Technical Memorandum 001

HYDRODYNAMIC/SEDIMENTATION MODELING FOR LOWER WILLAMETTE RIVER

Development of Modeling Approach

Prepared by

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Prepared for

Lower Willamette Group (LWG)

February 20, 2004

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Portland Harbor Vertical Datum Conversion Table.

River Mile	NAVD88 Elev.	NGVD29/47 Elev.	CRD Elev.
	10.0'	6.8'	5.4'
0.4	0.0'	-3.2'	-4.6'
	-10.0'	-13.2'	-14.6'
	10.0'	6.8'	5.4'
1.3	0.0'	-3.2'	-4.7'
	-10.0'	-13.2'	-14.7'
	10.0'	6.7'	4.9'
5	0.0'	-3.3'	-5.1'
	-10.0'	-13.3'	-15.1'
	10.0'	6.5'	4.7'
9.8	0.0'	-3.5'	-5.3'
	-10.0'	-13.5'	-15.3'
	10.0'	6.5'	4.6'
12.8	0.0'	-3.5'	-5.4'
	-10.0'	-13.5'	-15.4
	10.0'	6.5'	4.6'
15.6	0.0'	-3.5'	-5.4'
	-10.0'	-13.5	-15.4'

1 INTRODUCTION AND PURPOSE

In 1997, the Environmental Protection Agency (EPA) and the Oregon Department of Environmental Quality (DEQ) found that sediments in the Lower Willamette River contained a number of contaminants including mercury, tributyltin (TBT), DDT, PCBs, petroleum products, and dioxins. In December 2000, EPA placed part of the Lower Willamette River, referred to as "Portland Harbor", on its National Priorities List further study.

EPA contacted 69 Potentially Responsible Parties, a portion of whom came forward to form the Lower Willamette Group (LWG) to voluntarily work with EPA and DEQ on the study. In September 2001, EPA and LWG negotiated an Administrative Order on Consent (AOC) under which the LWG agreed to perform a Remedial Investigation and Feasibility Study (RI/FS) for the Initial Study Area (ISA). This "Hydrodynamic/Sedimentation Modeling for the Lower Willamette River" is part of LWG's agreed responsibilities under the AOC.

The ISA runs from the southern tip of Sauvie Island, at about River Mile (RM) 3.5 (as measured from the confluence with the Columbia River) to the southern end of Swan Island at about RM 9.2. However, the modeling effort will initially include the lower Willamette from RM 0 (confluence with the Columbia) to the Willamette Falls at RM 26.6 and the model will focus on the reach from RM 2 to RM 11 (Figure 1-1). Along this reach, constituent concentrations in the sediments are variable, with "hot spots" observed in some locations. This variability means that there may be a range of physical cleanup strategies from natural attenuation to localized capping or localized dredging, as well as source control.

The physical system of the Lower Willamette River (hydrology, hydrodynamics and sediment movement) is being investigated as a key element of the Portland Harbor RI/FS. This is being done to gain a sufficient understanding of the Lower Willamette River to support contaminant nature and extent characterization, ecological and human health risk assessments, and the feasibility study, by providing information on where sediments in the study area are stable and where they are unstable, and the magnitude, and extent of those instabilities over time and a full range of hydrologic conditions. This will: 1) allow the risk assessments to focus on sediments that have the potential to become re-exposed to biota through physical processes; and 2) allow the feasibility study to identify and evaluate remedial alternatives based on an understanding of long-term sediment stability patterns throughout the site.

1.1 Modeling Objectives

The model will simulate the important hydrodynamic and sediment transport processes of the Lower Willamette River at spatial and temporal scales sufficient to evaluate corresponding Data Quality Objectives described in the revised draft programmatic work plan (SEA et al., 2003). It is not intended to simulate processes at very fine scales, such as around individual dock piles. To achieve the Data Quality Objectives, the objectives of the model are:

- Determine the spatial and temporal sediment transport patterns so that surface contaminant distributions and risks to ecological and human receptors in the Lower Willamette River can be adequately characterized.
- Determine whether physical processes expose previously buried contaminated sediment, including during major flood events.
- Determine whether physical processes result in burial of contaminated sediment.
- Quantify the rates and locations of sediment accretion and erosion associated with various flows, including extreme events.
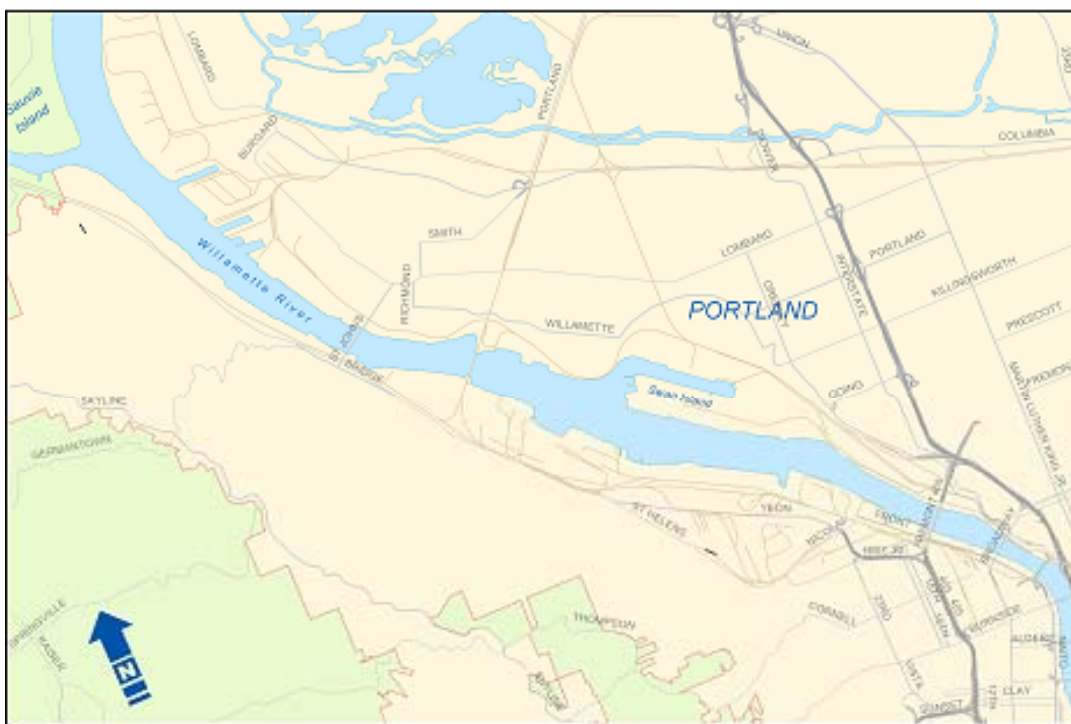
Figure 1-1 Main Study Area

One purpose of this Technical Memorandum (TM) is to detail the objectives of the modeling program, the proposed model selection, and the modeling approach. Available data are identified and analyzed to answer this, and other questions, in this TM. Other purposes are to define the type of model needed, and how it should be setup, calibrated, and applied to simulate system processes. It is clear that, at a

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minimum, a two-dimensional model is needed to adequately simulate the longitudinal and lateral variability in the physical processes. What is not immediately clear is whether a two-dimensional model is sufficient, or if a three-dimensional model is needed. This TM will includes a preliminary analysis of this question using available data.

This TM is divided into seven sections. Section 1 presents the introduction and study objectives. Section 2 reviews the data available to assess model processes. Section 3 analyzes the data, and presents which processes should be included in the numerical model, and the recommended model resolution. Section 4 proposes the numerical model to be used for the study. Section 5 presents the proposed modeling approach. Section 6 briefly describes the recommend model. Section 7 lists study references.

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2 DATA AVAILABLE

The development of a hydrodynamic and sediment transport model of the Lower Willamette River to evaluate sediment mitigation alternatives requires the following types of information:

- Bathymetry
- Tides
- River flows
- River velocities
- Sediment inflows (suspended and bedload)
- Characteristics of the bed sediments
- Bed chemistry
- Density structure
- Site meteorology
- Groundwater discharge

Bed chemistry is included in this review to estimate the physical spatial and temporal scales related to the nature and extent of contamination, to determine whether the model resolution is sufficient to evaluate remedial alternatives for the site. The following sections describe the information available for review for each data type.

2.1 Background Reports

A number of background information reports were provided to the modeling team, including:

- The Remedial Investigation (RI) work plan, including report, figures, tables, and appendices
- "Portland Harbor Sediment Investigation Report" (Weston, 1998)

2.2 Bathymetry and Structures

David Evans & Associates, Inc. (DEA) conducted detailed bathymetric surveys in December 2001 and January 2002, in July and September 2002, and in May 2003. A fourth survey was initiated following a large flow event in February 2004; these data are being processed. The following information was provided:

- (X,Y,Z) data for the December 2001 survey at 10-ft resolution
- (X,Y,Z) data for the Summer 2002 survey at 10-ft resolution
- (X,Y,Z) data for the May 2003 survey at 10-ft resolution
- (X,Y,Z) data for the difference between the surveys at 10-ft resolution

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- Various DEA bathymetry survey reports
- Several bathymetric change maps

Numerous structures, such as docks, pilings and bridge supports are present within the Lower Willamette River. The presence of these structures may have a significant effect on sediment erosion and deposition, particularly near the river's banks. Aerial photographs and other maps are available to identify the locations of these structures in the study area.

2.3 Tides

There are three NOAA tide gauges currently operating in the area:

Gauge #	Location	Northing	Easting
9439221	Morrison Street Bridge, OR	45 31.0 N	122 40.2 W
9440083	Vancouver, WA	45 37.9 N	122 41.8 W
9439201	St. Helens, OR	45 51.9 N	122 47.7 W

Data for each of these sites were obtained from the Internet for the period December 2001 to December 2002.

2.4 River Flows

There are U.S. Geological Survey stream gauges currently operating at:

Gauge #	Location		
14207770	Willamette River below falls at Oregon City		
14211720	Willamette River at Portland		

Daily average flows were obtained at these gauges for the period December 2001 to December 2002. Also, the highest peak flow and the corresponding daily-average flow were obtained for each year of record, to enable a comparison between them to determine if daily or more-frequent flow would be required for the model simulations. The Lower Willamette River is relatively large, and floods peak slowly. On similar systems, peak flows and daily-average flows on the same day can be very similar.

2.5 River Velocities

Relatively little data could be found about observed currents in the Lower Willamette River. However, large data sets were collected by DEA (2002b and 2003a) for the LWG studies. A third data set was collected during a large flow in February 2004, and is not yet processed. Acoustic Doppler Current Profile (ADCP) data were collected at 16

transects in the study reach on April 19, 2002. Additional data were collected at multiple times at four transects during a tidal cycle around the confluence with the Multnomah Channel on May 13, 2003. These data are very dense and represent by far the largest data set available in the river. Therefore, no other data sources were pursued.

