

Hydraulic and Sediment Transport Modeling For the Willamette River And Ross Island Lagoon

FINAL REPORT

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Hydraulic and Sediment Transport Modeling for the Willamette River and Ross Island Lagoon

Executive Summary

WEST Consultants, Inc. (WEST) was tasked by Landau Associates (Landau) to investigate hydraulics and sedimentation in the Willamette River and Ross Island Lagoon for Perkins Coie LLP on behalf of Ross Island Sand & Gravel. The investigation was to evaluate hydraulics and natural sedimentation in the lagoon due to flood flows, evaluate the possibility of headcuts within the lagoon and to explore options to increase sedimentation in the lagoon. A set of two-dimensional hydraulic and sediment transport models, the U.S. Army Corps of Engineers' RMA-2 and SED2D, were used in the analysis.

WEST reviewed numerous reports prepared by Landau, CH2M-Hill, GeoSea Consulting, the US Army Corps of Engineers, US Geological Survey, and others. The Willamette River was modeled for a 6.2 mile reach from the Broadway Bridge to about a mile below Elk Rock Island. Modeling consisted of both hydraulics and sedimentation to determine flow patterns and sedimentation rates that could be expected in Ross Island Lagoon due to natural flows in the river.

Modeling indicated that flow in the immediate area of Ross Island is controlled by a constricted area at the downstream end of Ross Island. This constriction limits the impact of lowering the berm between Ross and Hardtack Islands. Due to the downstream constriction, only very limited increases in flow and sedimentation resulted from the lowering of the berm. Currently flood waters overtop the southwestern edge of Ross Island and flow into the lagoon. This water then flows along the western edge of the lagoon and exits over the narrow western and northeastern portions of the island which separate the lagoon from the river and Holgate Slough. High flows do not cause significant velocities into or out of the lagoon via the entrance on Holgate Slough.

Based on model results it appears that natural sedimentation in the lagoon, consisting primarily of fines (silts and clays), is on the order of a few inches per year with more deposition occurring at the lagoon inlet. Increased deposition occurs at the inlet due to the reduction of flow velocities in the entrance allowing the suspended sediment load to deposit. Events that overtop the river side of the island do carry some sediment into the lagoon but flow patterns are such that most deposition is along the river side of the lagoon. Deposition rates were low over the entire range of flows modeled from 10,000 cfs to 459,000 cfs. Deposition of sediment in the lagoon could be expected to be fines based on the upstream geomorphology of the river.

A plan to lower the existing 900 ft long berm between Ross and Hardtack Islands to an elevation of +15 ft NGVD was also modeled. Model results showed some increase in the amount of flow

entering the Ross Island Lagoon but increases were not as dramatic as expected. The flow constriction at the downstream end of the island limited the impact of this option. The increased flow did not increase the depth of sedimentation but only increased the area of the lagoon receiving the maximum deposition for a fixed duration of flow.

The lowering of the berm would require erosion protection for the remaining berm as well as for the thin portions of the island between the lagoon and the river and Holgate Slough at the northern end of the lagoon. The erosion protection would be necessary to prevent the berm from eroding during a flood event with subsequent damage to the other perimeter areas at the northern end of the lagoon. Protection may also be necessary where the flows exit the lagoon to prevent floods from breaching the relatively narrow portions of the island at the northern end of the lagoon.

If the berm were to fail during a flood, a head cut could be propagated up the river from the lagoon as well as endangering the containment cells in the lagoon just downstream of the weir. Given the modest increase in flow and sedimentation in the lagoon it is unlikely that the increased risks of erosion, bank failures and other problems are warranted.

1. Introduction

WEST Consultants, Inc. (WEST) was tasked by Landau Associates (Landau) to investigate hydraulics and sedimentation in the Ross Island reach of the Willamette River for Perkins Coie LLP on behalf of Ross Island Sand & Gravel. The investigation was to evaluate flow patterns and natural sedimentation in the lagoon due to flood flows and to explore options to increase sedimentation in the lagoon. The evaluation of flow patterns and natural sedimentation required the use of two-dimensional hydraulics and sediment transport models. The U.S. Army Corps of Engineers' (Corps) RMA-2 and SED2D models were used to perform this analysis in conjunction with the SMS model interface.

1.1 Scope

The study, as commissioned by Landau Associates, consisted of developing an existing condition hydraulic and sediment transport model of the Willamette River upstream and downstream of Ross Island as well as for the Ross Island Lagoon and Holgate Slough. This model was to estimate existing deposition rates in the lagoon for various flood flows that overtopped the island perimeter for both existing, proposed lowered berm conditions, and a proposed fill scenario.

Two proposed plans were developed and studied. One plan consisted of lowering the existing berm between Ross and Hardtack Islands as a possible means to increase sedimentation and to possibly improve habitat in the lagoon. This alternative involved lowering the berm that prevents flow between Ross Island (the western island) and Hardtack Island (the eastern island where Ross Island's plant equipment is located) to an elevation of +15 ft NGVD for a distance of approximately 900 ft. This option is referred to as the "lowered berm" plan.

The second alternative involved placing fill in the lagoon to reinforce the northern perimeter and protect existing disposal cells in the southern portion of the lagoon. Fill was to be placed along the northern perimeter to reduce the existing steep slope as well as to increase the top width of the island around the northern perimeter of the lagoon. Fill was proposed to be placed along the south end of the lagoon not only to reduce the slope and provide extra protection for confinement cells, but also to allow wetland and upland plants additional area for improved aquatic and upland habitat.

1.2 Project Overview

As a means to accomplish the desired tasks, WEST developed a two-dimensional finite element grid of the Willamette River from Broadway Bridge (River Mile (RM) 11.8) to a location approximately one mile downstream of Elk Rock Island Park near Waverly Heights (RM 18) as shown in Figure 1. The upstream and downstream limits of the model were selected so as to be sufficiently far from the area of interest to allow the model to overcome any effects of upstream and downstream boundary conditions for flows through the Ross Island reach of the model.

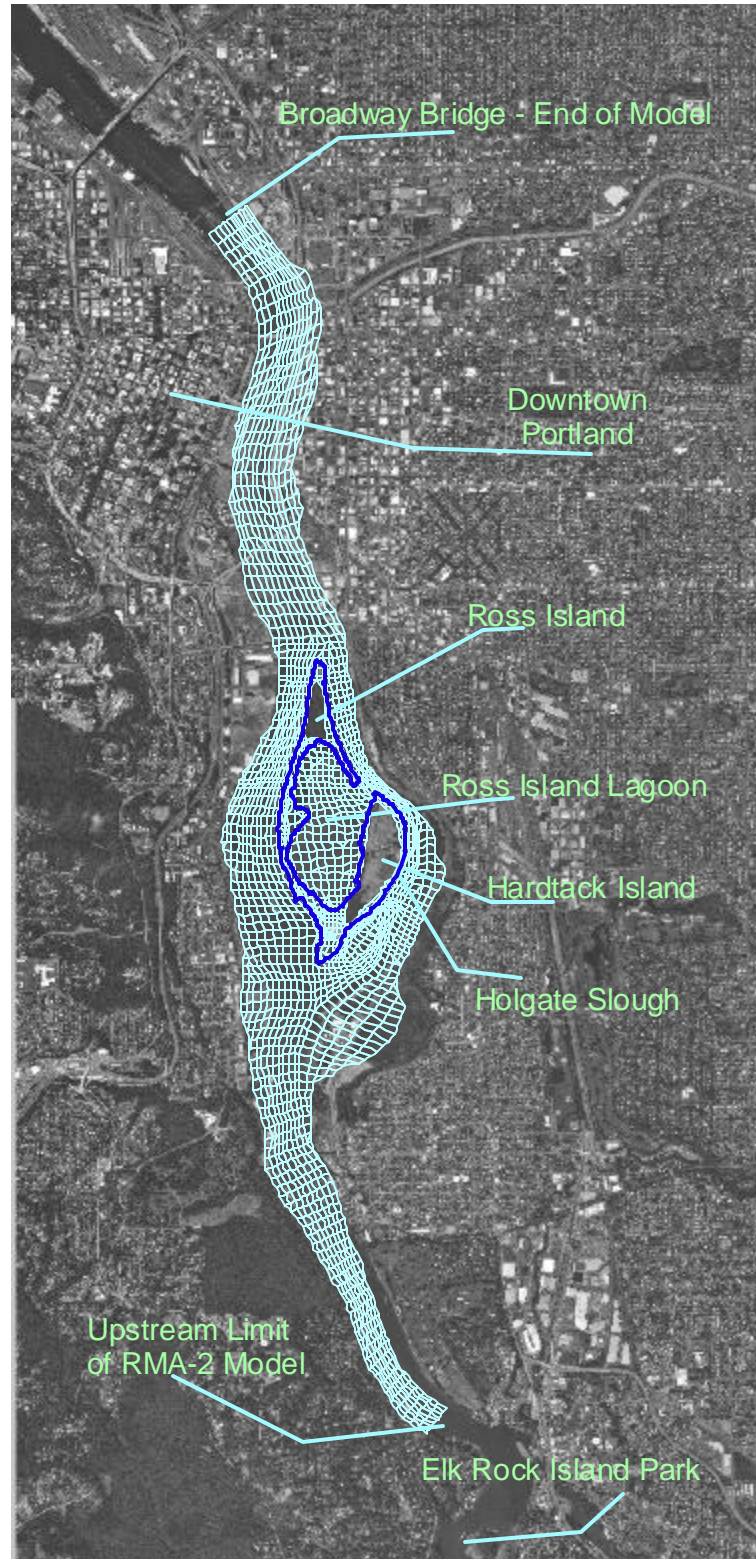


Figure 1. Aerial View of Project Location showing River, Computational Mesh and Study Limits.

Relative amounts of sedimentation that would occur in the lagoon for flood conditions for existing and a proposed lowered berm conditions were investigated by modeling the peak flow for what were estimated to be the 5-yr, 10-yr, 100-yr, and 1996 floods. On the basis of the 23 years of data that were obtained for this analysis, the 1996 flood appears to be on the order of a 500-year flood. However, another flow of approximately the same magnitude can be found in December 1964 when all but a few of the dams on the Willamette River were completed. This would lend credence to the idea that the 1996 flood was not the 500 year flood but something much more frequent. The detailed analysis of the hydrologic data was beyond the scope of this study and flows presented here are listed as actual flow rates rather than by recurrence intervals.

2. Review of Existing Data and Prior Studies

Large volumes of data were reviewed in preparation for the modeling effort. Numerous reports were furnished by Landau and additional data were obtained from USGS and Corps sources. The reports reviewed can be seen in the References section of this report. The reports included previous modeling efforts to assess turbidity in the lagoon, suspended sediment sampling and analysis program reports and sediment characteristic reports of deposits located just downstream of the study reach in the Portland Harbor as well as upstream at the Willamette Falls Lock. Several Corps and USGS reports were also reviewed and found to contain helpful information. A report titled "Sediment Trend Analysis for the Lower Willamette River" by GeoSea Consulting was also reviewed and provided some insight into sediments in the area.

Several studies have been conducted in regards to sediment transport and the makeup of deposits in the Willamette River and the Portland Harbor. These study reports contained information on sediment gradations, classifications and size distributions.

2.1 Bathymetry and Topography

Bathymetry for the model was obtained from the US Army Corps of Engineers, Portland District. The bathymetry consisted of the most recent data available as of December 31, 2001 and was provided in digital format. This data included bathymetry for the river as well as Holgate Slough but no topographic data for overbank areas. In order to augment this data digital elevation models (DEMs) developed by the USGS were also downloaded and trimmed to remove the river and areas away from the river floodplains. The data used was contained in the Portland and Lake Oswego 7.5 minute quadrangle files. Digital orthophotos were also obtained for the areas of interest and used as background photos to assist in model development and n value determination.

The river bathymetry showed very deep holes in the Willamette River upstream from Ross Island. These deep holes showed bottom elevations as low as -115 ft NGVD. Other holes exist with bottom elevations on the order of -85 ft to -90 ft NGVD. These very deep holes would tend to trap any large bed material moving in the river, i.e. gravels, cobbles, and coarse sands. Bed elevations for the Willamette River in the Ross Island reach are much shallower, being on the order of -30 to -50 ft NGVD.

2.2 Hydrology

The Ross Island gage is located at the Ross Island bridge and gage zero or elevation 0.00 ft at the gage is referred to as the Ross Island Datum. This datum differs from NGVD 1929 by +1.55 ft. This means that 0.00 NGVD is actually -1.55 ft Ross Island datum. The Ross Island gage is subject to tidal influences as well as backwater from the Columbia River. The stage discharge plot is shown in Figure 2 and the wide variation in stage for a particular flow rate can be readily noted. This scatter complicates the modeling of flow through the reach. Modeling was performed assuming a low downstream head which increases velocity and transport in the river. The higher tidal and backwater conditions will most likely result in lower velocities in the river and less ability to transport sediment into the lagoon. The slower velocities due to deeper water may offset deposition by allowing more time for deposition as the water passes, however, velocities in the lagoon are already very low under conditions of no backwater from the Columbia River. Velocities inside the lagoon will not change significantly based on backwater given the 130 ft depths already present in the lagoon.

