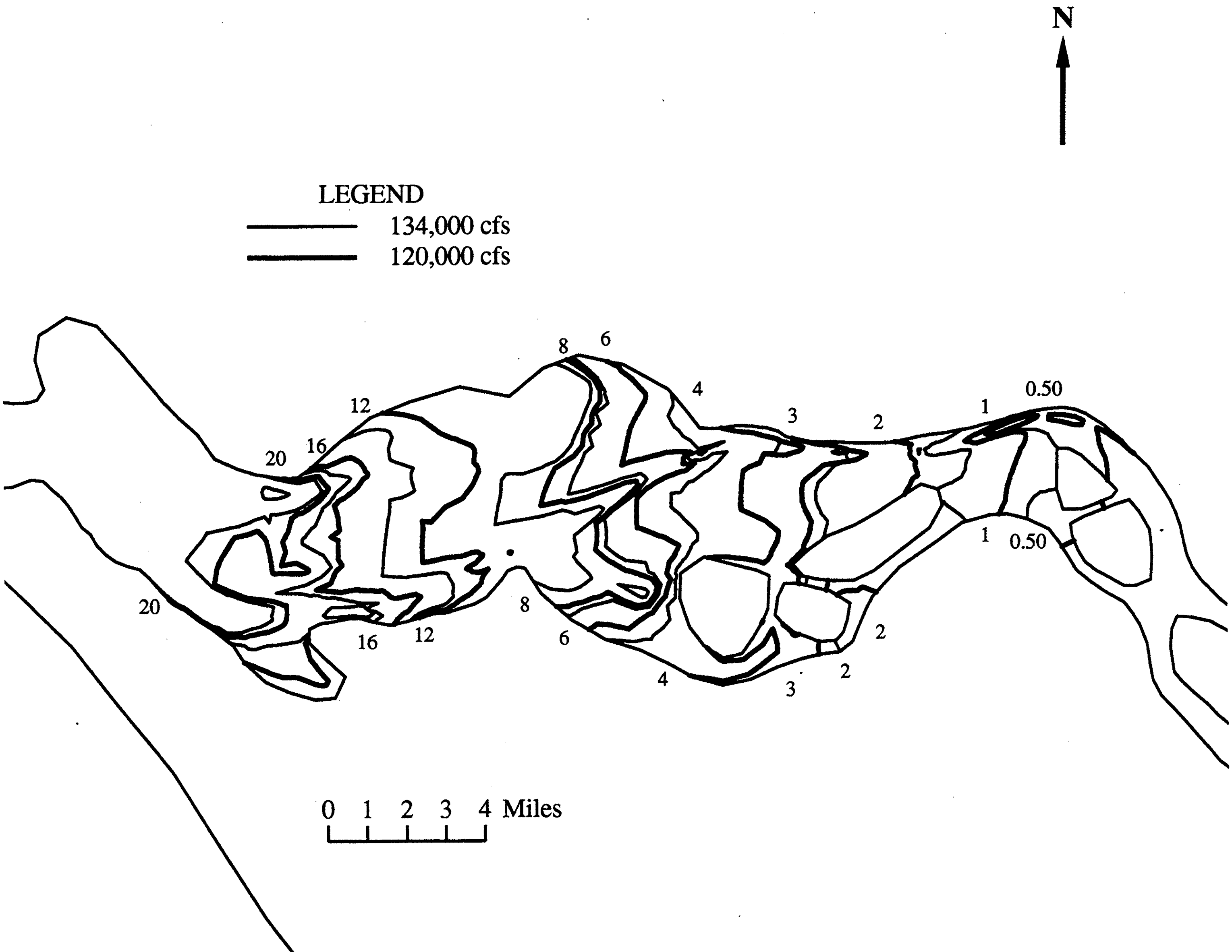

Figure 20. Bottom isohalines, base channel, hour 1030, 134,000 cfs versus 120,000 cfs