2.6 Sediment Inflows

The U.S. Geological Survey maintains a water quality sampling station along the lower Willamette River in the vicinity of Ross Island (about RM 15). This station records sediment concentrations that will be correlated with stream flows to estimate sediment loads to the river from upstream. There are also limited sediment observations in the Columbia Slough and on the Columbia River at Bonneville Dam.

2.7 Bed Sediments

GeoSea Inc. conducted a Sediment Trend Analysis (STA$^®$) of the Lower Willamette River in 2000 (GeoSea, 2001). This study included sampling and characterizing the bed sediments and their grain size distributions. Striplin Environmental Associates (SEA) performed a sediment profile image study (SEA, 2002a) and integrated the STA$^®$ analysis with bathymetric survey data to characterize bed sediments. SEA also compiled a database of existing surface and subsurface sediments samples that characterize grain sizes. Specific data available include:

- GeoSea georeferenced sediment distribution data and report
- SEA's sediment profile image data and report
- SEA's database of existing sediment samples

2.8 Bed Chemistry

Weston (1998) conducted a sediment investigation in Portland Harbor for EPA Region X. Figures in the report show the along-channel distributions of a number of chemicals. As part of the LWG investigations, SEA is conducting a number of benthic surveys, including sediment chemistry. Preliminary results and distributions of chemicals are available to the modeling team and PDF files showing individual sample concentrations (rather than spatial distributions).

These data are being reviewed to estimate the physical spatial and temporal scales related to the nature and extent of contamination, to determine whether the model resolution is sufficient to evaluate remedial alternatives for the site.

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2.9 Density Structure

The Lower Willamette River is tidal. However, it is not saline. While thermal gradients can modify circulation patterns, perhaps from the mixing of Columbia River and Lower Willamette River water, there is no strong evidence that temperature differences are a significant influence on circulation in the study area. Scientists at Portland State University developed a numerical model of a larger study area that included the Lower Willamette River (Berger et al., 2001). Experience from this study, and their reports, will be useful in addressing the importance of the density structure in the lower river.

2.10 Meteorology

Meteorology can influence circulation in a number of ways. Pressure changes can increase or decrease water surface elevations. Wind can drive near-surface currents, and air temperature, dew point temperature and solar radiation influence heat exchange. Meteorological data exist at Portland airport. Again, the Berger et al. (2001) study will be useful in deciding the relative importance of meteorological data in the circulation in the Lower Willamette River.

2.11 Groundwater Discharge

Groundwater discharge to the Lower Willamette River is a part of the overall mass balance of the system. There are two regional studies that provide information about groundwater discharges. The first is a groundwater model study conducted by the U.S. geological Survey (Morgan and McFarland, 1997). The second is a study conducted for the City of Portland by several contractors (Koreny and Fisk, 2001).

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When developing a model to simulate hydrodynamics and sediment transport, it is important to identify the major processes that should be simulated in the model and the spatial scales dictated by regulatory requirements. Issues to be considered include:

- What are the scales of bathymetric changes? This is related to the selection of the horizontal resolution.
- What are the scales of horizontal changes in bed chemistry? This is also related to the selection of the horizontal resolution for the sediment transport model, and the scale needed to assess physical remedial alternatives.
- While it is clear that at least a two-dimensional model is needed to resolve horizontal distributions of bathymetry and bathymetry changes, a three dimensional model may be required to provide resolution sufficient to assess the remedial alternatives. The modeling effort will include a preliminary evaluation using existing data to see if a two-dimensional model provides sufficient resolution to assess the remedial alternatives modeled.
- The reach of interest begins at RM 2, downstream of the confluence of the Lower Willamette River and the Multnomah Channel. Should the Multnomah Channel be included in the model?
- How far should the model extend upstream beyond RM 11 in order to define a suitable boundary condition?

3.1 Bathymetry and Structures

David Evans & Associates, Inc. (DEA) conducted detailed bathymetric surveys in December 2001 and January 2002, in July and September 2002, and in May 2003. A fourth survey is being conducted in February 2004. All surveys are referenced to the North American Vertical Datum of 1988 (NAVD88) and have a vertical accuracy of 0.25 feet (7.6 cm). Figure 3-1 shows the bathymetric changes between the December 2001 and summer 2002 surveys in part of the lower river, Figure 3-2 shows the bathymetric changes between the December 2001 and May 2003 surveys in part of the lower river, and Figure 3-3 shows the distribution of differences between the first two surveys to an accuracy of $\pm$ 0.25 feet. More than 99 percent of the change in bed elevation is less than 40 cm, and about 80 percent is less than 10 cm. The figures show that much of the larger changes in bed elevation occur near the shorelines in the vicinity of docks and berths, and are probably due to vessel hydrodynamics or propeller interaction with the bed and the steeper geometry.

A discussion with Steven Hill of GeoSea Consultants, Ltd., who conducted the bed sediment sampling, concluded that changes in bed sediment characteristics are generally seen at scales of 25-50 m across the river, and longer in the along-river direction. We believe that a nominal resolution of about 50 m across the river is

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sufficient to model the lateral variability of geometry and sediments within the ISA, including the navigation channel and shallow nearshore areas. The resolution will be increased in areas of special significance, such as close to the shoreline.

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Figure 3-1 Bathymetric Changes Between Dec. 2001 and Summer 2002 Surveys

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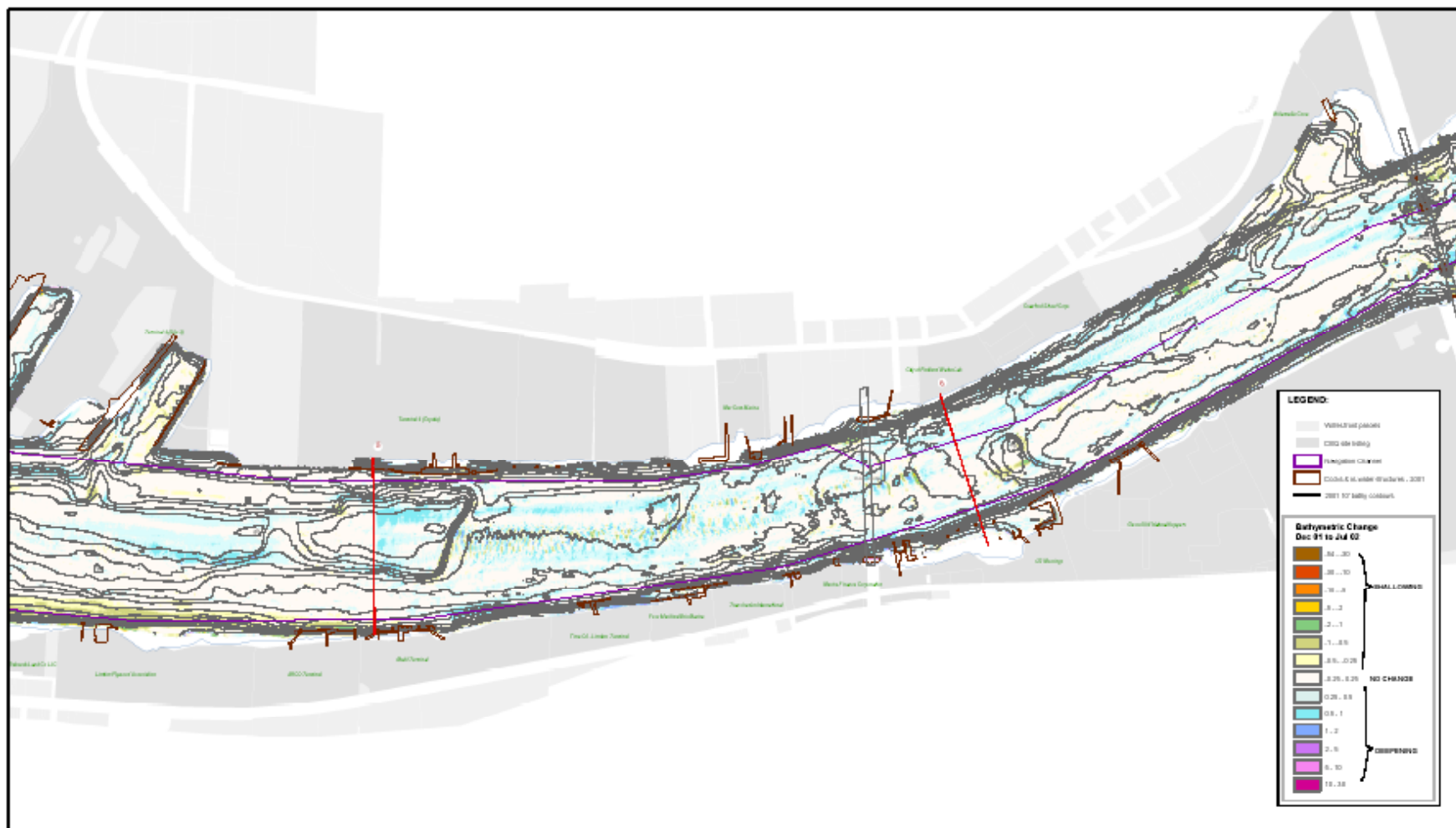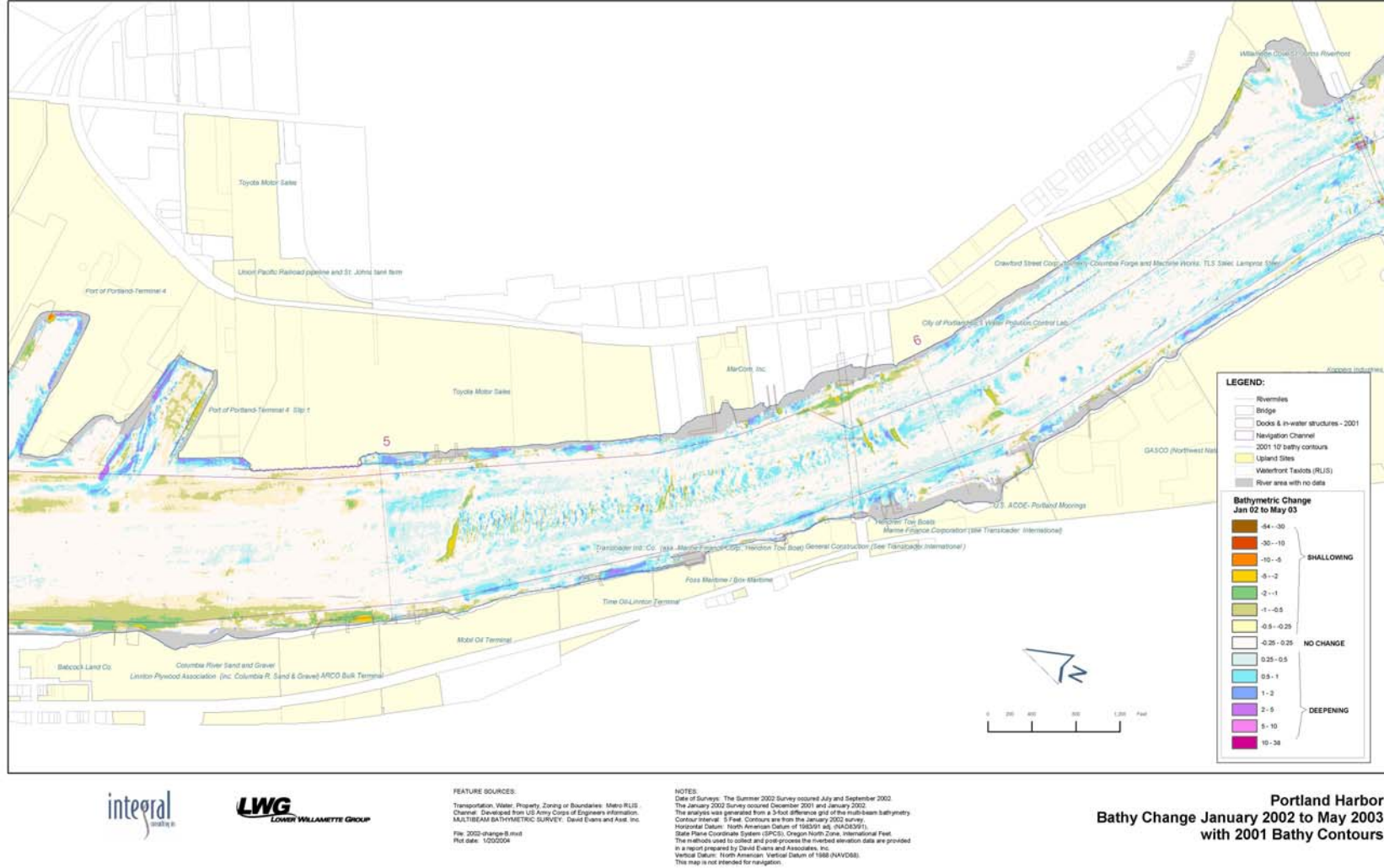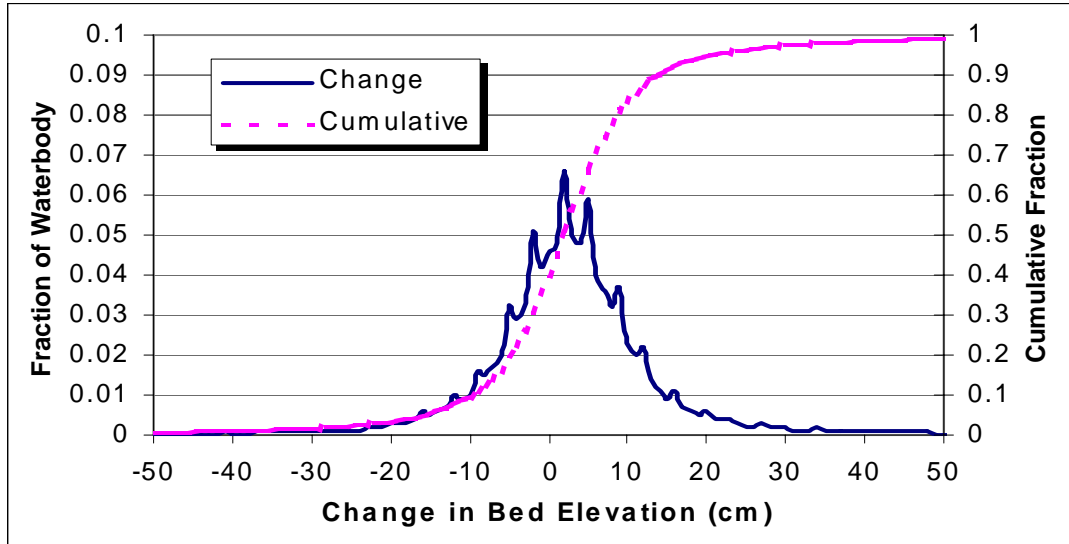
Figure 3-2 Bathymetric Changes Between December 2001 and May 2003 Surveys