A detailed analysis of the current hydrology of the Willamette River was beyond the scope of this study. Peak flow values for the Ross Island gage were available from the USGS website for a 23-year period from 1972 until 1994. Flows based on the routing of upstream reservoir releases were available for the same gage from 1994 until 2000 from the U.S. Army Corps of Engineers.

The annual peak discharge data was analyzed using both the USGS estimation software and the Corps' FFA program and estimates were obtained for the various return periods. Analyses were run on the USGS record, the combined record and the combined record without the 1996 flood peak. Based on the data available since 1972, the February 1996 peak daily average of 420,000 cfs was considered to be a statistical outlier. The various estimates for return periods varied significantly depending on the length of record used. Since the exact return period was not critical to the analysis, estimated peak values calculated from the USGS data were used as the inflows for the models. The flows used in the modeling effort were as follow:

1996 Flood Peak	459,000 cfs
100 Year Peak*	318,500 cfs
10 Year Peak*	224,000 cfs
5 Year Peak*	195,400 cfs

* Estimates based on 1972-1994 Period of Record.

The 1996 flood peak is based on an hourly record while the other peaks are based on daily averages. The daily average of the 1996 flood was approximately 420,000 cfs. The determination of more exact flow rates for the return periods was not necessary for the current modeling effort since a simple range of flows were needed to view the hydraulics and sediment transport due to differing flow conditions. The estimates based on the 23 years of USGS data were considered to give an adequate range of flows to meet the purposes of this study, especially when used in conjunction with the 1996 flood peak.

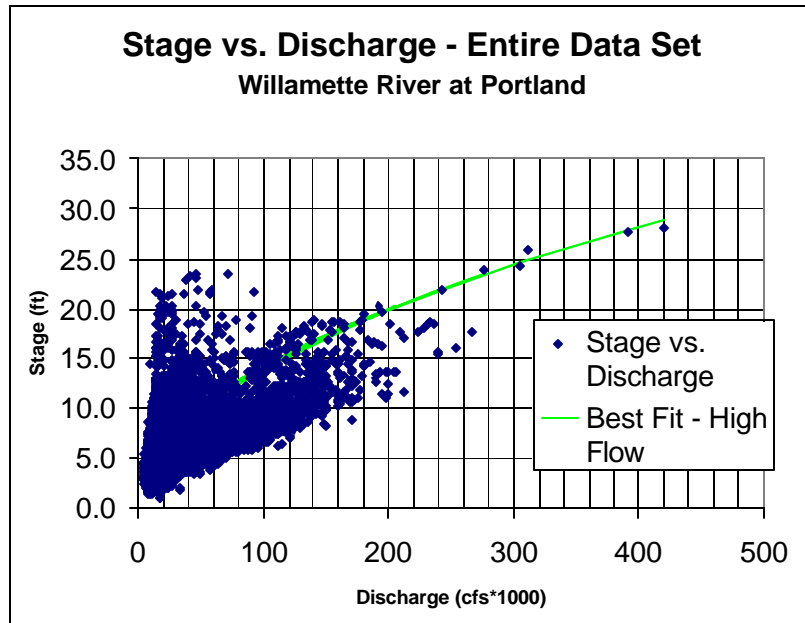


Figure 2. Stage Discharge Relationship for Willamette River at Portland. (Ross Island Datum)

The upper portion of the February 1996 hydrograph was used to estimate total sediment deposition within the lagoon during the flood event. Due to sediment model limitations, it was necessary to use a stepped hydrograph to model the hydrographs of interest. The 1996 hydrograph as implemented in the Corps' UNET model is shown in Figure 3. It can be noted that the model peaks at 420,000 cfs as opposed to the 459,000 cfs in the observed record.

The minimum flow modeled for the 1996 flood hydrograph was 195,400 cfs. Extended flows below 195,400 cfs were not modeled as they do not flow over the island and directly into the lagoon under the normal head conditions on the Columbia River which were modeled. The only sediment transfer into the lagoon under these lower flow conditions is through the inlet. Later modeling verified that sediment deposition under these conditions is not large unless the flows occur for a relatively large number of days. This stage of the modeling was evaluating high flows that entered the lagoon directly from the Willamette River across the existing berm.

Near the end of the study it was determined to be necessary to construct an "average annual" hydrograph to view sediment transport into the lagoon for an "average" year. This was done by dividing the observed flows into 10,000 cfs bins, summing the number of daily flows for each bin and then dividing the number of days at each flow rate by the total number of days observed. This procedure resulted in a flow duration curve based on observed values for the period of record used. The resulting time duration curve is shown in Figure 4. In order to model this hydrograph a series of steps was again used to represent differing time periods during an "average" year.

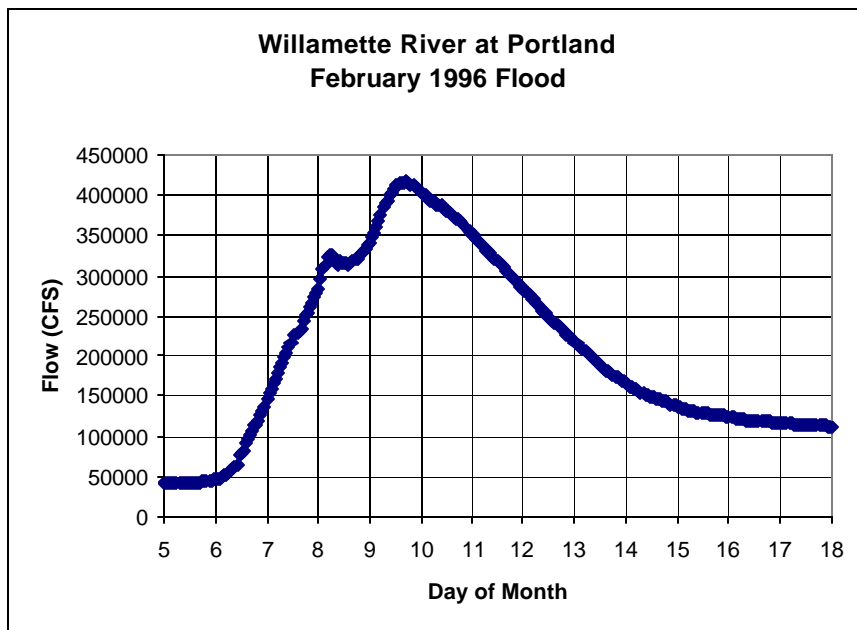


Figure 3. February 1996 Flood Hydrograph from the UNET Model.

35,000 cfs, 75,000 cfs and 200,000 cfs. The data for Figure 4 was discretized using these four flow rates. A flow rate of 10,000 cfs was determined to last for 180 days, 35,000 cfs for 110 days, 75,000 cfs for 70 days and 200,000 cfs for 5 days totaling 365 days and being representative of the average annual flow distribution.

2.3 Inflowing Sediment Loads

Numerous sediment samples have been collected and analyzed for the reach being modeling for this project. Sediment samples for the most part were described in terms of the percent smaller than 0.0625 mm (clays and silts) and total concentration. Suspended sediment samples indicated that very little sand is present in suspension in the river. Concentrations of

A previous RMA-2 study by Northwest Hydraulic Consultants (NHC) utilized three flow rates in studying turbidity inside the Ross Island Lagoon. In reviewing Figure 4 it was determined that utilizing the three flows used in the NHC model (as well as the NHC model for these flows) along with the lowest flow from the current study would adequately characterize the “average” annual flow duration curve. Thus four basic

flow rates were identified for use in modeling the “average” annual hydrograph: 10,000 cfs,

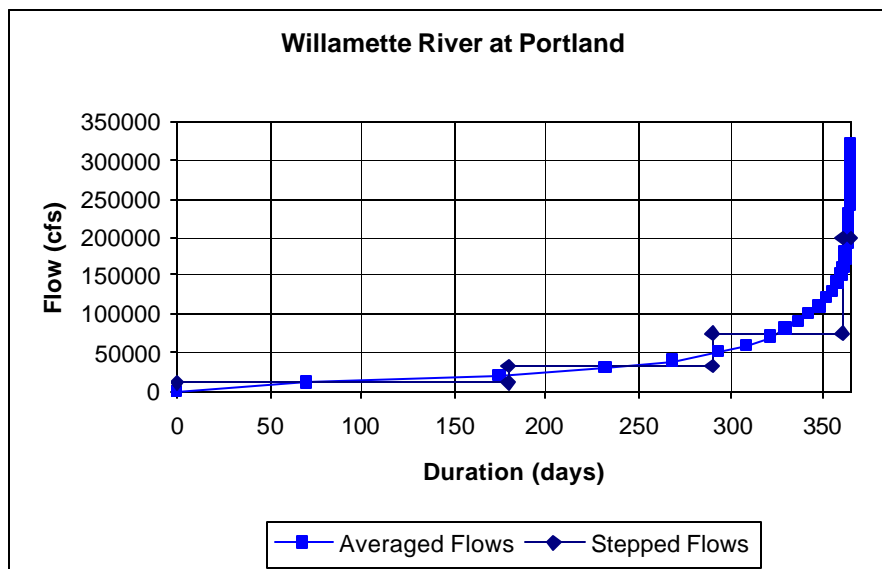


Figure 4. Flow Duration Curve for Willamette River at Portland.

materials in the sand sizes are usually less than 15% of the total and most commonly on the order of 5-10%.

Observed concentrations vary widely based on flow but this is common to sediment sampling programs. A plot from the 1964 Willamette River flood showing flow and sediment load illustrates the disconnect between the flow hydrograph and the sediment concentrations. (Figure 5) As can be noted, the highest concentration of sediment often does not occur with the peak flow. For the purposes of this study the two peaks were taken to correspond since a detailed analysis of when the sediment samples were taken in relation to peak flows was also beyond the scope of this project. Given the scatter that exists in flow-concentration curves (See Figure 6), further analysis was not warranted for this study.

Sediment samples existed for the entire range of flows modeled in this effort. The observed

sediment concentrations for various flow rates are shown in Figure 6. The best fit line used to estimate sediment concentrations at the Ross Island Bridge is also shown.

The highest observation shown in Figure 6 was actually obtained at the St. Johns Bridge at RM 6 rather than at Ross Island Bridge (RM 14) but it is the only sample that was found for the 1996 flood and appears to be a reasonable value based on observations at lower flows.

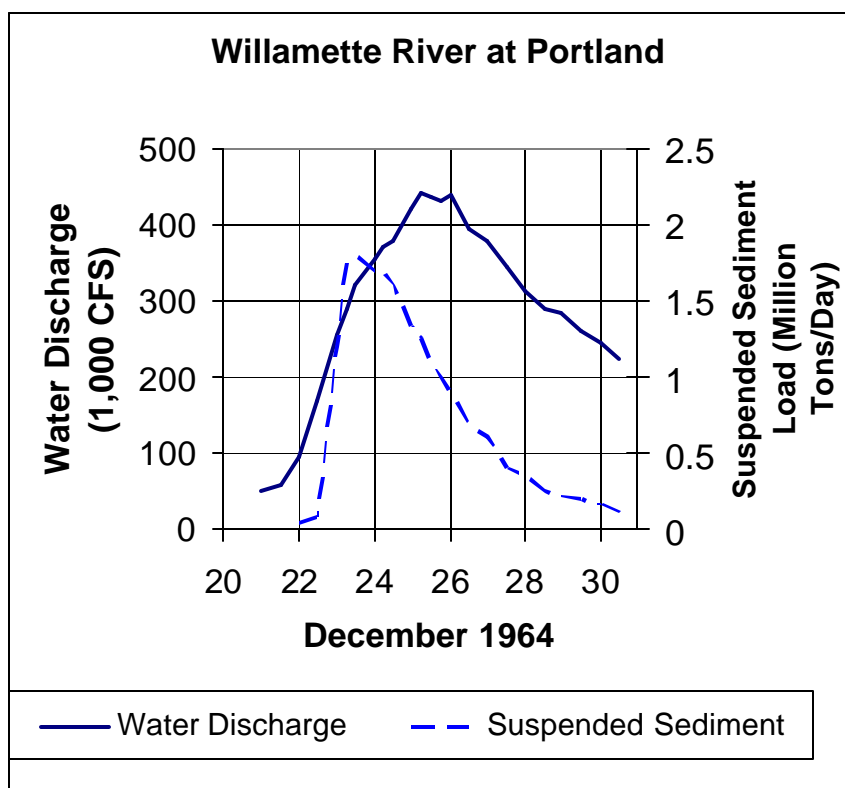


Figure 5. Observed Flow and Sediment Load for 1964 Willamette River Flood.