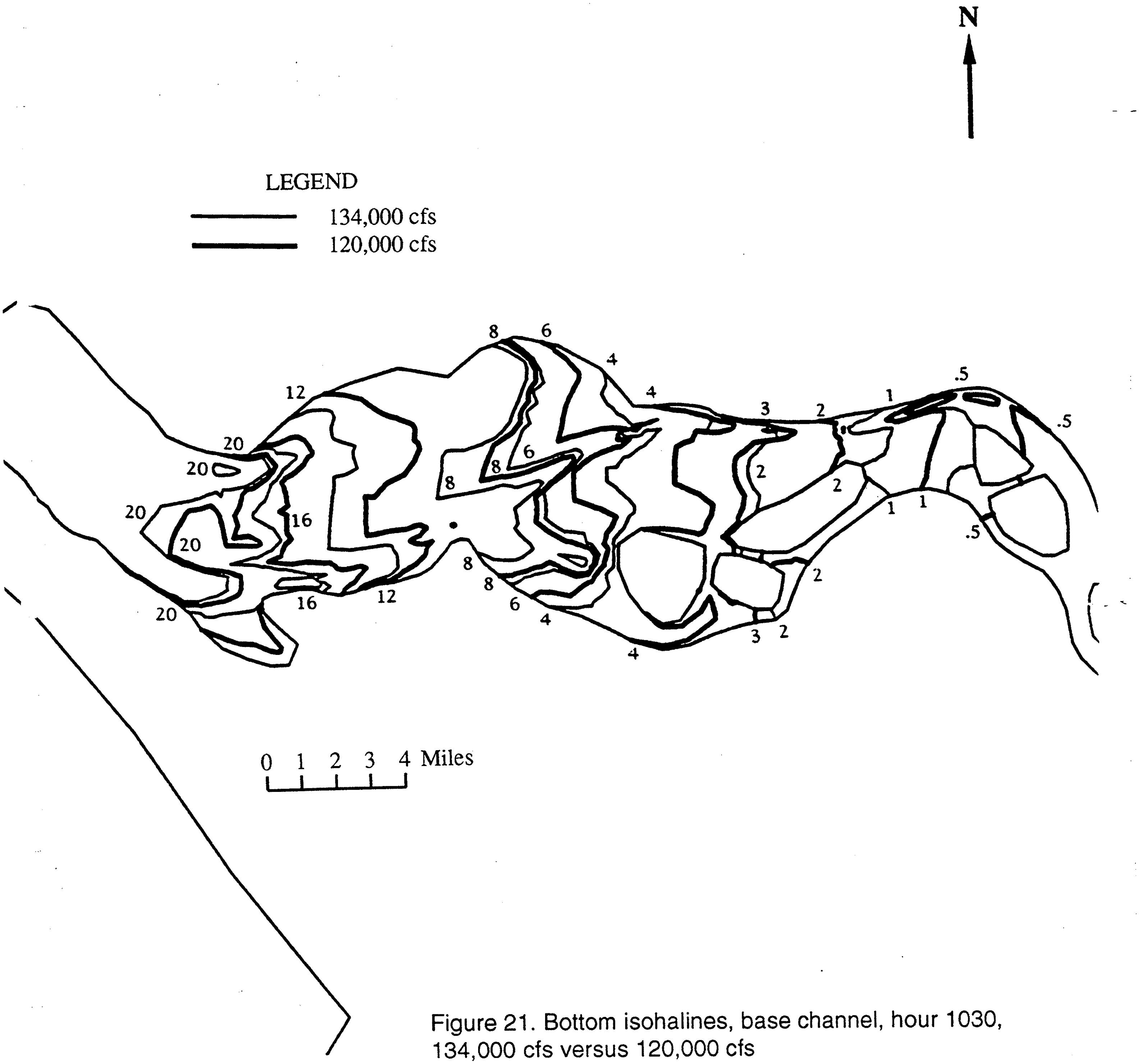

Figure 21. Bottom isohalines, base channel, hour 1030, 134,000 cfs versus 120,000 cfs