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Figure 3-3 Distribution of Bed Elevation Changes Between 2001 and 2002 Surveys

Aerial photographs, field reconnaissance information, charts and other information exist to describe the locations of various structures, including docks, pilings and bridge supports. These locations will be identified to include their appropriate description in the numerical model.

Below the low water level, the model is expected to simulate erosion using the local computed shear stress. However, in the inter-tidal region and also during and following large river flows, mass wasting may add additional sediment loads to the system. We propose to treat mass loading empirically by reviewing the available data including (1) bathymetric/topographic surveys and (2) sediment elevations measured using stakes throughout the study area. These data, and literature empirical formulae will be used to estimate bank mass wasting loads for various hydraulic conditions.

3.2 Tides

There are NOAA tide gauges located at Portland (Oregon) on the Lower Willamette River, and at Vancouver (Washington) and St. Helens (Oregon) on the Columbia River. The St. Helens gauge is located near where the lower part of the Multnomah Channel, which leaves the Lower Willamette River near RM 2, reaches the Columbia River. Observations at these three gauges are plotted in Figure 3-4 for the period April 2002. The data show that, during low flows in the Columbia River, tides at all three stations are similar, and show clear tidal fluctuations. However, at high Columbia River flows, the slope of the water surface of the Columbia River controls the resulting water surface elevations in the Lower Willamette River and down the Multnomah Channel. Figure 3-5 zooms in on the tidal signal during 4-6 April 2002. The figure shows the difference in

tidal phase between the three stations. The tides at St. Helens are approximately two hours ahead of Vancouver, and about two and a half hours ahead of Portland.

While the dynamics of the interaction between the Multnomah Channel, the Columbia River and the Lower Willamette River are unclear, observations of currents (see Section 3.4) indicate that there are times when significant flows can be seen down he Multnomah Channel. Therefore, we recommend that the numerical model include the Multnomah Channel, and that tides be specified at its downstream end (using the St. Helens gauge data) and at the confluence of the Lower Willamette and Columbia Rivers (using the Vancouver gauge data). Tides at Portland can be used to calibrate water surface elevations and tidal phase.
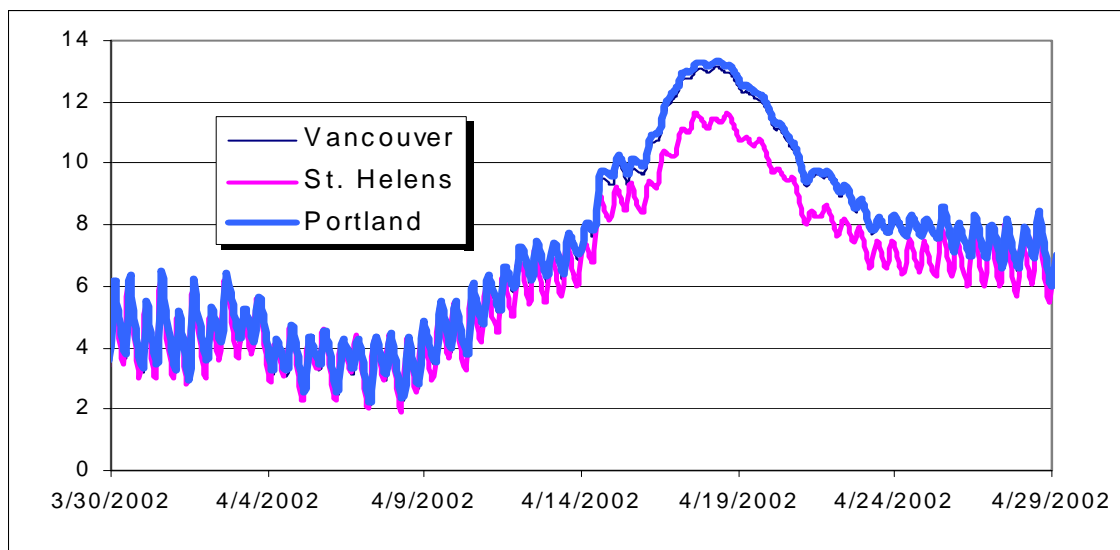
Figure 3-4 Tidal Data for April 2002
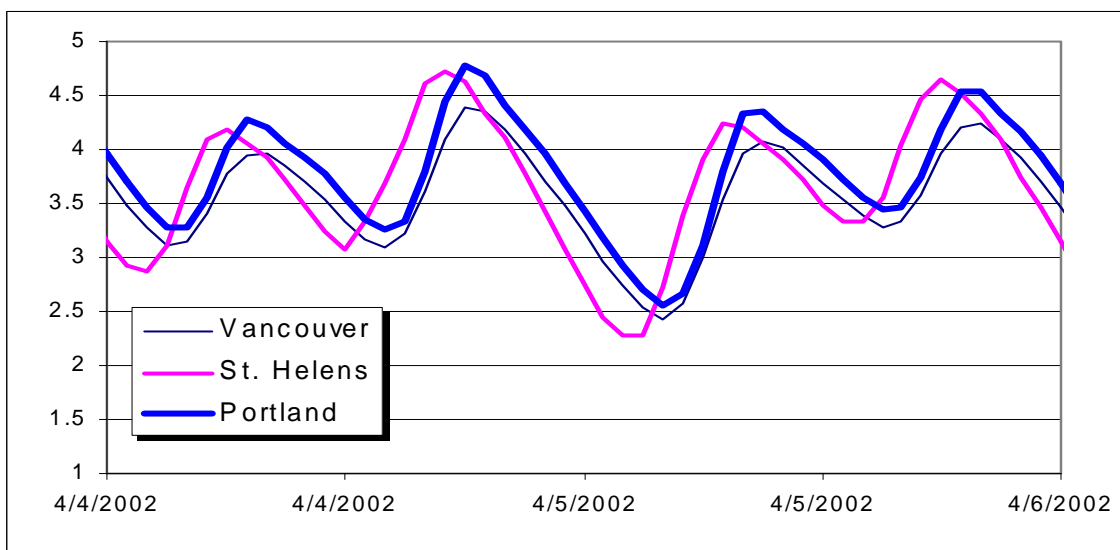
Figure 3-5 Tidal Data for April 4-6, 2002

Tidal observations at Portland show a two-plus-feet tidal range. In addition, USGS measurements of water surface elevations downstream of the Willamette Falls (RM 26.5) and the results of Berger et al. (2001; Figure 3-24) also show tidal stage fluctuations. While it is reported that flow reversals are not seen upstream of about RM 18, the fluctuations in tidal stage further upstream might be an important element to be represented in the numerical model. A more downstream boundary could reflect the tidal signal rather than allow it to propagate further upstream. This should be an element of a model sensitivity analysis to determine if a more downstream boundary is adequate.