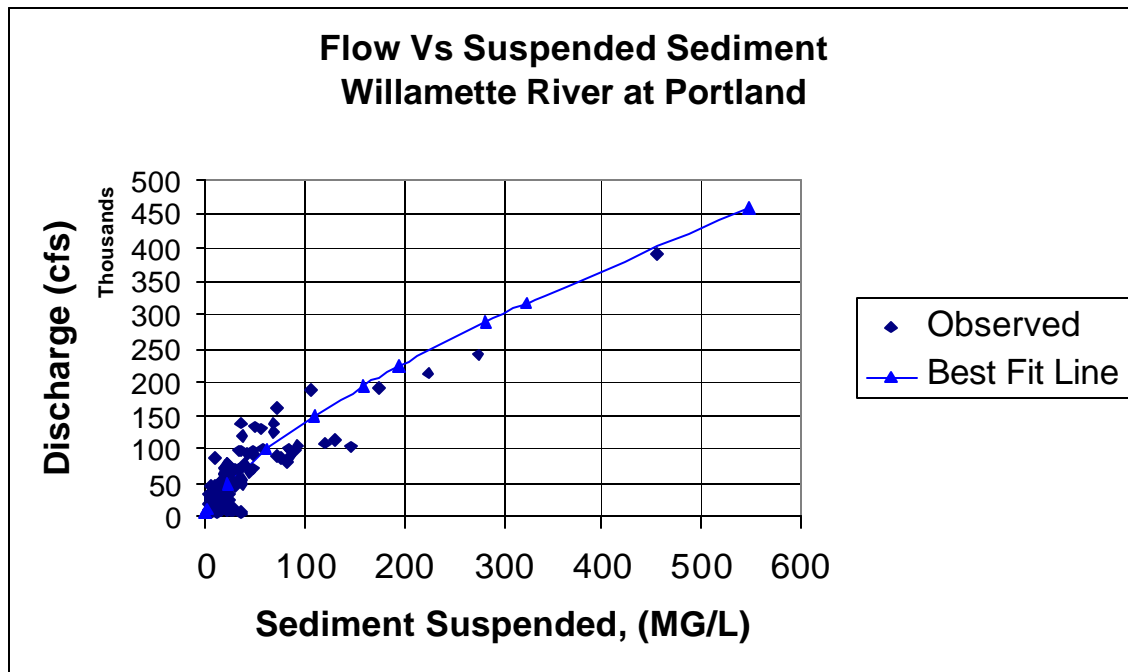


Figure 6. Observed Suspended Sediment Data for Willamette River at Portland.

The sediment sample taken at St. Johns Bridge during the 1996 flood should not be extremely different unless significant deposition or erosion is occurring between the two points. Examining the placement of the point in Figure 6 lends credence that the data from St. Johns Bridge appears to correspond with the data taken at Ross Island Bridge. Taking into account the uncertainty associated with the flow-concentration curve the value plots within the expected scatter and was thus used as an estimate of the sediment concentration at Ross Island Bridge for the 1996 flood. It would appear that the observation from St. Johns Bridge may be on the high side of the scatter and thus could slightly over predict the actual value at the Ross Island Bridge. This would tend to slightly over estimate deposition in the lagoon and associated river reach.

2.4 Determination of Sediment Gradation for Use in SED2D

The SED2D model uses a single grain size for the calculation of sediment transport. The selection of this grain size should correspond to the predominate size that is expected to be of importance in the area of interest. All available data that could be readily located were reviewed to insure that the sediment size used in the modeling effort was representative of the sediment being transported and deposited in this reach of the Willamette River.

Numerous suspended and bed sediment samples have been taken in the Willamette River near Portland. The suspended sediment samples have most often been taken at the Ross Island Bridge just downstream from Ross Island. Other suspended sediment samples were taken in the Ross Island Lagoon, at various locations in the river and Holgate Slough near Ross Island and in the Harbor area.

The concentrations of the various size classes in the suspended samples is not normally measured or reported. Only the percent of the sample below the lower sand limit of 0.0625 mm is

reported. This size corresponds to the break between fines (silts and clays) and sands. Samples from the Ross Island area indicate that sands are not found in abundance in this reach of the river. Sand concentrations in suspended sediments vary from 0% to about 30% sand, with the vast majority being 15% or less.

Samples obtained from the National Water Information System (NWIS 2002) show the percentage of fines ranges from a low of 58% to 100% with only 3 samples of 210 analyzed being less than 70% fines (1.4%). 67% of the samples have more than 90% fines and 89% of the samples have more than 80% fines. No sieve analysis was found for the coarse fractions of the suspended sediment samples taken in this reach of the Willamette River.

Sediment analysis data were also found for sediment deposits in the Willamette Falls Lock and deposits in the Portland Harbor. Sediment samples obtained from deposits in the harbor area again indicate that most of the materials transported in the river are fines. Samples from depositional areas indicate that while some sands come into the system from upstream the amount of sand material that is deposited is only about 1/3 of the amount of total deposition. Since the sand is much more likely to deposit than the silts and clays the fact that only about a third of the deposit is sand indicates again that the vast majority of sediments being transported down the river are fines. Results from the various samples are found in Table 1.

The material marked Willamette Falls / Oregon City in Table 1 was taken from the downstream entrance to the lock (RM 26.5) and was obtained from USACE 1996a while other information for other samples were taken from the harbor and described in USACE 1988, 1992, 1996 and 1999.

Sediment load calculations performed by the USGS and others show very little bed load movement in this reach. Laenen in 1995 estimated that bed load for the Willamette at Portland was on the order of 1% of the total load. He defined bed load as that portion of the total load that was unsampled in the suspended sediment samples. Given the extremely deep areas upstream from Ross Island it would be very unlikely that bed material would move into the reach adjacent to Ross Island. These very deep holes would be expected to very effectively trap any bed load (i.e. large sediment sizes such as gravels and coarse sands) prior to its reaching Ross Island.

Given the flow regime in the river it would also be expected that any sand that was in suspension would be very fine. Larger sediment sizes would drop from the flow at the first reduction in velocity and deposit in the deep holes upstream where velocities drop due to increased flow areas. These analyses suggest that modeling should concentrate on sediment sizes near the break between the sand and silt size classes.

Since the average measured sediment size in the observed deposits was 0.04 mm for the last two sampling regimes in the lower Willamette, this was selected as the size to be used in the sediment analysis. Several model runs were also performed using sand with a grain size of 0.0625 mm which is the lower limit of sand and the upper limit of silts and results were similar.

Table 1. Historic Bed Samples for Willamette River Deposits.

Site / Year	Material	Observed %	Mean Values	Mean Diameter
Willamette Falls Oregon City				
	Sand	72-75		
	Fines	25-28		Not Reported
	Silts	91		
	Clays	9		
Portland Harbor				
1988	Fines	6.3-89.9	64.6	Not Reported
1992	Sand	11.5-93.2	33.2	0.084
	Silt	5.9-75.5	58	
	Clay	0.9-13.0	8.8	
1996				
	Sand	22.2-50.1	34.9	0.04
	Silt	24.5-53.2	37.1	
	Clay	19.5-31	25.5	
1999				
	Gravel	0.0-2.9	1.2	0.04
	Sand	29.5-43.7	35.2	
	Silt/Clay	55.1-74	63.7	

3. Development of the RMA-2 Hydraulic Model

The modeling of hydraulics in the Willamette River was performed using RMA-2 developed by the US Army Corps of Engineers. RMA-2 employs the finite-element method to solve the depth-averaged hydrodynamic equations to calculate horizontal velocities and water surface elevations on a finite-element mesh. The finite-element mesh makes use of quadratic triangular and quadrilateral elements which have six and eight nodes, respectively. In order to model different discharge rates, it is customary to use the wetting and drying option in RMA-2.

The RMA-2 model of the Willamette River was constructed using the Surface water Modeling System (SMS) developed by Brigham Young University in conjunction with the U.S. Army Corps of Engineers Engineering Research and Development Center (ERDC, formerly WES). The system is a graphical interface for the RMA-2 and SED2D models and allows visualization of input as well as model results.

Current limitations in the SED2D model lead to serious complications when using wetting and drying in RMA-2 and the option was not used for final modeling in this study. In the current version of SED2D deposition in dry areas of the grid is not calculated correctly and it was necessary to use an alternate approach that utilized only elements that were “wet” – i.e. under approximately 3 feet or more of water during the flow of interest.

To enable modeling the flows at different discharges, several finite-element meshes were developed covering the main river channel and extending into shallow floodplain areas until depths were on the order of 2-3 feet. This required trial-and-error approach using the wetting and drying option in RMA-2 until the boundaries of the wet mesh could be determined. After the wet areas were determined the elements that were dry or shallower than approximately 2-3 ft were eliminated from the mesh and wetting and drying turned off.

Bathymetry for the model was obtained from the US Army Corps of Engineers, Portland District as described in the previous section. Digital orthophotos were also obtained for the areas of interest and used as background photos to assist in model development and Manning's n value determination.

The RMA-2 model also requires that boundary conditions are prescribed along the upstream and downstream boundaries. The river flow rate or discharge is prescribed at the upstream boundary, in this case at the south-end of the model just downstream of Elk Rock Island. At the downstream end, the water-surface elevation is prescribed as the boundary condition. The water-surface elevation varies with the discharge and appropriate values were determined from the UNET model and observed gage data. The length of the river to be modeled was determined such that the model extends sufficient distance above and below Ross Island so as to eliminate the impact of errors in setting the boundary conditions on flows in the vicinity of Ross Island. Given the wide range of stage for a given flow, it is unlikely that any error in stage would be unrealistic in the river's flow regime.

Prior RMA-2 modeling performed by NHC (Northwest Hydraulics 2000) concentrated on low flows and turbidity inside the Ross Island Lagoon. The NHC model used a Manning's n value of 0.25 in the river in order to calibrate to low flow head data. This value was used for the channels and lagoon in the WEST model. Overbank and vegetated areas were assigned a value of 0.045. Flows used in the NHC models were all in-channel flows and were 75,000 cfs or less.

3.1 Calibration of Two-dimensional RMA-2 Model

The RMA-2 model described above was run for the peak of the 1996 flood and water surface elevations were compared with results from a UNET model provided by the Portland District of the U.S. Army Corps of Engineers. The UNET model used for the calibration of the RMA-2 model is identified in the first lines of the model as follows:

```
* LOWER COLUMBIA RIVER - UNET MODEL
* DEVELOPED BY MIKE KNUTSON,USACE,PORTLAND DISTRICT (CENWP-PE-HY) 04-25-96
* MODIFIED BY KEN YOKOYAMA, USACE, PORTLAND DIVISION (CENWD-NP-ET-WH) 06-18-99
*
* REVISIONS:
* 1. -ORIGINALLY CALIBRATED TO FEB 1996 FLOOD (APRIL 96)
*    -INCLUDED LAKE RIVER, BACHELOR ISLAND SLOUGH, VANCOUVER LAKE,
*      & CONNECTIONS DEVELOPED BY BOB ELLIOT OF NORTHWEST HYDRAULIC
*      CONSULTANTS, SEATTLE (JUNE 99)
*    -COMMENTED OUT NHC SHILLAPOO DRAINAGE ADDITIONS
*    -MANNING N VALUES READJUSTED BY NWD TO CALIBRATE TO FEB 1996 DATA
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The UNET model covers the lower Columbia River as well as the Willamette from its confluence with the Columbia to the Willamette Falls at Oregon City (approximately RM 26.5). The UNET results are stored in a DSS file and values can be viewed either in dedicated Corps software or in the HEC-RAS hydraulic model. The UNET output consists of hourly flow rates and stages for each cross section in the UNET model for this application.

The water surface elevation for the RMA-2 model was compared to the maximum stage values from the UNET model and values compared quite well between the two models as shown in Figure 7. While the models appear to diverge above RM 18, the models follow very closely from Mile 12 to Mile 18 with a only a couple of exceptions. The differences above RM 18 are not significant to the Ross Island reach and may be due to the elimination of sharp river bends between River Mile 18 and Elk Rock Island as well as constrictions and bends around Elk Rock Island.

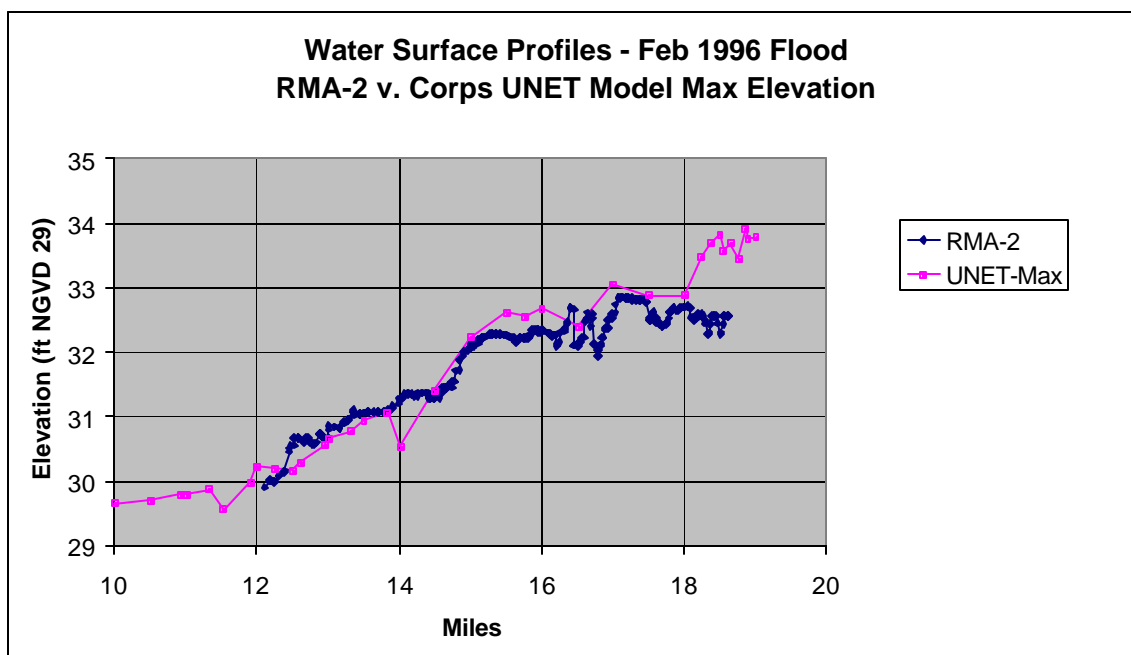


Figure 7. Calculated Water Surface Elevations for WEST RMA-2 model and Corps UNET model.

The RMA-2 water surface elevation appears to oscillate between RM 16 and 17 but velocities through this reach vary due to the large variations in water depth previously described. Deep holes with depths greater than 90-100 ft and relatively shallow areas with depths of approximately 30 feet exist in this reach and velocities increase and decrease accordingly. Some deep portions of these holes may be ineffective flow at the bed but flows recover prior to reaching Ross Island and are smooth through the Ross Island reach. When variations in velocity heads are taken into account, the oscillations disappear in this reach.

Differences exist between the UNET model and the RMA-2 model in the area of Ross Island due to differences in the way the lagoon and islands were modeled. The lagoon was modeled as a storage cell in UNET while RMA-2 calculated flow across the island and through the lagoon. This increases the flow area and reduces the water surface through the Ross Island reach (RM 15 to 16) as can be seen in Figure 7 for the RMA-2 model.

Average river slope in this reach is very low and is approximately 9.5×10^{-5} ft/ft (0.5 ft/mile) for the 1996 flood and 3.2×10^{-5} ft/ft (0.167 ft/mile) for a 195,000 cfs flow based on the UNET model results. From the review of gage records at the Ross Island gage, it appears the Willamette is tidally influenced up to a flow of approximately 200,000 cfs depending on flow conditions in the Columbia River.

Video taken during a visit to the Ross Island processing plant during the 1996 flood by Ross Island Sand and Gravel personnel shows little water movement around the Ross Island equipment and a very calm lagoon area – at least near the equipment. Results from the RMA-2 model also indicate that very little velocity is present in the area of the processing plant along the east bank of the lagoon. This field observation tends to confirm that the two-dimensional model is working properly in the lagoon area.

The only portion of the Ross Island video showing significant velocities was the portion showing the approach to the northeast (outer) bank of Holgate Slough in the area where the Ross Island boat house is normally located and across the slough from the entrance to the lagoon. Video footage in this area shows higher velocities along the outer bank of Holgate Slough but still not extremely high – probably on the order of 2-4 ft/sec. This is in the same range as the velocity results produced by the RMA-2 model and again indicates that the model is reproducing the 1996 flood event correctly.

4. Hydraulic Results

4.1 Existing Condition Results

Hydraulic results for the RMA-2 study indicated that, during large floods, water flows over the southwestern perimeter of Ross Island roughly parallel to the flow in the river and then flows back out over the lower portions of the island. This phenomenon can be seen in Figure 8 for the 1996 flood. It can also be quickly seen that flow into and out of the entrance to the lagoon is minimal even when flows have overtopped the island along the Willamette main stem. This

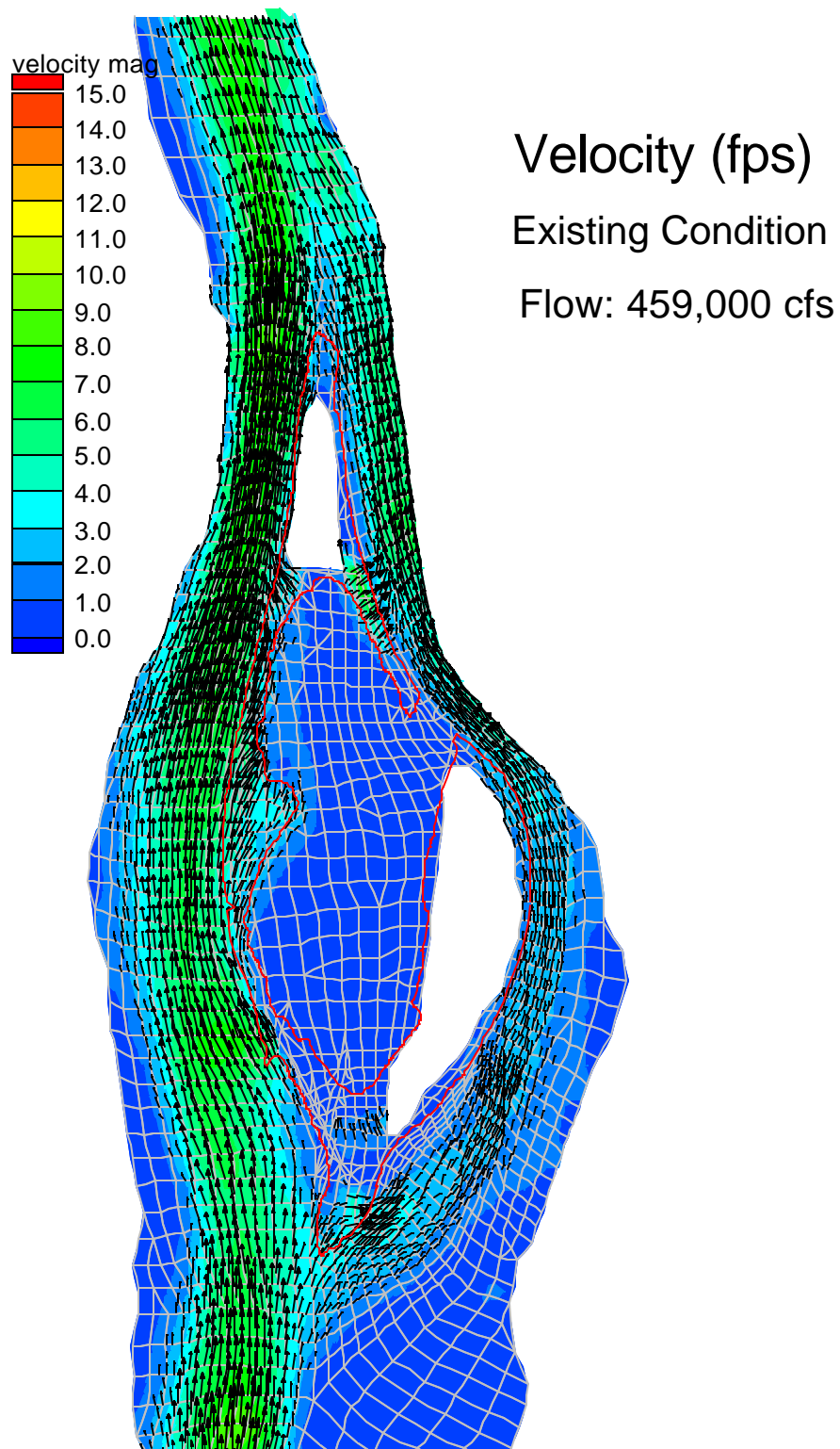


Figure 8. Velocity for 1996 Flood Peak for Existing Conditions.

phenomenon is not limited to very large floods such as the 1996 flood but the same process occurs during lower flows as can be seen by viewing the velocity plots for all four flood flows modeled. (See Appendix I for the 318,500 cfs, 224,000 cfs, and 195,400 cfs flows respectively.)

It can be seen in Figure 8 that some flow is diverted from the mainstem Willamette to the Holgate Slough under the 1996 flood conditions. This flow exits the lagoon over the portion of Ross Island that borders the north edge of the lagoon along Holgate Slough rather than through the lagoon inlet. This flow pattern can also be seen to lesser extents in Appendix I for the remaining flows