3.3 River Flows

There is a U.S. Geological Survey (USGS) stream gauge near the Morrison Street Bridge in downtown Portland. Daily-average flows are available on the internet, while historical hourly observations must be ordered through the USGS. Daily-average flow data exist from water year 1973 through present, except the data for water year 1995 are missing. The daily-average flow for the period of record is shown in Figure 3-6. Figure 3-7 shows the yearly runoff volumes of the Willamette River at Portland.
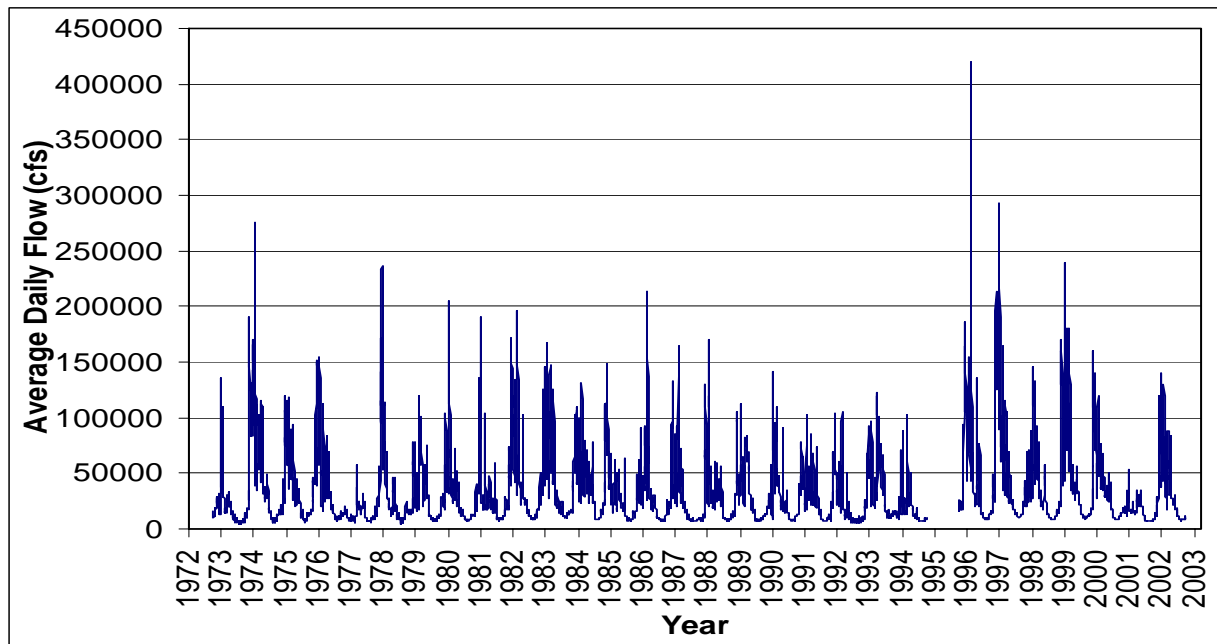
Figure 3-6 Willamette River average daily flows at the USGS Portland Guage

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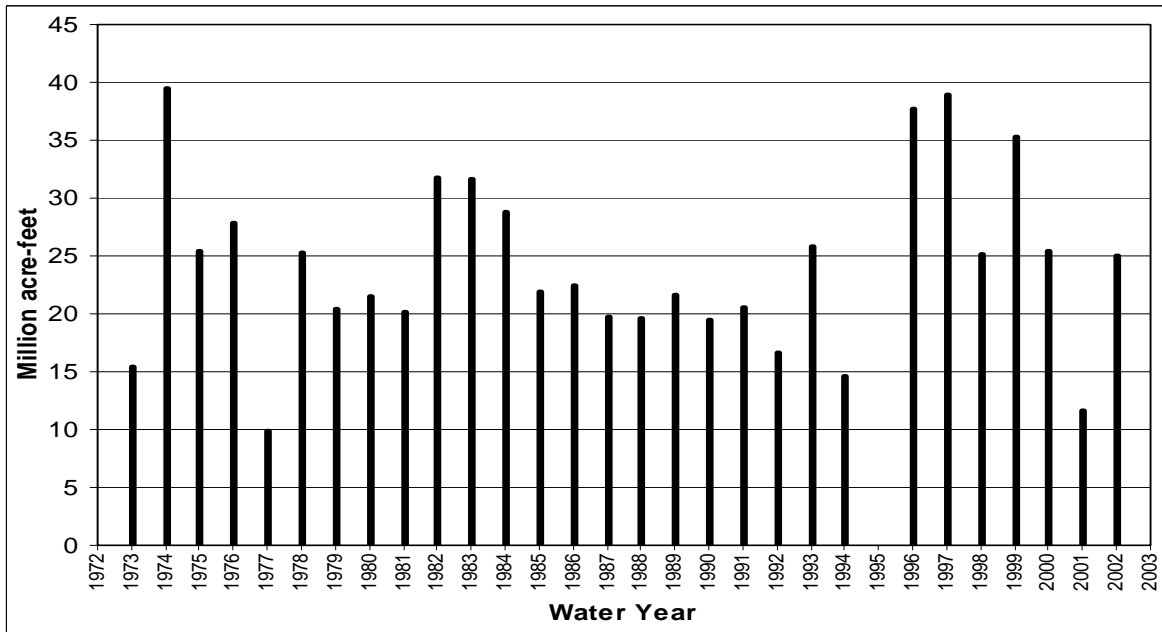
Figure 3-7 Willamette River yearly runoff volumes at the USGS Portland Gauge

The Lower Willamette River is a large river, and generally flows change relatively slowly. To examine whether daily or hourly flows should be used as model input data, the instantaneous peak annual flows were plotted against the daily-average flow that occurred on the same day (Figure 3-8). Peak flow data are only reported from water year 1973 through water year 1994 at the USGS Portland gauge. Additionally, for water years 1977 – 1979 and 1985 – 1993, the instantaneous peak flows that are reported are not measured flows. Instead, the instantaneous peak flows reported for these years are the daily-average flows. There are only measured instantaneous peak flow data for water years 1973 – 1976, 1980 – 1984, and 1994. Figure 3-8 displays only the data from the 10 years in which there were coincident instantaneous peak flow and daily-average flow measurements. For these ten years, the peak flows are generally within ten percent of the daily-average flows. Because the flows are so similar, and within the accuracy of measurements, we believe that daily-average values are adequate to describe flows in the Lower Willamette River.

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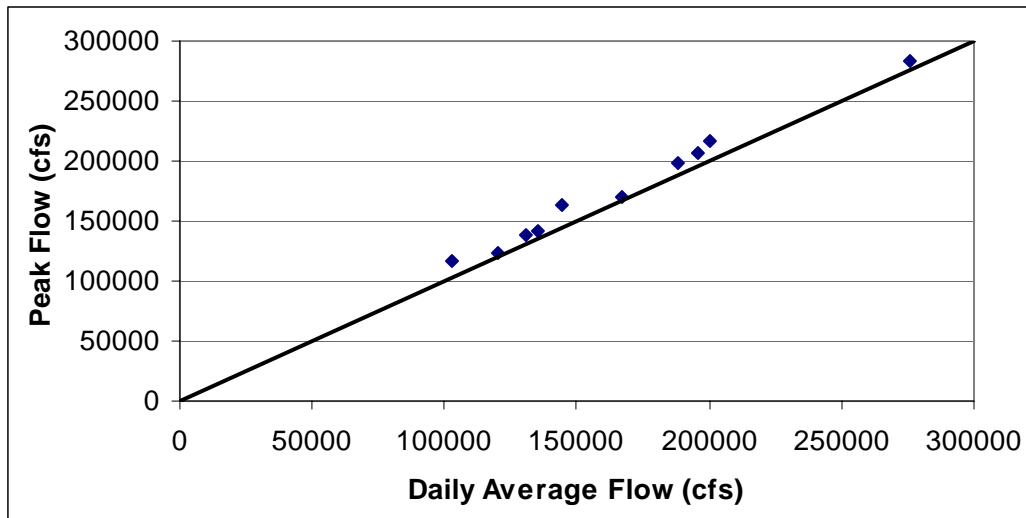
Figure 3-8 Relationship between peak flows and daily flows at the USGS Portland Gauge

The Willamette River basin has been steadily impounded over the years. A number of large dams have been built on the various forks. One of the largest floods on record occurred in 1964, and is often considered to be approximately the theoretical "100-year event". However, more recent upstream dams would probably alter that runoff distribution if a 100-year event were to occur today.

Whilst not strictly appropriate for a relatively impounded system, we developed a flood frequency distribution of the observed flows at Portland, using annual peak flows when measured and daily-average flows when the peak was not reported. From the results of Figure 3-9, the February 1996 peak flow of 420,000 cfs was close to the estimated 100-year flow of nearly 450,000 cfs. We propose to use this event to simulate sediment transport conditions during a major flood.

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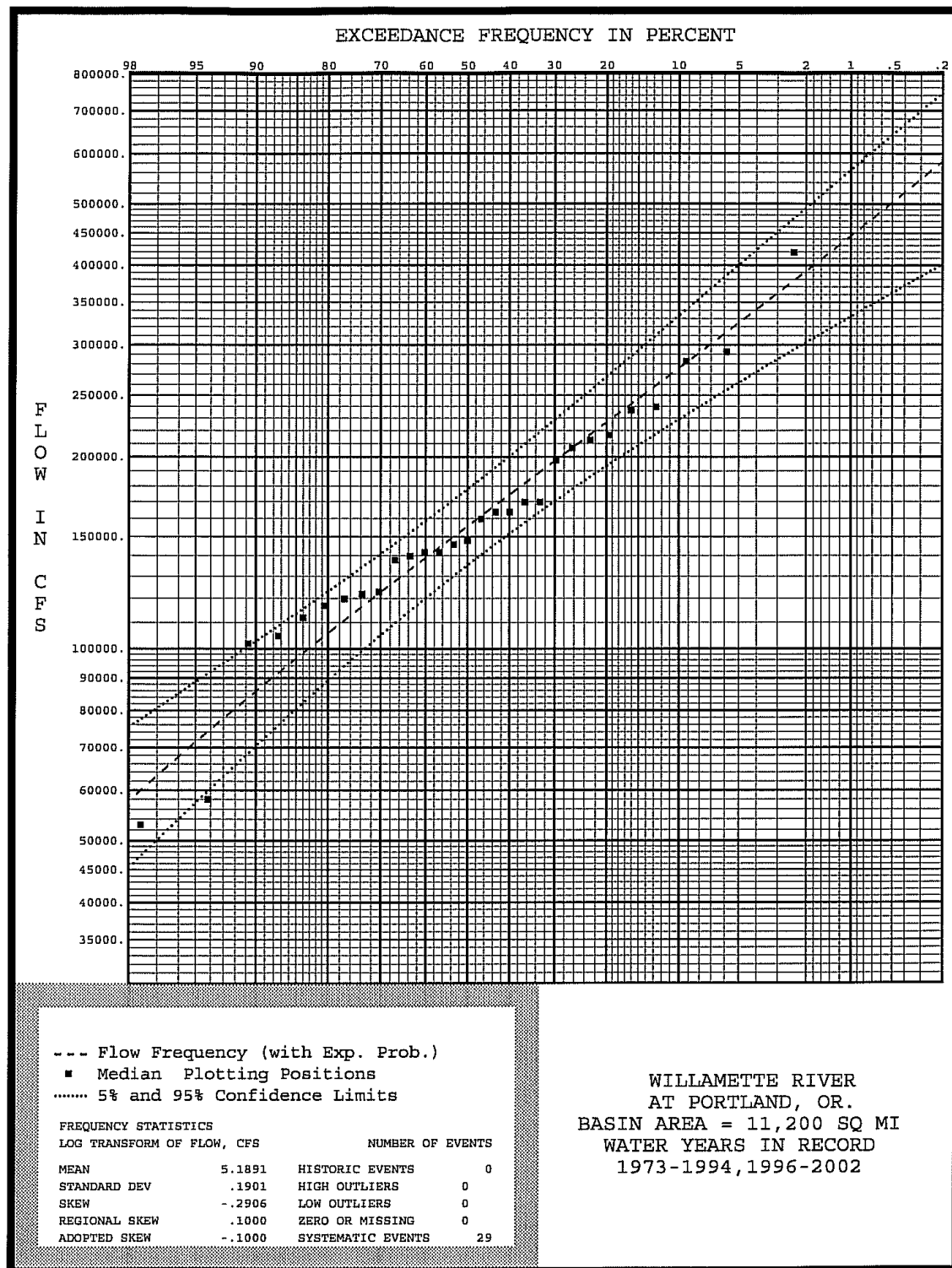
Figure 3-9 Flood Frequency Analysis of River Flows at Portland

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3.4 River Velocities

DEA collected current data at 16 transects between RM 1 and RM 11 in the study reach on April 19, 2002 (DEA, 2002b), and at multiple times at four transects during a tidal cycle around the confluence with the Multnomah Channel on May 13, 2003 (DEA, 2003a). Data from the April 19, 2002 survey were further analyzed to plot vertical current profiles at three points in each transect in the main river, and at the centerline of the two transects in the Swan Island Lagoon. Figure 3-10 and Figure 3-11 show examples of the vertical current profiles for two transects in the main River. From these plots, there is no clear evidence that physical processes modify the vertical structure of the distributions. The figures do show large variability of the vertical currents. This is considered to be "noise" in the measurements (the accuracy of the instrument used is about +/- 0.2 ft/sec) and not "structure" readily attributable to specific processes (such as wind or density currents). Given the shape of the vertical velocity distributions (roughly logarithmic) and the range of currents speeds measured, we believe that it is reasonable to simulate vertically-averaged velocities. We also note that most sediment transport models adjust the velocity to estimate a near-bed velocity to calculate the bed shear stress used for erosion calculations.
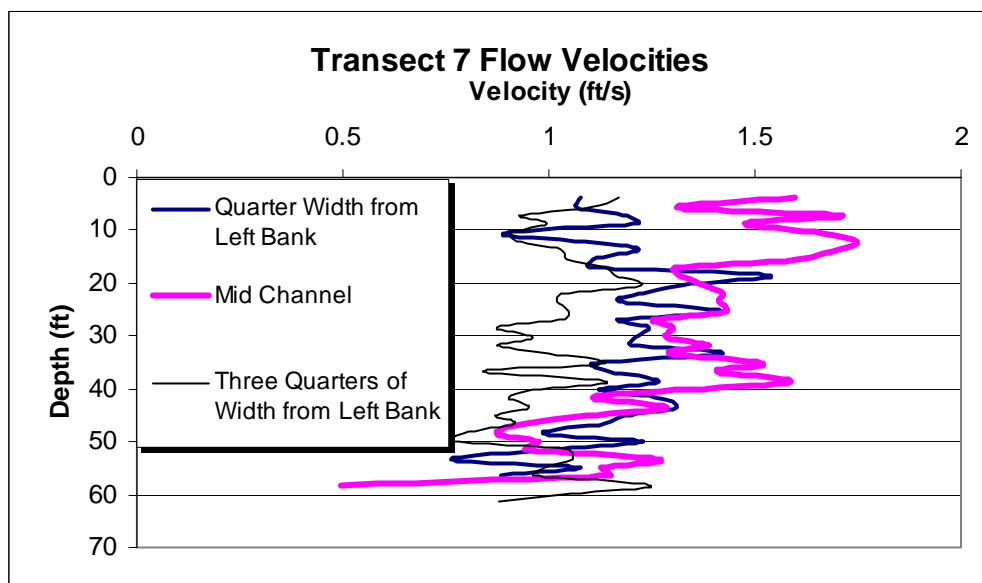
Figure 3-10 Vertical Currents at Transect 7 on April 19, 2002

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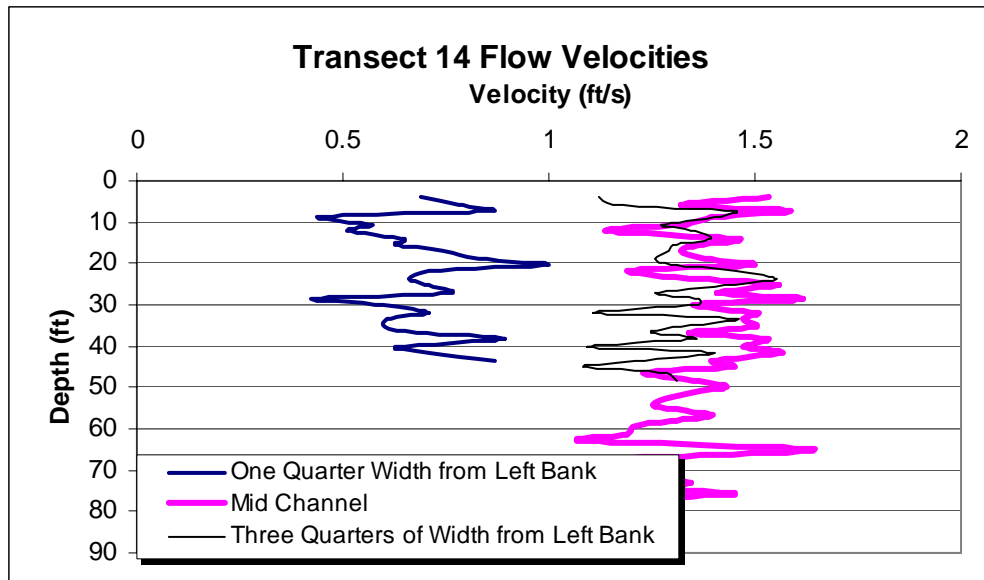
Figure 3-11 Vertical Currents at Transect 14 on April 19, 2002

Figure 3-12 shows the vertically-averaged velocity vectors (in blue) along three transects (in red) in the vicinity of the Multnomah Channel. Figure 3-13 shows the magnitude of current velocities along the transect at the mouth of the Multnomah Channel. These measurements were made during relatively large flows in the Columbia River (see April 19 in Figure 3-4) in which there are large gradients down the Multnomah Channel between Portland and St. Helens. Looking at the measured flows at these transects (developed from integrating the lateral distribution of velocity), approximately 50 percent of the upstream flow at this point in time is directed along the Multnomah Channel. As this condition persists for several days, it is clear that the Multnomah Channel should be included in the numerical model to simulate at least the flow rates leaving the Lower Willamette River at this location.

Data from May 2003 show similar processes and support the same conclusions (DEA, 2003a).

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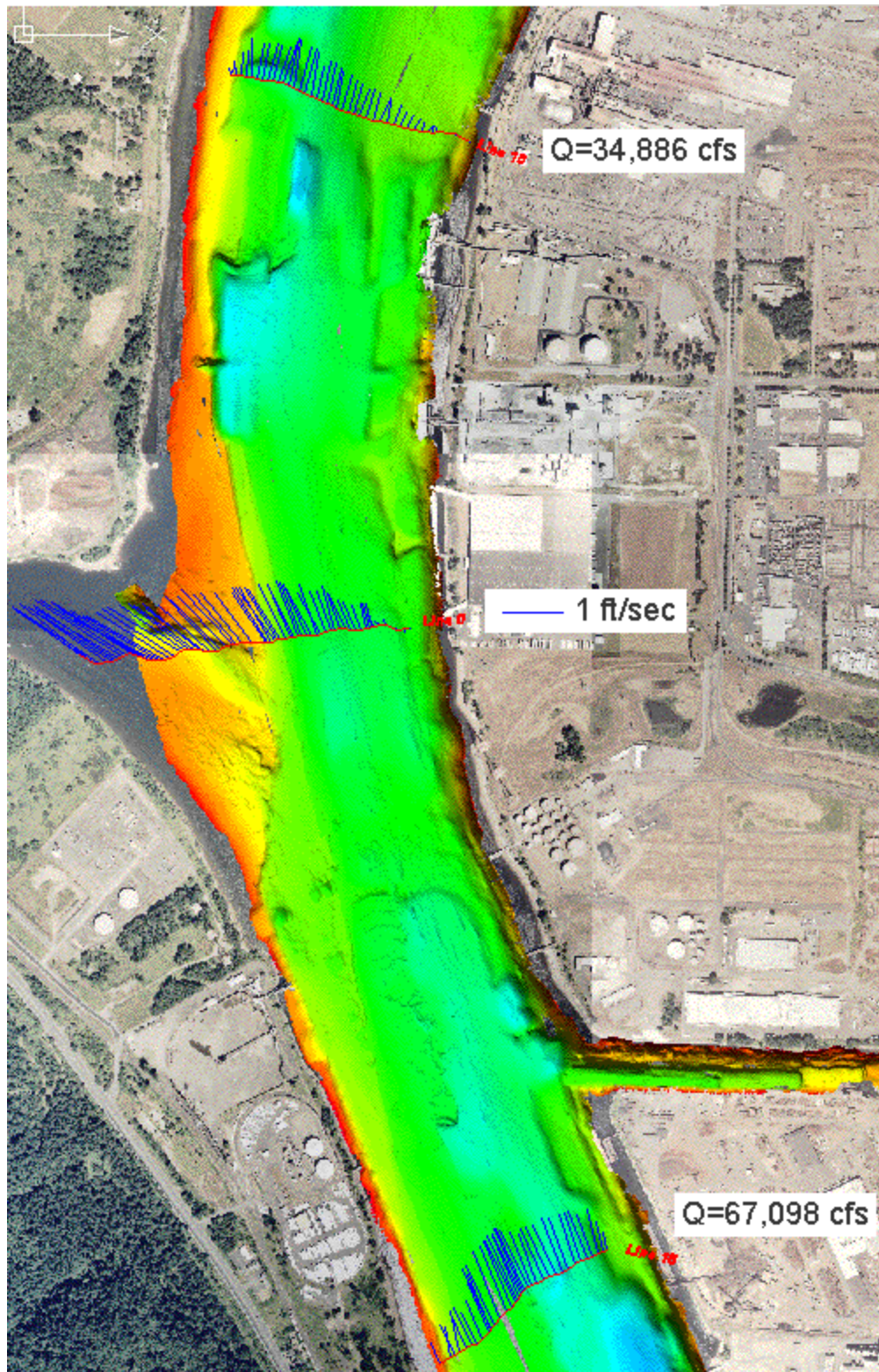
Figure 3-12 Velocities in the Vicinity of the Multnomah Channel on April 19, 2002