4.2 Proposed Plan Condition Results – Lowered Berm

Ross Island proposed the lowering of a berm installed between the southern ends of Ross and Hardtack Islands to prevent normal river flows from entering the lagoon formed by the excavation of materials. This berm is approximately 900 feet long and is high enough that only flows near the 1996 flood elevation overtop the berm. The plan, as evaluated, consisted of lowering the berm to elevation +15 ft NGVD for the 900 foot length of the berm. The specified flow rates were again run for this plan condition.

The lowering of the berm allowed somewhat more water to flow into the lagoon from the Willamette River as can be seen in Figure 9 for the 1996 flood. The water that entered the lagoon over the lowered berm did not, however, flow out of the lagoon entrance into Holgate Slough. The increased inflow simply increased the flow over the lower portion of Ross Island into both Holgate Slough and the Willamette River. This added flow increases velocities across the higher portion of the island and increases the potential for erosion along these forested areas. Flow moving out of the lagoon also impacted velocities in the river not only along the lower portion of the island but downstream from Ross Island. Under this plan condition more flow is diverted across the lagoon and into Holgate Slough for all floods modeled. However, given the length of the berm that was lowered to obtain these results, the necessity to protect the lowered section against erosion, the marginal increase in flow into the lagoon and the limited increase in sediment deposition; the risks associated with the alternative most likely outweigh any benefits that could be obtained.

The results for the 1996 flood under existing conditions can be seen in Figure 8. A plot showing the difference between the base and velocity magnitudes for the lowered berm plan can be seen in Figure 10. The difference plot in Figure 10 shows the values for the plan or lowered berm condition minus the existing condition velocity values. The positive values indicate velocity increases for the plan condition and negative values indicate decreases in velocity for the plan condition. Plots for the other flow rates can be seen in Appendix II. It can be noted that no large differences exist between base and plan flow conditions. The maximum differences occur due to the lowering of the berm along the southwestern edge of the lagoon. The moderate changes in the lagoon are constrained by the exit conditions from the lagoon during high flows. The flows in the Willamette River and Holgate Slough are constrained in the area where the river and Holgate Slough must pass around the lower portion of Ross Island. Thus changes in geometry at the upstream end of the lagoon do not have large impacts on the flows within the lagoon.

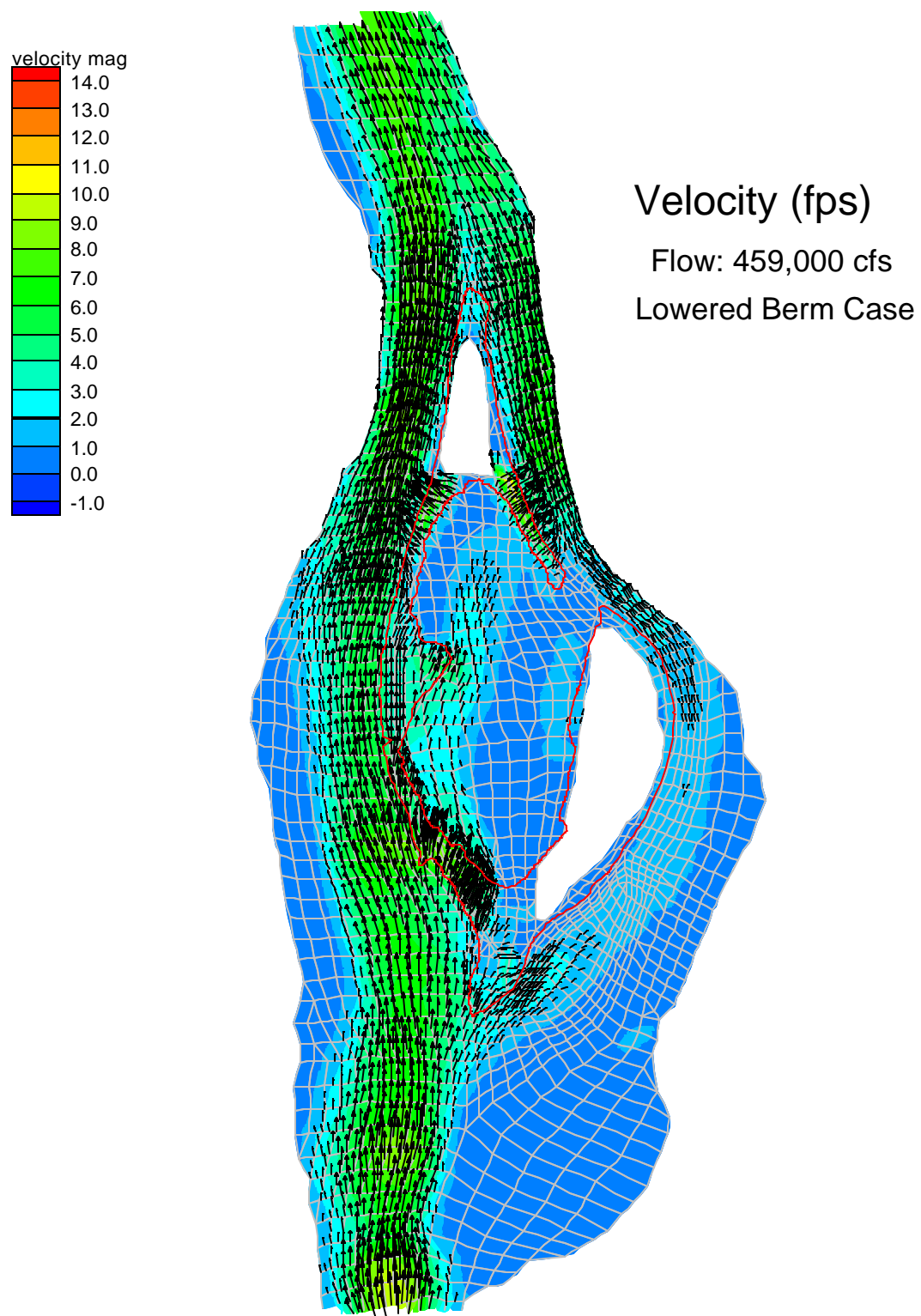


Figure 9. Velocity for 1996 Flood Peak for Lowered Berm Conditions.

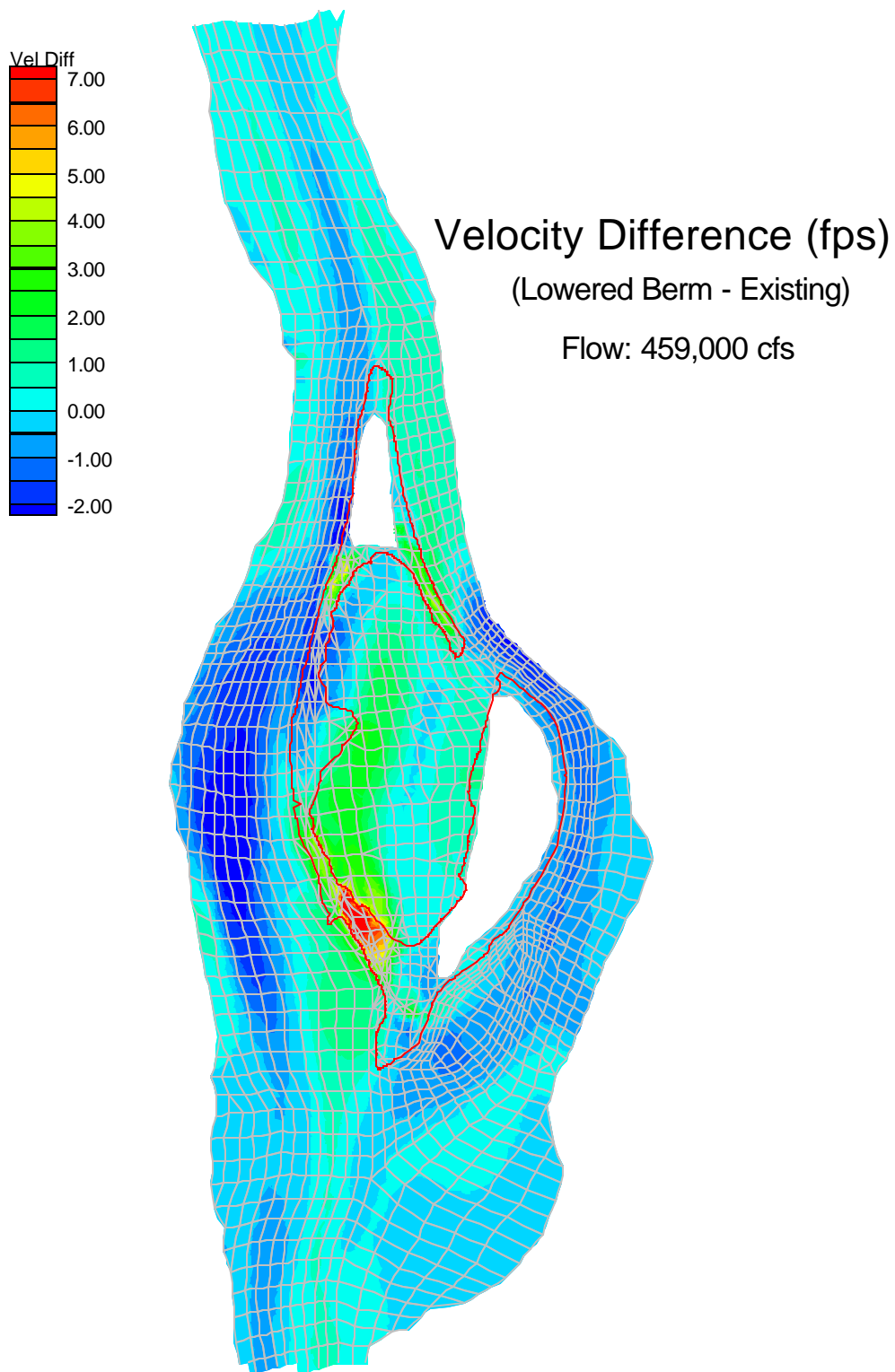


Figure 10 Velocity Difference between Existing and Lowered Berm Conditions – 1996 Flood Peak.

If the berm were to breach it is possible that a head cut could be propagated some distance up the Willamette River. The deep holes upstream would likely arrest the upstream movement of any head cut and given the flow constriction at the lower end of Ross Island it is unlikely that any head cut would impact the containment cells inside the lagoon. If erosion were to occur on the channel banks at the lower end of Holgate Slough it is possible that an erosive feature could be propagated some distance upstream from the lagoon. The area around Ross Island will likely continue to be depositional given the sudden expansion in flow area at Ross Island and the constriction downstream. The historical forces that formed the islands will continue to operate and the Ross Island reach of the river will, for the most part, continue to be depositional.

4.3 Lagoon Fill Scenario

Currently the slopes of the lagoon are steep and extend to approximately -130 ft NGVD. The second scenario modeled called for the placement of fill along the north and west boundaries of the lagoon as well as at the south end of the lagoon as shown in Figure 11. The berms are designed to reduce the slope and provide additional geotechnical support for the portions of the island immediately adjacent to the lagoon. The reduced slope will also enhance public safety when the area is opened for public use by reducing the steepness of the bank.

The placement of this fill has minor impacts on flow through the lagoon as shown in Figure 12 for the 1996 flood peak. The impacts, while locally significant, do not significantly change the flow patterns in the lagoon, river or slough.

The velocity changes for the 1996 flood, as shown in Figure 12, highlight that changes are less than ± 1.5 ft/sec. The maximum values occur in areas where the fill is high enough to create shallow areas near the perimeter of the island. Changes in velocity for the other flow rates are shown in Appendix IV.

It can be seen in Figure 12 that changes in deposition for the 1996 peak flow between the fill and no fill scenario are less than 0.01 ft after 12 hours with most areas have almost identical bed changes for the both scenarios.

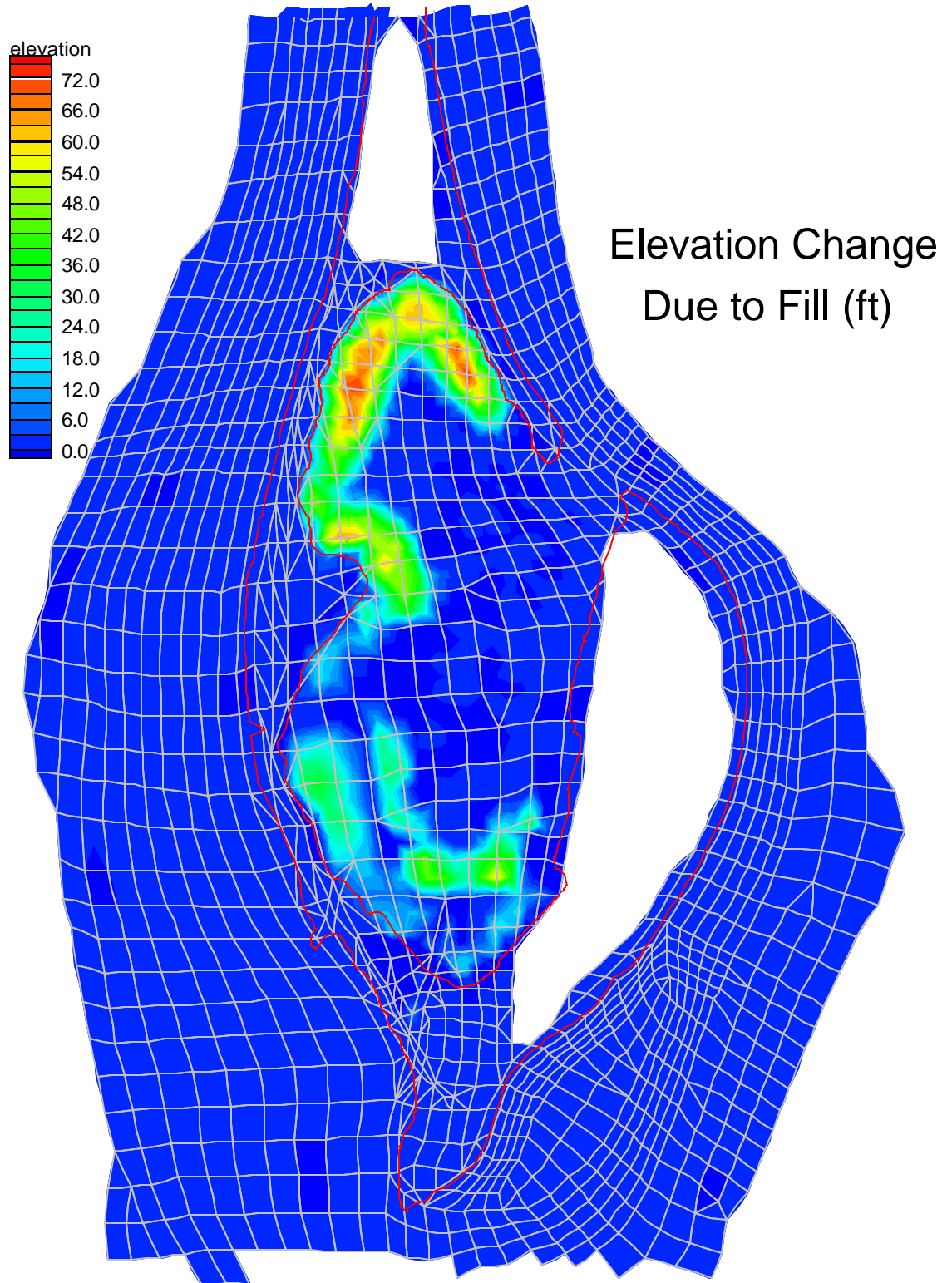


Figure 11. Elevation Difference Due to Fill.

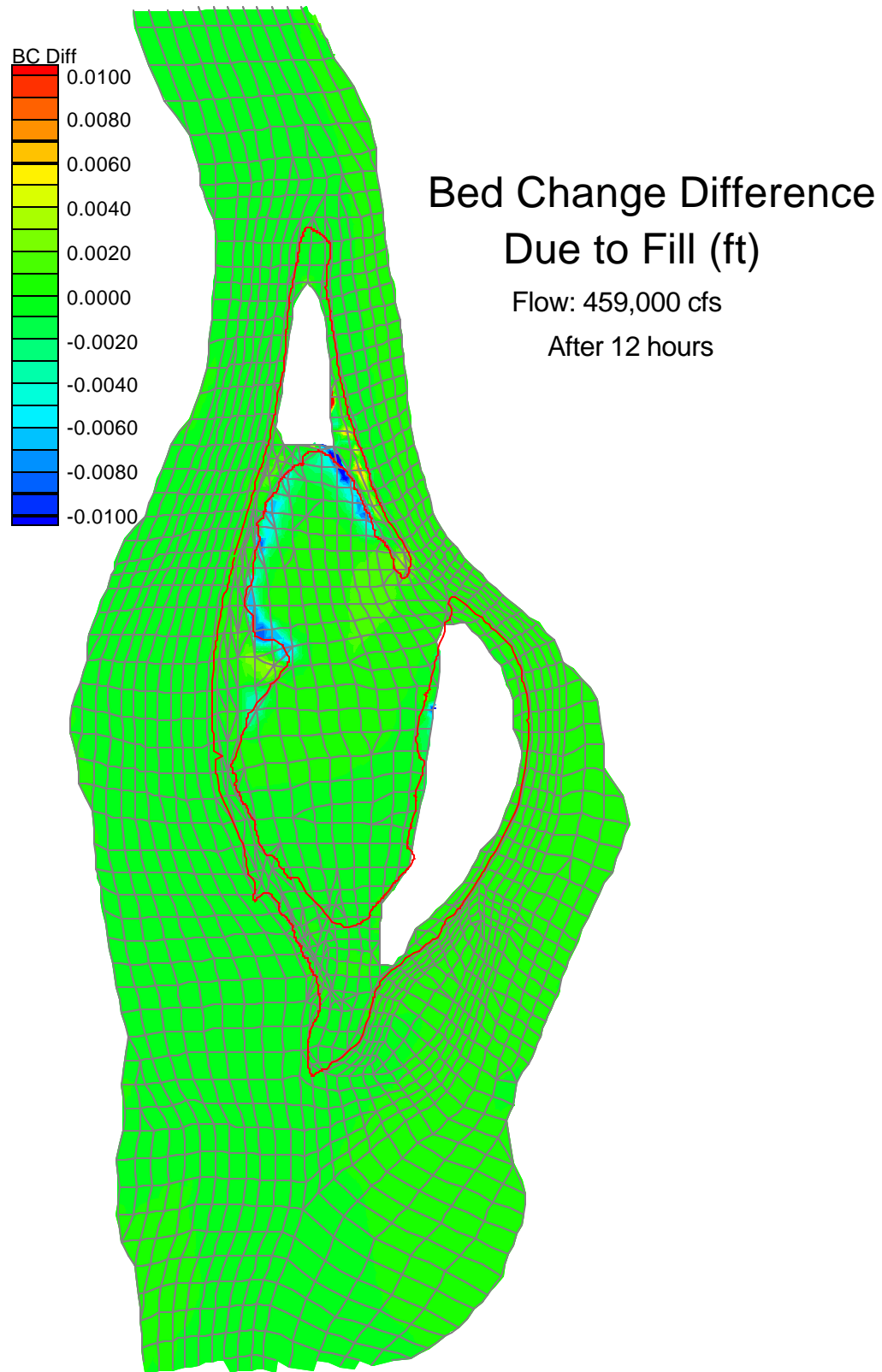


Figure 12. Velocity Difference Due to Fill.

5. Development of the SED2D Sediment Transport Model