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Figure 3-13 Velocity Magnitude Along Transect at Mouth of Multnomah Channel

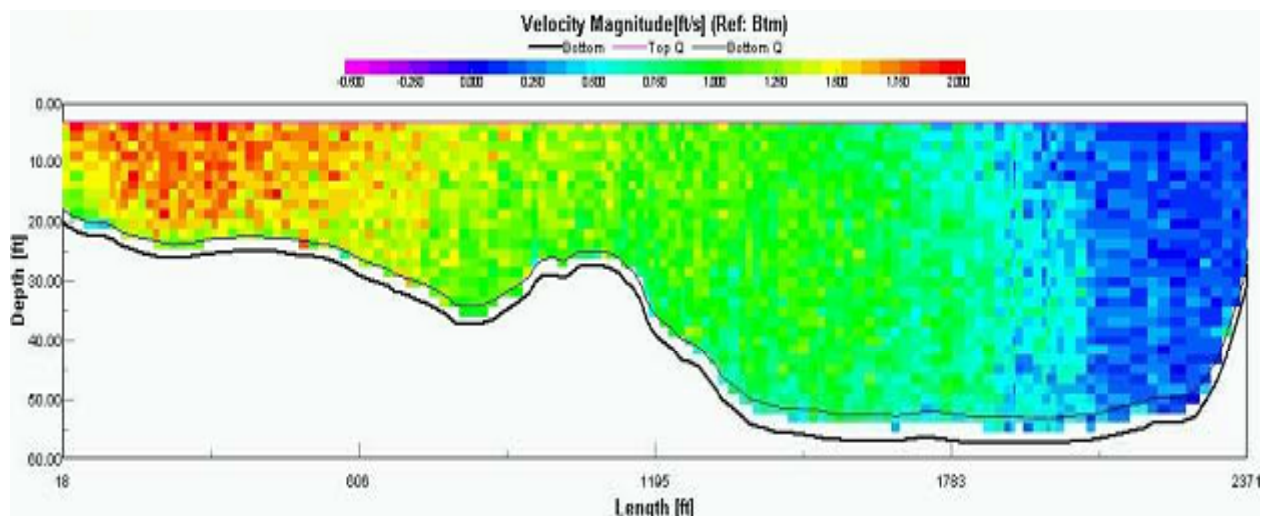## 3.5 Sediment Inflows

The U.S. Geological Survey has measured sediment concentrations approximately each month in the vicinity of Ross Island (about RM 15) since October 1974. All the measurements reported total sediment concentration, and many (but not all of them) also reported the concentration of "fine sand". During the largest measured flow of 391,000 cfs, only total sediment concentration was reported. These measurements are correlated with daily-averaged flows in Figure 3-14. The figure shows a strong linear correlation between flows and suspended sediment concentrations, particularly at higher flows. There is some scatter at lower flows. Figure 3-15 shows sediment load (rather than concentration) and also shows a strong correlation with flow. The highest flows are expected to move the most significant volumes of sediment in the Lower Willamette River.

Some of the measurements reported the differentiation between total suspended sediments and the sand fraction. Figure 3-16 shows the relationship between sand concentrations and flow, and Figure 3-17 shows the relationship with fine sediments (total minus sand). These linear relationships show some scatter at low concentrations, but a relatively strong relationship at high concentrations. These relationships can be used to estimate fine sediment (clays and silts) and sand sediment inflows for given river flows. These data are sufficient to model the system for several reasons. First, there are no major tributaries entering the Willamette River downstream of Ross Island. Second, we anticipate very little bedload to arrive at this reach because of the dam at the Multnomah Falls and because there are several deep holes upstream of Ross Island which would capture any large bedload.

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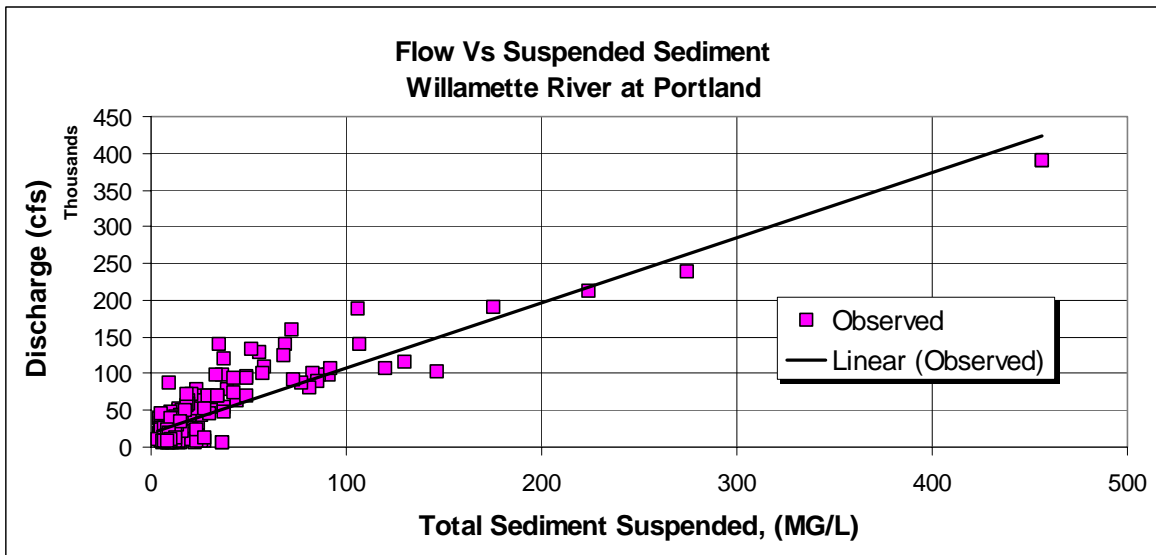
Figure 3-14 Total Suspended Sediment Inflows Near Ross Island
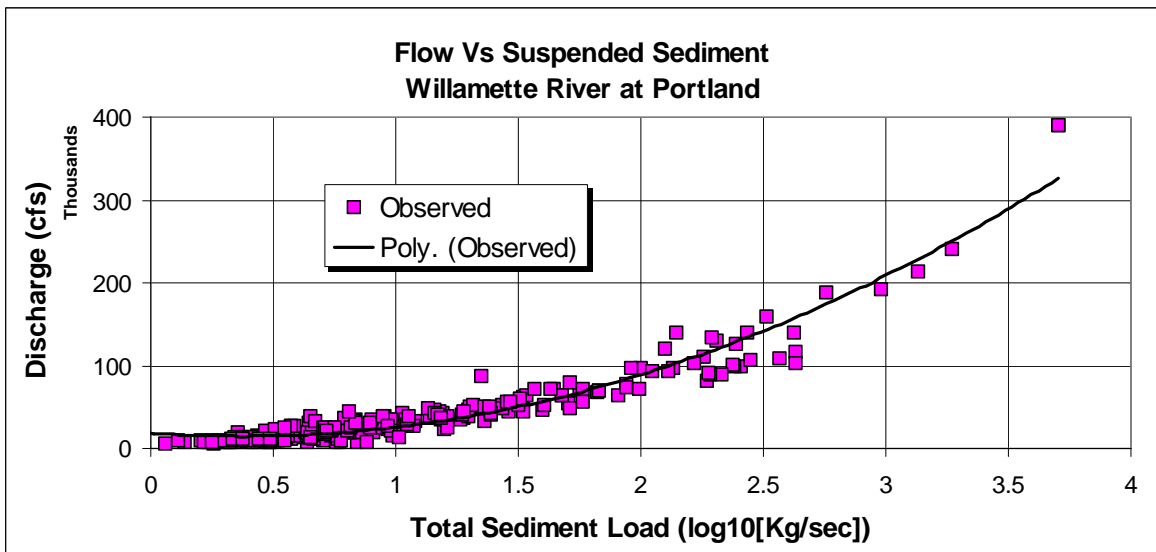
Figure 3-15 Total Suspended Sediment Loads Near Ross Island

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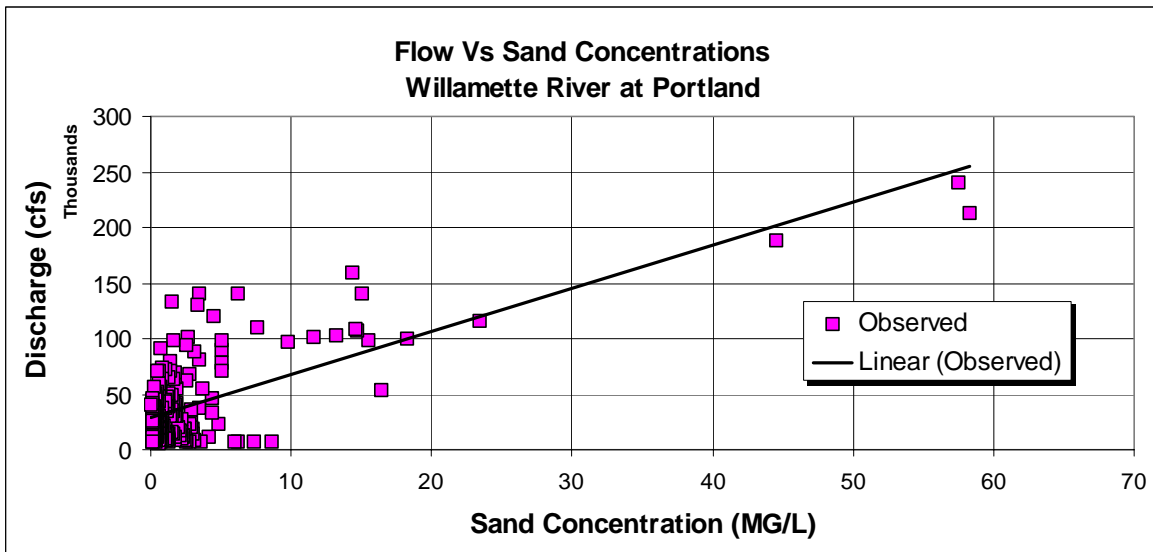
Figure 3-16 Sand Inflows Near Ross Island
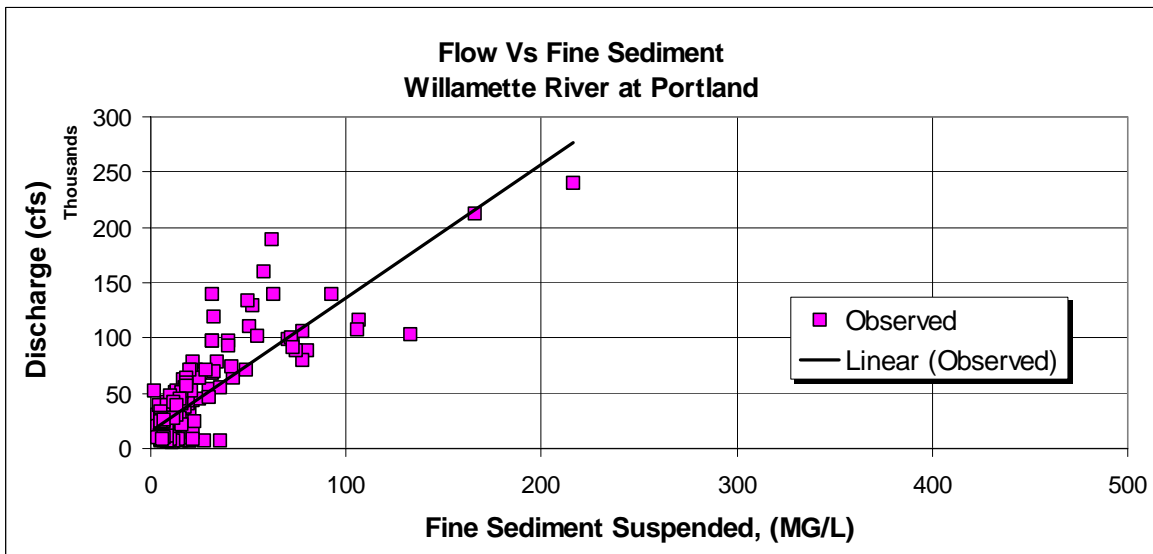
Figure 3-17 Fine Sediment Inflows Near Ross Island

There are some sediment data in the Columbia River (at Bonneville Dam) and in the Columbia Slough. The Columbia River data will be used to develop a flood tide sediment boundary at the confluence with the Willamette River. Other data represent sources that are small compared to the flows and sediment loads in the Willamette River above the Falls, and will not be included in the model.

3.6 Bed Sediments

GeoSea Inc. conducted a Sediment Trend Analysis (STA®) of the Lower Willamette River in 2000 (GeoSea, 2001). This study included sampling and characterizing the bed sediments and their grain size distributions. Striplin Environmental Associates

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(SEA) performed a sediment profile image study (SEA, 2002a) and integrated the STA$^®$ analysis with bathymetric survey data to characterize bed sediments. Both of these studies reported a gradation of material with coarser materials deposited upstream and finer materials deposited downstream.

Table 3-1 summarized the overall distribution of sediments (GeoSea, 2001). From this table, we note that three sediment types ("Sand", "Muddy Sand" and "Sandy Mud") explain over 80% of the bed, and explain nearly 95% if "hard ground" (or the absence of bed sediments) is included. This suggests that sediment deposition and erosion in the Lower Willamette River can be modeled using up to three sediment classes (sands, silts and clays).

Table 3-1 Summary of Sediment Types (from GeoSea, 2001)

Sediment Type	Percentage
Sandy Gravel	0.2%
Gravelly Sand	1.7%
Sand	32.6%
Muddy Sand	19.3%
Sandy Mud	31.6%
Mud	4.0%
Hard Ground	10.6%
TOTAL	100%

Figure 3-18 and Figure 3-19 show the distribution and sediment transport pathways in the vicinity of Swan Island Lagoon. These figures serve to visually describe the horizontal variability in bed sediments.

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Figure 3-19 Sediment Transport Pathways Near Swan Island Lagoon (from GeoSea, 2001)

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federal, state, and tribal partners, and is subject to change in whole or part.

3.7 Bed Chemistry

Figure 3-20 and Figure 3-21 show the longitudinal distributions of lead and mercury in the Lower Willamette River (Weston, 1998). Figure 3-22 shows a recent arsenic survey (SEA, 2002) and the horizontal distribution of observations. While these data are not contoured or "lumped" to show the size and extent of areas exceeding clean sediment standards, they do give an impression of the scale and variability of sediment chemical concentrations. From these figures, we visually estimated that a lateral resolution of 50 m and a longitudinal resolution of 200 m would be sufficient to define these distributions in term of model detail needed to simulate physical remedial alternatives. However, we propose to model the near-shore areas from approximately RM 2 to 11 with a lateral resolution of 25 m to more closely resolve the distribution of sediment processes related to erosion/deposition and the distribution of chemicals in the surface sediments.
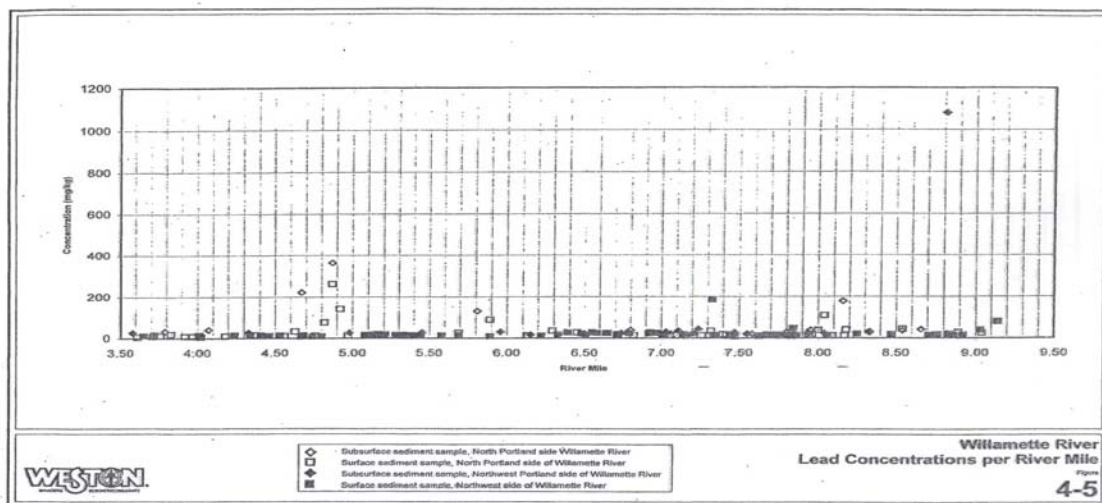
Figure 3-20 Longitudinal Distribution of Lead (from Weston, 1998)
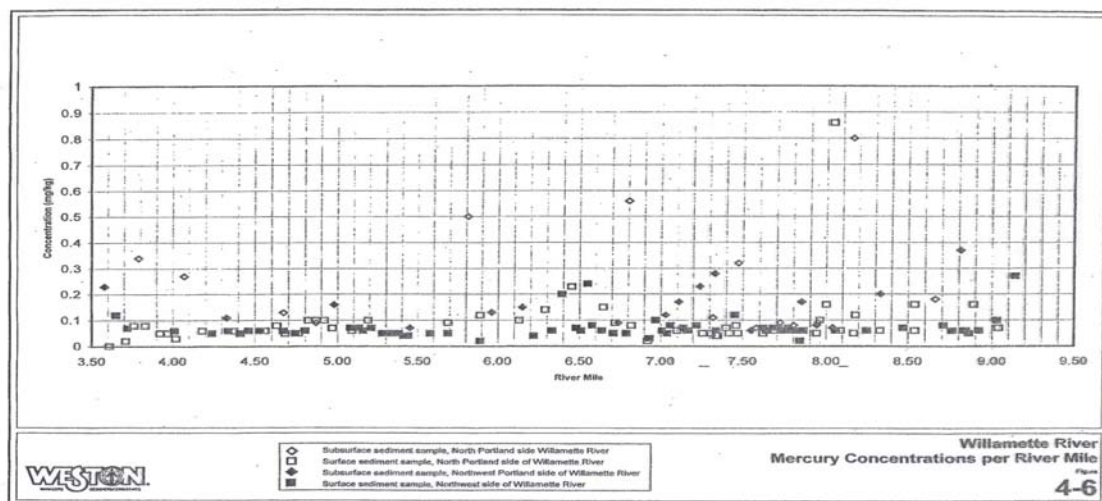
Figure 3-21 Longitudinal Distribution of Mercury (from Weston, 1998)
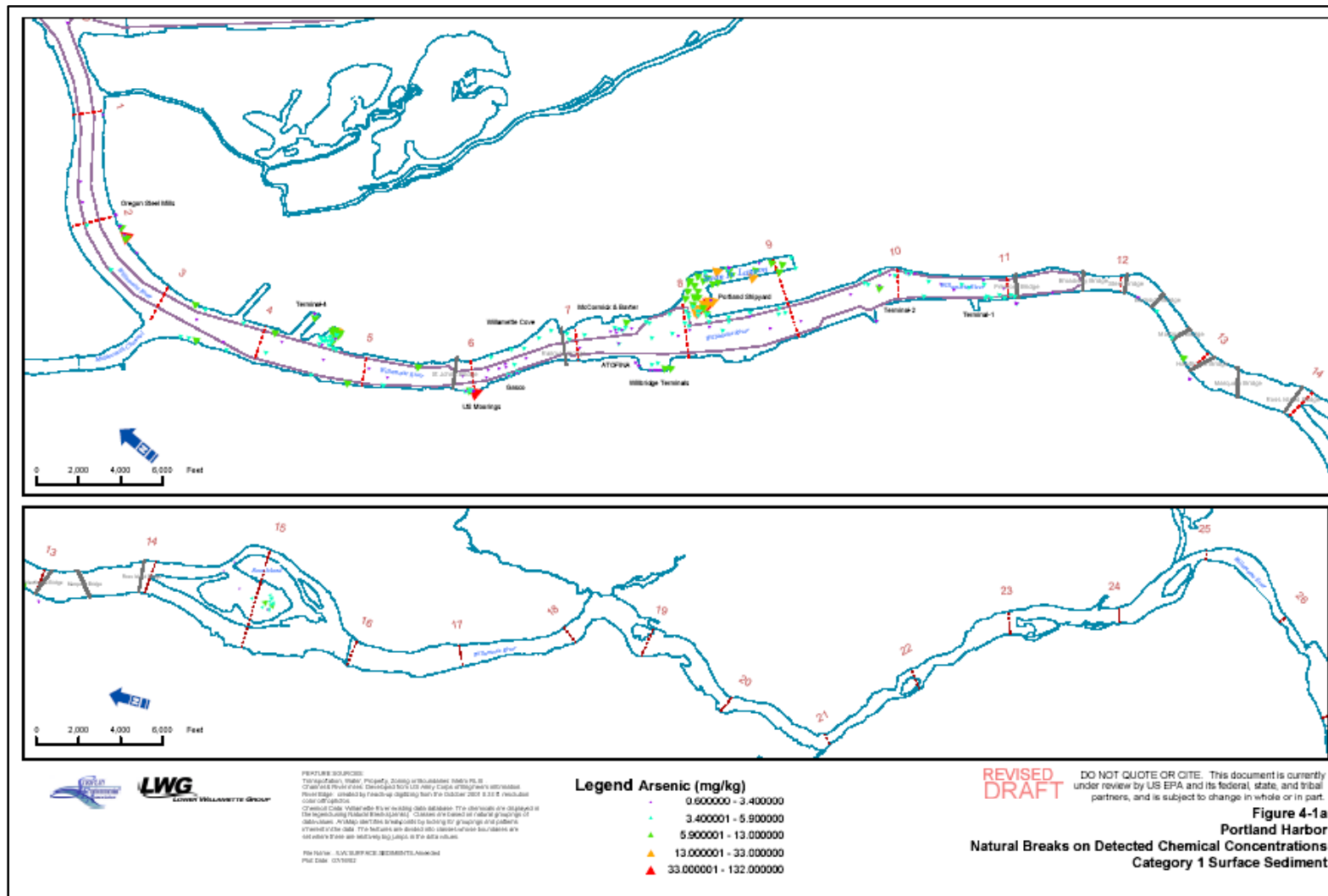
Figure 3-22 Distribution of Arsenic (from SEA, 2002)