The sediment model selected for use on this project was the Corps' SED2D model. SED2D was developed by the U.S. Army Corps of Engineers and is an updated version of the STUDH model developed by the Waterways Experiment Station in the 1970's and 80's. The model has been released for public use but the currently released version contains a number of bugs and quirks that make applying the model challenging. To avoid undesired encounters with the various limitations of the model, the modeling approach was specified to avoid wetting and drying in the sediment model. The avoidance of wetting and drying precluded the modeling of a hydrograph and limited the modeling effort to the modeling of discreet flow events. It is possible, however, to link a series of discrete flows together to represent a hydrograph. This is the approach taken to model sediment transport due to the 1996 Willamette River flood and the "average" annual hydrograph as described above.

The SED2D model uses the bathymetry and geometry from the RMA-2 model as well as the hydraulic output from RMA-2. The RMA-2 output includes velocity and water surface elevations and the SED2D model uses this information to calculate sediment transport in the flow field as well as to calculate deposition or erosion on the bed of model.

5.1 Model Adjustments and Modeling Variables

A sediment grain size of 0.04 mm was used in the entire model domain as discussed in Section 2.4. This sediment size is considered representative of silt which is the average grain size of the sediment being deposited in this reach of the Willamette River. For the purposes of this model it was assumed that the silt sizes being modeled would behave as non-cohesive material. This assumption was made since none of the parameters had been measured that would allow the modeling of the material as a cohesive material and the primary interest was the deposition of material in the lagoon.

Since the primary interest in this study was deposition in the lagoon, rather than erosion of previously deposited cohesive material, it was determined that the SED2D model could be used to model noncohesive material with a slightly smaller grain size than the sand limit. The settling velocity corresponding to this sediment size was estimated as 0.0012 m/sec by extrapolating slightly from Committee on Sedimentation (1957). Bed material depths were set to zero where erosion was occurring since the materials would not scour as easily as predicted by the Ackers White transport equation. It also appeared that bed materials were significantly larger than the silt size being modeled and thus would be less likely to scour. It was expected that, once the areas of concern for scour were identified, further scour analysis would be performed as necessary.

The initial sediment concentration was estimated based on the measurements made at the Ross Island Bridge and other nearby areas as previously described. The model was started with a uniform concentration approximately equal to the inflowing load and was allowed to stabilize. The model stabilized within approximately an hour of simulation time. For the various hydrographs the initial hour of the run was discarded and the model then run for the desired time period. The inflowing sediment concentration at the upstream boundary of the model was varied

so that an approximate match was obtained between the observed and computed concentration values at the Ross Island Bridge gage. The bed shear stress was estimated using the log velocity approach in SED2D and the sediment diffusivity was set at 25 m²/sec. The model time step was set to 0.05 hours (3 minutes) and the default value of 0.67 for the Crank-Nicholson weighting was used.

6. Results of the Sediment Transport Modeling

The SED2D model was used to model sedimentation for peak flow events described above as well as for two hydrographs. The model was thus used to estimate sediment deposition for three types of events, a peak flow, the 1996 flood hydrograph and an “average” annual hydrograph.

6.1 Peak Flood Events

Model runs were performed for the flows listed in Table 1 to compute sedimentation during a period of 12 hours. The results were compared to view relative sedimentation for a 12 hour peak flow of varying magnitudes. Deposition occurring during peak flows was determined for the modeled flow rates of 459,000 cfs, 318,500 cfs, 224,000 cfs, and 195,400 cfs.

Results for the 1996 peak flow existing and lowered berm conditions are shown in Figure 13 and Figure 14. Differences between the existing and lowered berm conditions can be seen in Figure 15. It can be noted that the plan condition allows more water into the lagoon and slightly increases sedimentation on the east side of the lagoon and downstream of the lowered berm. The results for the various flows for both the existing and lowered berm conditions can be found in Appendix III. The lowered berm condition results in slight increases in deposition in the lagoon due to increased water and sediment flow into the lagoon. The depths of the increased sedimentation are very small and are not extremely significant over a 12 hour period.

The areas along the perimeter of the lagoon that are shown in blue in Figure 15 indicate areas that are prone to erosion and areas that erosion protection may be necessary if the lowered berm plan were to be considered for implementation. Areas shown in blue away from the lagoon may be due to slight differences in geometry between the existing and lowered berm bathymetries. These are due to slight adjustments at shallow nodes to insure model stability and are normally small enough that hydraulic results are not significantly different.

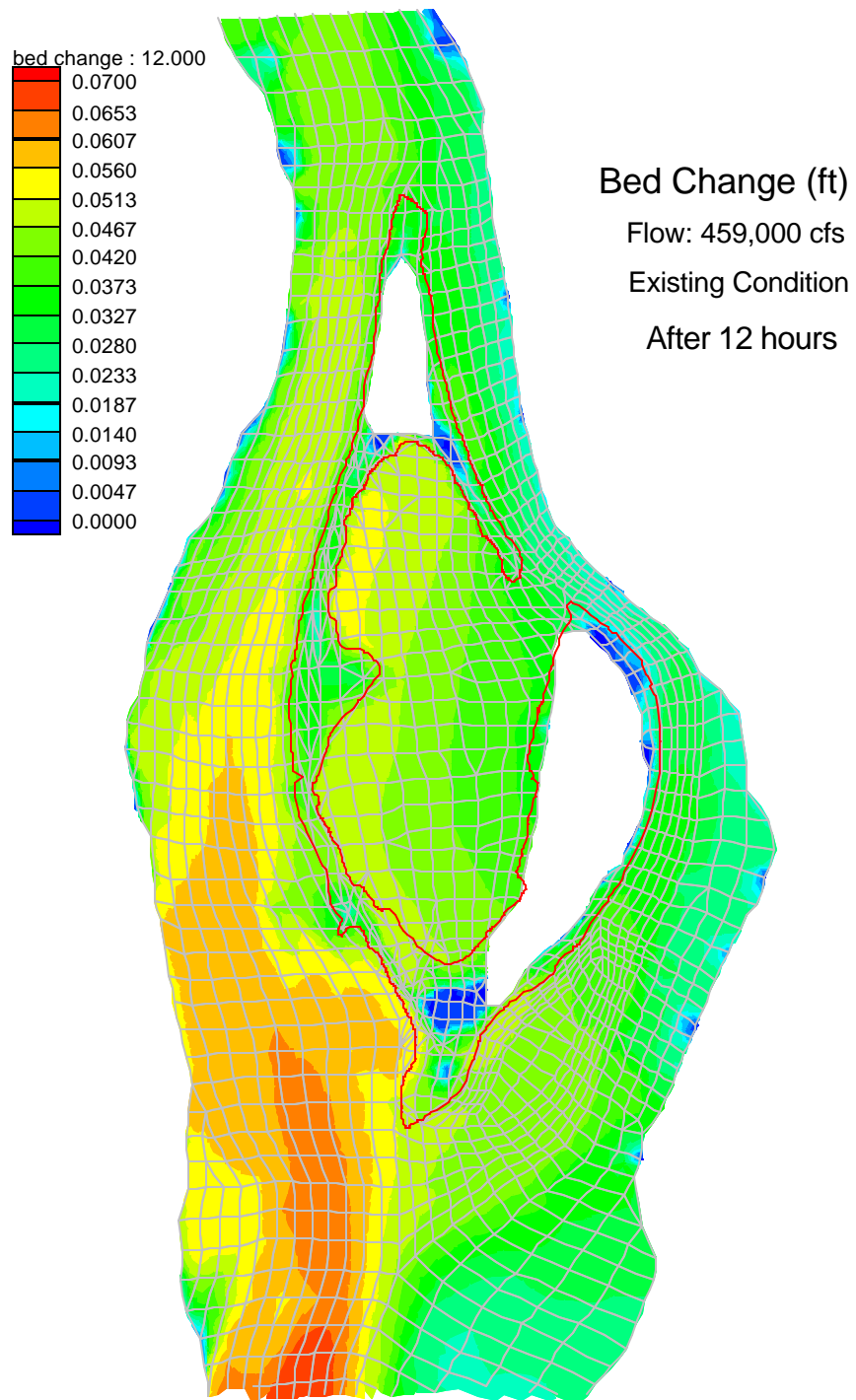


Figure 13. Sedimentation for 1996 Peak Flow for Existing Conditions.

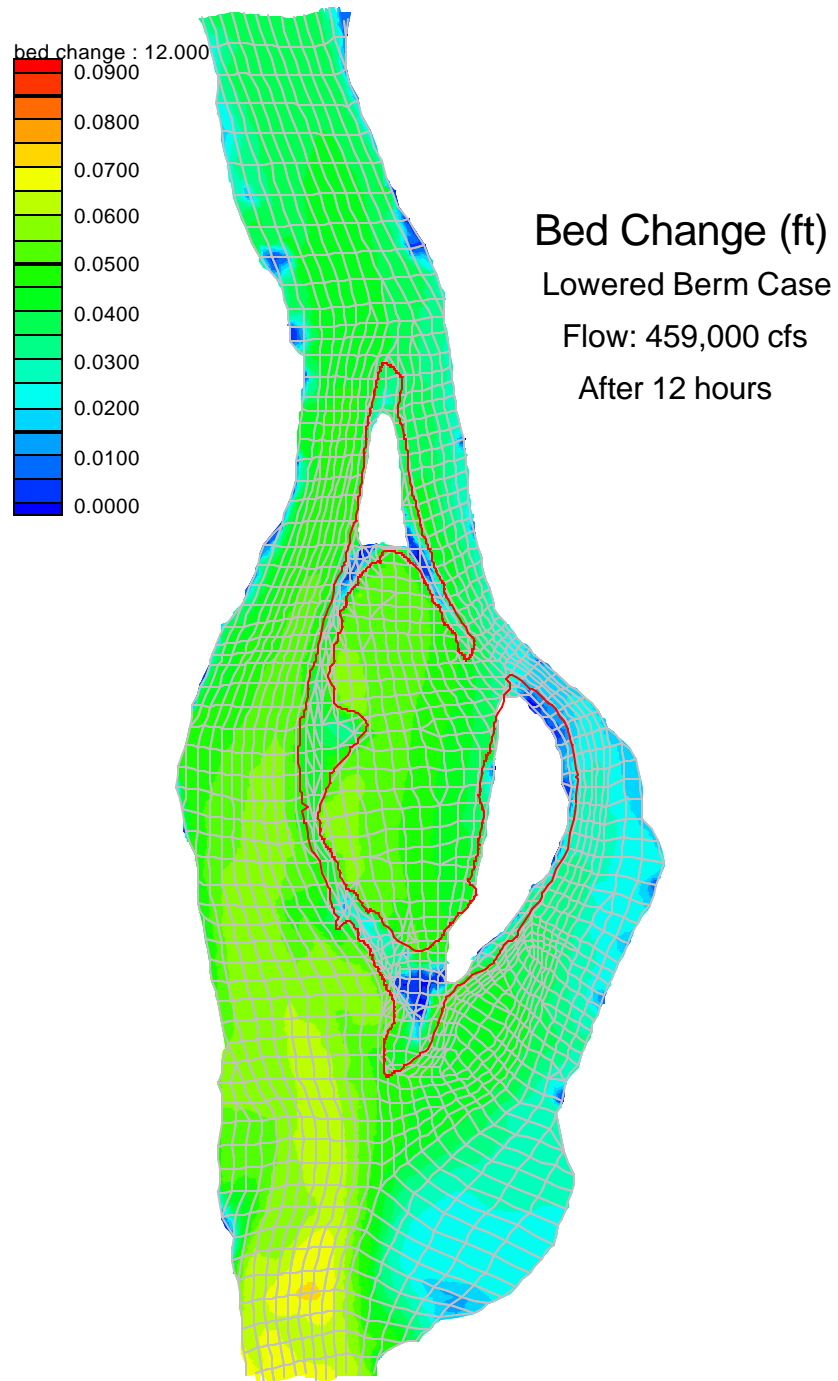


Figure 14. Sedimentation for 1996 Peak Flow for Lowered Berm Condition.

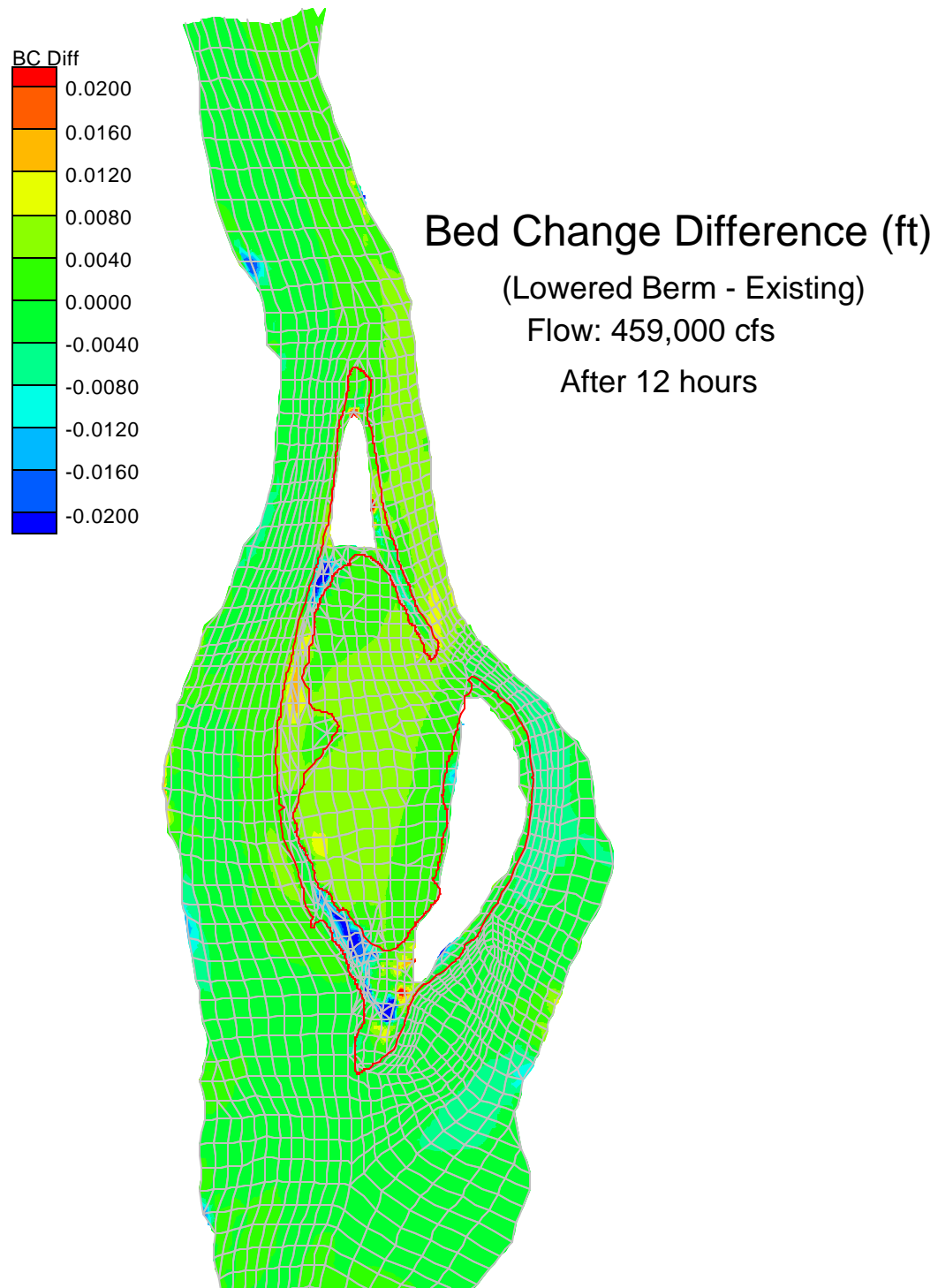


Figure 15. Difference in Sedimentation for 1996 Peak Flow between Lowered Berm Condition and Existing Conditions.


6.2 1996 Flood Deposition

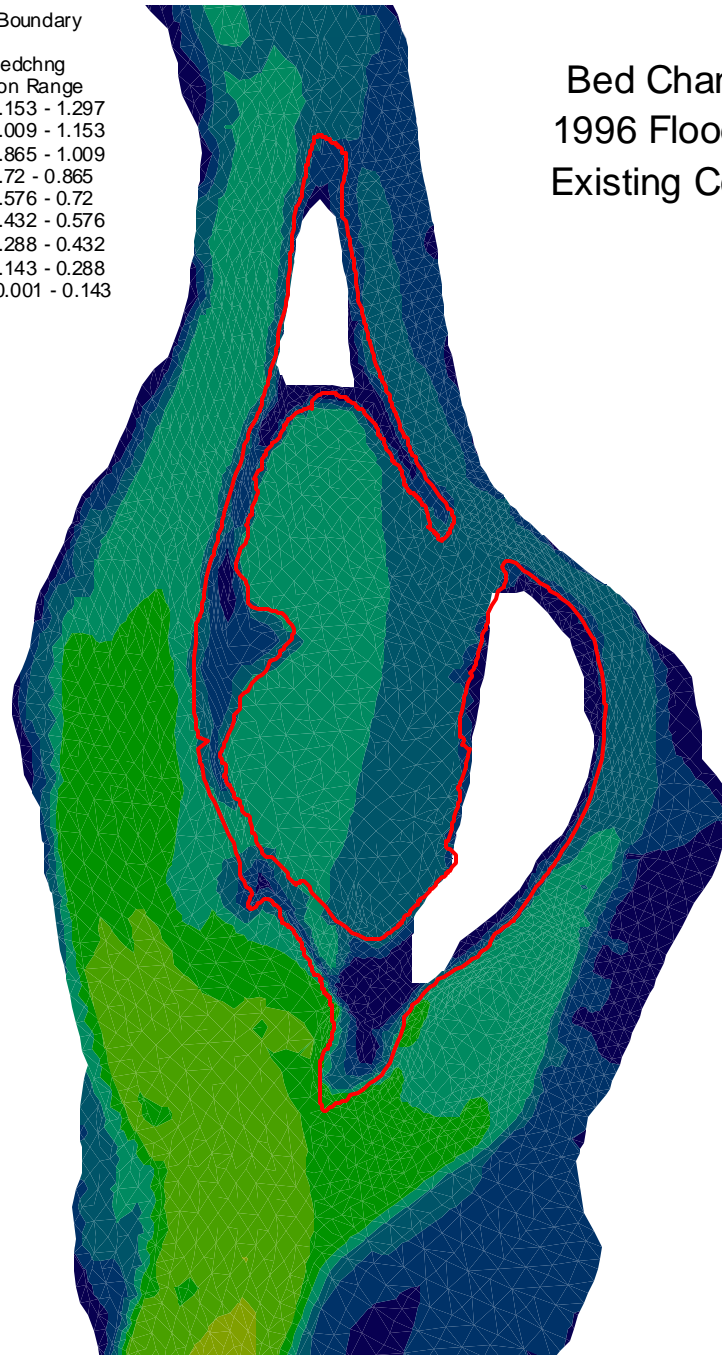
The 1996 flood event was modeled by discretizing the flood hydrograph into the four discharges previously run individually to view the impact of individual flows on sedimentation in the lagoon. These four cases were considered separately and the bed changes computed for each case. The resulting bed changes were then combined in ARCVIEW to give the total bed change for the 1996 flood event.

Deposition was only modeled for the portion of the 1996 flood hydrograph when flow was approximately 180,000 cfs or above. The lower portion of the hydrograph was neglected since 1) most sedimentation would occur during high flow rates when sediment concentrations were high and 2) during lower flows, flow does not move into the lagoon from the Willamette River but only through the lagoon inlet from Holgate Slough. The exact flow at which the berm overtops is unknown and will vary dramatically based on downstream backwater conditions from the Columbia River.

Lower flows had also not been modeled at this point in the analysis. Later modeling for the “average” annual hydrograph confirmed that a few days at the lower flow rates would not dramatically change depositional volumes and depths in the lagoon. Only when long periods (typically weeks) of the lower flows are modeled does the deposition due to these flows become significant.

The results of this analysis can be seen in Figure 16 for the 1996 flood event for the existing conditions case. It can again be seen that most of the sedimentation during the peak of the hydrograph occurs along the west side of the lagoon. The sediment gradually reduces in depth towards the lagoon inlet. The existing island is shown as a red outline in Figure 16 as well as the other plots in this report.

Island Boundary

 Base-bedchg
 Elevation Range
 1.153 - 1.297
 1.009 - 1.153
 0.865 - 1.009
 0.72 - 0.865
 0.576 - 0.72
 0.432 - 0.576
 0.288 - 0.432
 0.143 - 0.288
 -0.001 - 0.143



Bed Change (ft)
 1996 Flood Event
 Existing Condition

Figure 16. Sedimentation for 1996 Flood above 180,000 cfs under Existing Conditions.

6.3 Average Annual Deposition

The “average” annual hydrograph was also modeled using the same approach as the 1996 flood. The hydrograph was again discretized and run in four steps. Hydraulic results from the model originally used by NHC provided hydraulic data for the lower flows and the SED2D model was used to calculate sediment transport for the various flow rates. The deposition due to the modeling of the “average” annual hydrograph is shown in Figure 17.

In order to construct the stepped hydrograph the sediment model was run for a period of 10 days or the full step duration for steps shorter than 10 days. For periods of time with flow periods of more than 10 days the deposition was extrapolated from the ten-day run to account for the various lengths of the steps. This extrapolation was accomplished by simply multiplying the 10-day deposition by the number of 10-day durations contained in the time step.

The extrapolation of model results would cause concern if the depth of deposition was a significant portion of the water depth. As can be seen in Figure 17 the deposition amounts are insignificant in terms of the water depths in the model. Most depths are 30 ft or greater and depths in the lagoon are in excess of 100 ft while deposition is a maximum of approximately 1 foot for the entire simulation. Even shallow areas along the boundaries were not significantly impacted by these assumptions. Areas where water depths may have been only 3 ft (this being approximately the shallowest boundary nodes) had depositions of only 0.35 ft or approximately 10% of the total depth. Velocities in these areas are normally small as well so hydraulic impacts are extremely limited.

Deposition during the various time periods is shown in Table 2 for selected nodes. The location of the nodes is shown in Figure 18. It can be seen that very little deposition occurs at the very low flow rates. Most deposition occurs at higher flows in the 75,000 cfs range. Flows in this range contribute significantly to sedimentation due to the long duration of the flows and the higher sediment concentrations. The large floods contribute significant amounts of sediment and contain high sediment concentrations but their shorter duration means that overall contributions are less than that from more midlevel floods that occur more often with longer durations.

Bed Change (ft) Annual Average Hydrograph

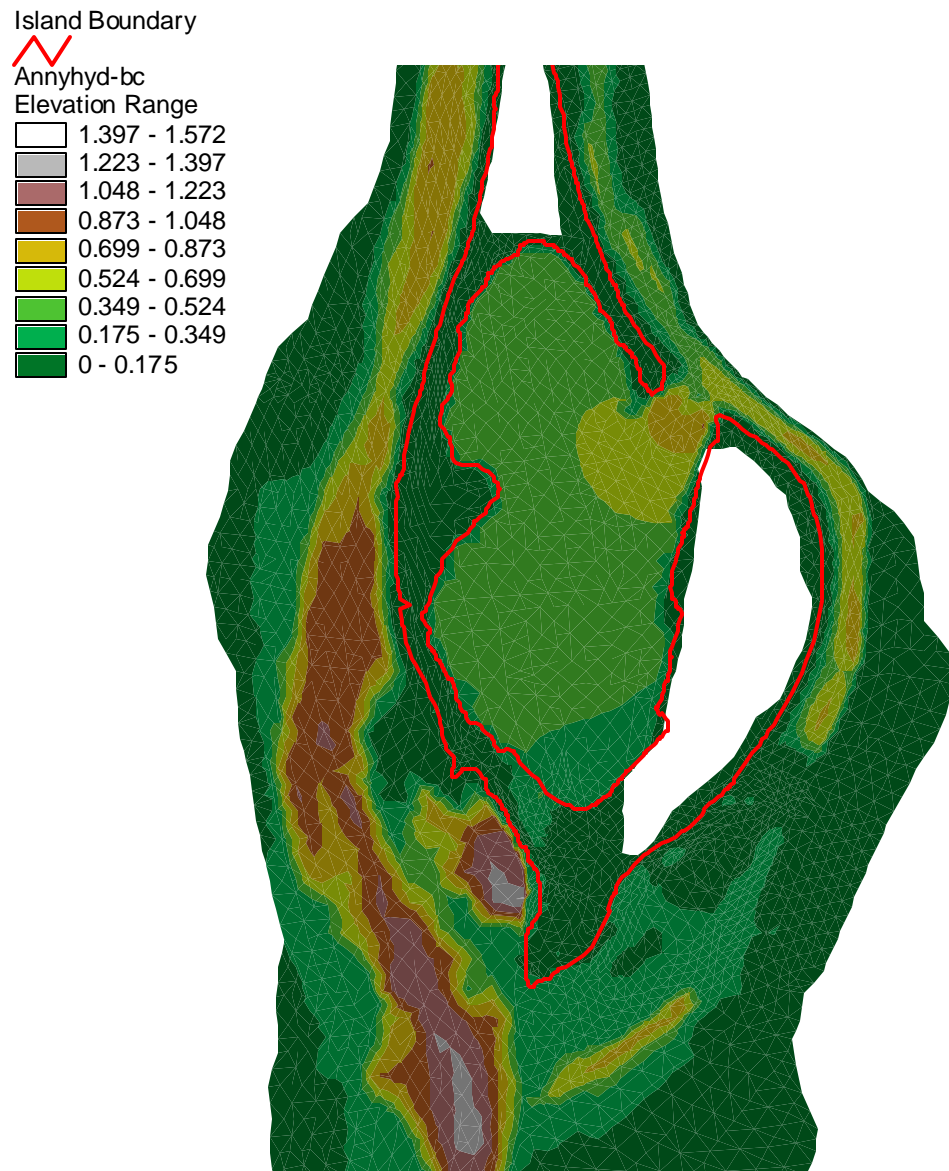


Figure 17. Sedimentation for Existing Conditions Average Annual Hydrograph.

Table 2. Deposition Rates for Various Flows for Selected Nodes based on Average Annual Hydrograph.

Flow Event (CFS)	Duration (days)	Bed Change at Locations (feet)		
		Lagoon Interior (south)	Lagoon Entrance	Lagoon Interior (north)
10,000	180	0.005	0.01	.006
35,000	110	0.007	0.02	.009
75,000	70	0.15	0.58	.27
200,000	5	0.19	0.18	.18
Total	365	0.37	0.79	0.46

The SED2D model predicts approximately 0.8 ft of deposition in the entrance to the lagoon and approximately half of that value in the interior of the lagoon for the “average” annual hydrograph. The impact of the higher flows and higher sediment concentrations can be seen in the amounts deposited in the lagoon. It can be noted that once the flows overtop Ross Island and begin to enter the lagoon directly from the Willamette River that sedimentation becomes more uniform in the lagoon. During periods when flows are below the crest of Ross Island most sedimentation occurs in the mouth of the lagoon entrance where velocities lower drastically and sediment can no longer be held in suspension.

The values calculated in the lagoon entrance compare fairly well with the approximately 1.5 ft of annual deposition that has been observed historically by Ross Island Sand and Gravel. While the two values may not agree perfectly the results are of the same order of magnitude and the model results are representative of what has been observed over the years. The ratio of deposition should be approximately the same for points inside the lagoon and points in the entrance. Thus in years where 1.5 ft of deposition occurs in the inlet approximately 0.75 ft of deposition could be expected in the interior of the lagoon.

6.4 Lagoon Fill Scenario

The addition of fill to the lagoon has only minor local impacts on sedimentation. This is primarily due to changes in local velocities. The bed changes for the 1996 flood between the existing and fill scenarios are shown in Figure 19 and show very little bed change within a 12 hour modeling period with the exception of areas where the fill produces shallow depths and either increased or decreased velocities significantly. The changes do not appear to be significant even in these areas. Of concern are areas shown in blue that may exhibit scour tendencies if very fine fill material is used and no vegetative cover is established. Since cover is expected to be established in this area and fill material is expected to be larger than the silt size used, or at least a mixture that contains larger particles, scour on the fills is not expected to be substantial. There may be some local scour during large flood events but the scour should not be more than that observed on the higher portions of the island during floods of similar magnitudes if fill materials similar to natural soil are used. If vegetative cover is established on the more elevated portions of the fill material the danger from erosion should be relatively minor.

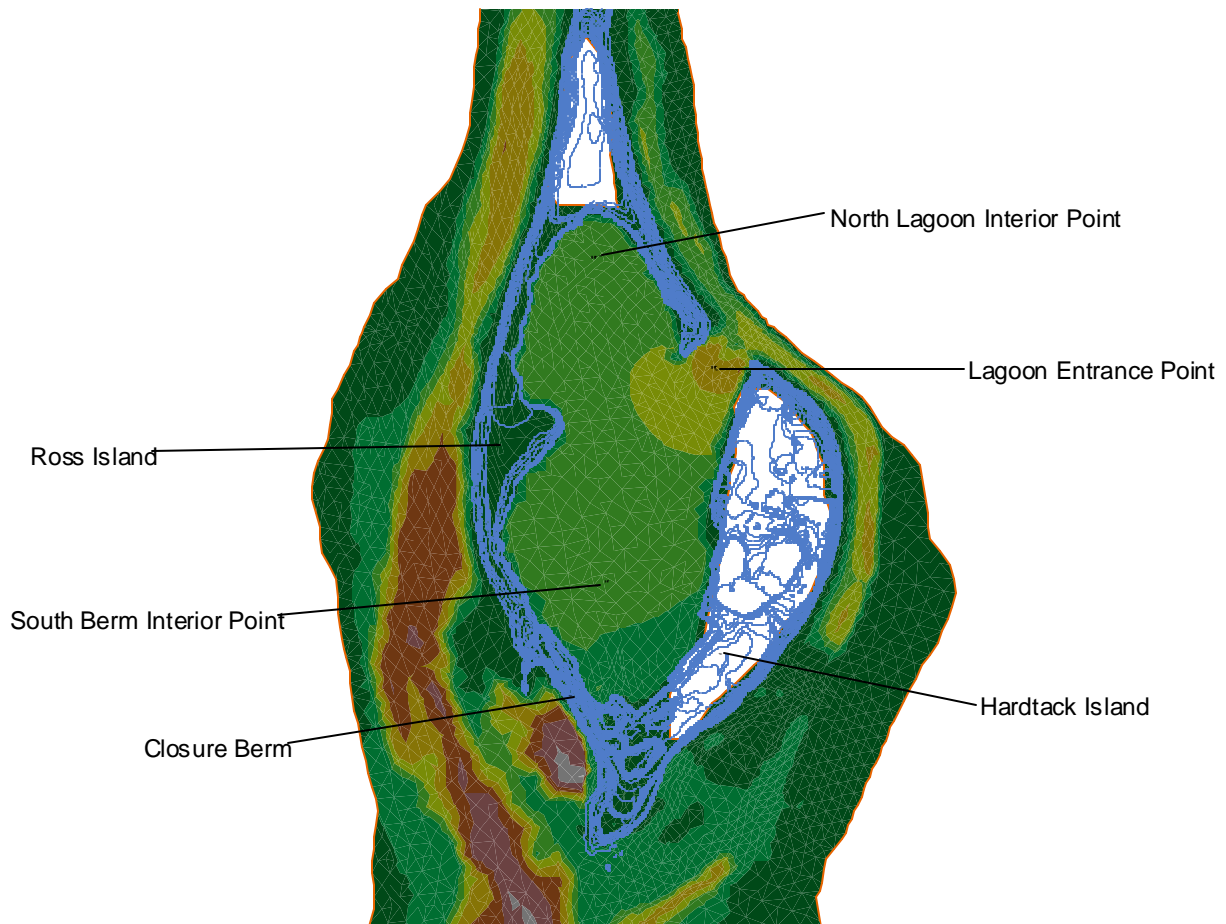


Figure 18. Location of Points for Depths Reported in Table 2 showing Closure Berm Location. Existing Island Shown in Blue.

7. Summary of Results

The hydraulic modeling of the Ross Island reach of the Willamette River indicates that flow is currently controlled by the narrower channels at the downstream end of Ross Island. These channels form the river and slough between Ross Island and the west bank of the Willamette River and Ross Island and the east bank of the Holgate Slough. This constriction controls the flow through the reach of the river associated with Ross Island and minimizes the benefits that might be obtained in other situations from the lowering of the berm between Ross and Hardtack Islands. The primary impact of lowering the berm was to increase flow along the west side of the lagoon and over the narrow lagoon perimeters that separate the lagoon from the Willamette River and Holgate Slough at the north end of the lagoon. It could be expected that the increase in flow due to berm lowering would cause erosion in these areas and could ultimately result in breaching of the narrow portions of the islands.

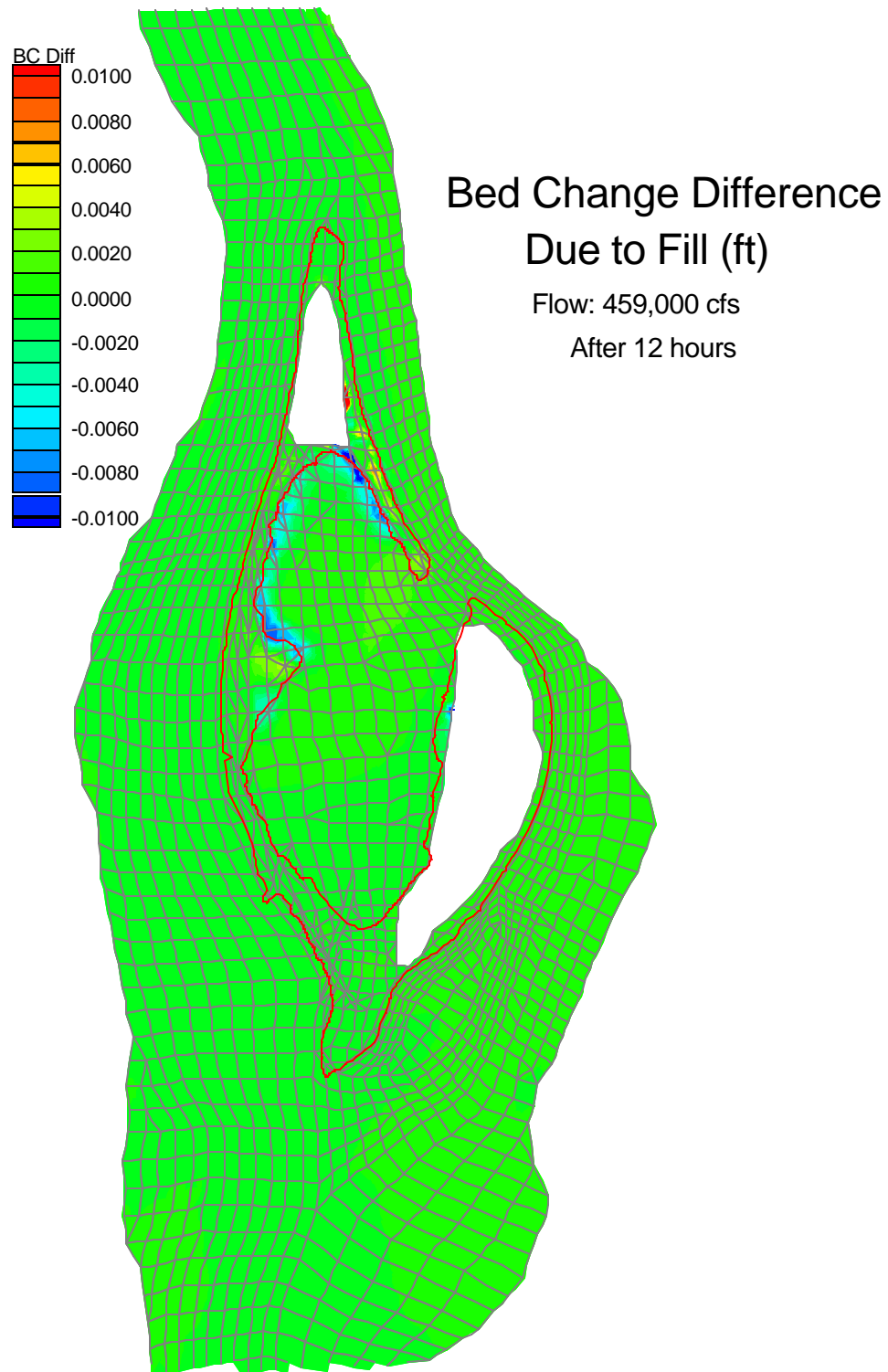


Figure 19. Differences in Bed Changes for 1996 Peak Flow due to Lagoon Fill.

The SED2D model predicts that natural sedimentation in the lagoon, consisting primarily of fines, is on the order of a few inches per year with more deposition occurring in the lagoon inlet. Increased deposition occurs at the inlet due to the reduction of flow velocities as flow moves into the lagoon and the suspended sediment is deposited. Events that overtop the river side of the island do carry some sediment into the lagoon but flow patterns are such that most deposition is along the river side of the lagoon. Deposition rates were low over the entire range of flows modeled from 10,000 cfs to 459,000 cfs. Results for the 1996 flood showed some deposition inside the lagoon but, due to the relatively short nature of the event (where the island was overtopped for approximately one week), the maximum depths of deposition were not large with a maximum of approximately 0.5 ft (6 inches).

A plan to lower the existing 900 ft long berm between Ross and Hardtack Islands to an elevation of +15 ft NGVD was modeled to evaluate the possibility of increasing sedimentation in the lagoon. The increase in flow obtained by lowering the berm did not increase the depth of sedimentation but only increased the area of the lagoon receiving the maximum deposition during a particular duration of flow.

The lowering of the berm would require erosion protection for the remaining berm between Ross and Hardtack Islands. The erosion protection would be necessary to prevent the berm from eroding during a flood event with subsequent damage to other perimeter areas. Protection may also be necessary where the flows exit the lagoon to prevent floods from breaching the relatively narrow portions of the island at the northern end of the lagoon and causing turbulence and flow problems in the already constrained areas of the river and Holgate slough. If the narrow portion of the island on the Holgate Slough side of the lagoon were to breach, bank scour could very likely be expected on the opposite bank of Holgate Slough.

If the berm were to fail during a flood, a head cut could be propagated some distance up the river from the lagoon. This could endanger the containment cells in the lagoon just downstream of the weir as well as cause additional erosion problems downstream. It is unlikely that a severe head cut would move rapidly upstream or be large given the constrained flow in the area. Further any head cut would be arrested by either the deep holes or rock controls upstream.

The SED2D model produced results for the “average” annual hydrograph for the lagoon entrance that are of the same magnitude of deposits observed at Ross Island. From model results it appears that annual deposition in the lagoon is on the order of 6-10 inches depending on the location within the lagoon and the duration of flows above approximately 50,000 cfs.

Results obtained from the analysis of the fill scenario indicate that high areas of the fill may be subject to scour if left unvegetated and if non-cohesive fine material is used. For final design an additional analysis of large flood events should be performed to insure stability of the material to be used.

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