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3.8 Density Structure

The Modeling Team contacted Scott Wells of Portland State University (personal communication, January 2003). Dr. Wells and his colleagues had conducted a model study of the Lower Willamette River using the Corps of Engineers' laterally-averaged model, CE-QUAL-W2 (Berger et al., 2001). Dr. Wells confirmed that the waters of the Lower Willamette River are not saline, and also believed in general, that temperature differences play a small role in the overall circulation. He did state that there could be temperature differences between Columbia River water and Willamette River water. However, we do not believe that there are sufficient differences to significantly influence currents in the study area. The modeling of the Lower Willamette River (Berger et al., 2001) considered only horizontal variations in temperature, and did not report vertical variations.

3.9 Meteorology

The two main meteorological parameters for estuarine circulation are wind and heating. Wind shear can cause residual circulation, wind-waves, and influence temperature mixing, and temperature and solar radiation affect heat exchange and the density structure of the water column.

The CE-QUAL-W2 model of the Lower Willamette River developed by Berger et al. (2001) used meteorological data mainly to compute the longitudinal temperature variations for use in chemical reaction processes. While their report does not indicate that wind plays a major role in modifying the circulation, wind forcing was included in the model. In addition, wind-induced circulation and high-frequency surface waves can influence sediment transport, particularly in shallow areas. This is where some of the more significant bed elevation changes were seen in the analysis of bathymetric surveys. Therefore, we intend to include wind shear and wind-waves, using data from Portland Airport (Figure 3-23), in the model of the Lower Willamette River, and conduct a sensitivity analysis to determine its importance.

In the CE-QUAL-W2 model (Berger et al., 2001), the temperatures computed just downstream of the Falls at RM 20, are very similar (within a degree) to temperatures modeled further downstream at the Morrison Street Bridge at RM 12.7 (Figure 3-24). This indicates relatively little change from water temperatures entering from upstream. The model simulated residence times of water in the Lower Willamette River on the order of half a day at high flows to about four days at low summer flows, which is generally short when simulating atmospheric heating and cooling. Water column temperatures can affect sediment dynamics, but generally this influence is small compared to the variability and uncertainty in sediment concentrations. For these reasons, we do not recommend including meteorological heating data in the model.

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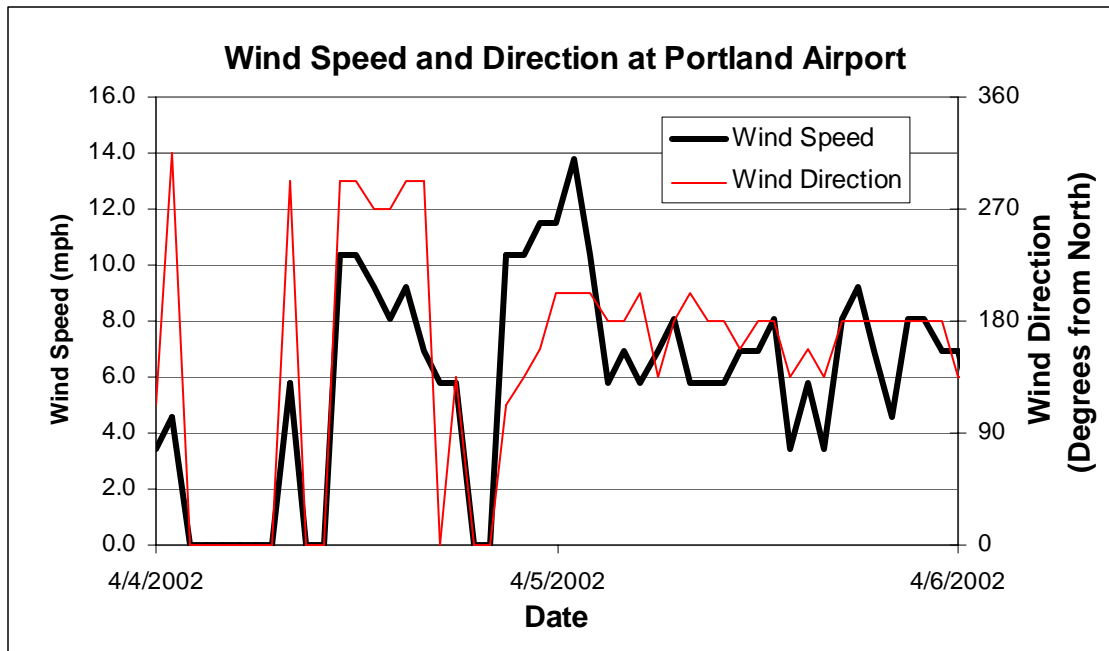
Figure 3-23 Wind Speed and Direction at Portland Airport
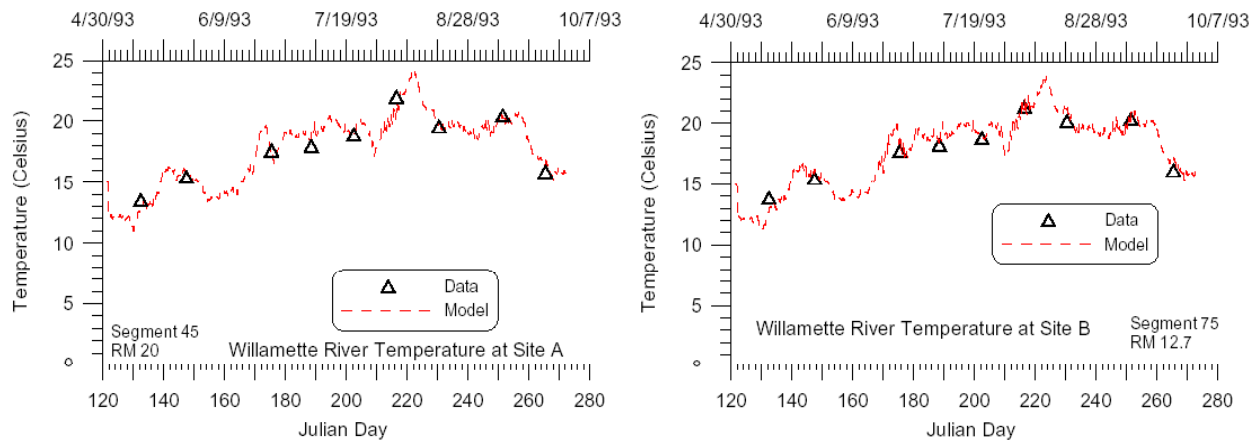
Figure 3-24 Modeled Water Temperatures in Lower Willamette (from Berger et al., 2001)

3.10 Groundwater Discharge

Groundwater discharge to the Lower Willamette River is one part of the overall mass balance of the system. A groundwater model study conducted by the U.S. Geological Survey (Morgan and McFarland, 1997) reported "seepage to the Columbia and Willamette Rivers and other large water bodies (457 ft^3/s)." A second regional groundwater study (Koreny and Fisk, 2001) found similar results.

The lowest measured flow on the Lower Willamette River was 4,200 ft^3/s on July 10, 1978. If all the groundwater discharge were to the Lower Willamette River, this would represent about 11 percent of this extremely low flow. If we consider the portion likely

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to discharge to the Lower Willamette River and more typical summer flows, the groundwater discharge would probably be significantly less than five percent of the total river discharge, and within the error of flow measurements (typically about 10 percent). For this reason, we believe that groundwater discharge plays a small and insignificant role in the hydrodynamics and sediment transport of the Lower Willamette River.

3.11 Major Physical and Spatial Scales

From an analysis of the available data in the study area, it is clear that the important physical processes in the Lower Willamette River are (Table 3-2):

- Tides
- River flows
- Sediment inflows
- Sediment bed dynamics (deposition and erosion), including the dynamics of post dredging

Table 3-2 Summary of Important Processes in Numerical Model

Process	Importance		
	Very	**Maybe**	**Not**
Tides	✓		
River inflows	✓		
Sediment inflows	✓		
Bed sediments	✓		
Density (salinity)			✓
Density (temperature)			✓
Wind		✓	
Groundwater discharge			✓

Tides and river flows operate at scales that influence the circulation of the entire lower Willamette River system below the Willamette Falls. Sediment inflows and sediment bed composition and dynamics must be included to simulate sediment transport in the study area. The data indicate that density (salinity and temperature) and groundwater discharges are not processes that are influence large-scale circulation and sediment transport. Wind dynamics (wind-driven circulation and wind-wave sediment dynamics) are less well quantified. We propose to include these processes because they are relatively simple to include in the model and data are readily available at Portland Airport. We will define their importance through sensitivity analyses.

While the vertical profiles show significant and large vertical variations in current speed, they show no clear influence of processes such as density structure and wind-driven circulation that should be included in the model. In fact, we believe this is "noise" in the measurements. Therefore, we recommend that initially at least, a two-dimensional, depth-averaged model be developed, and the results of this model assessed before

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considering whether a three-dimensional model is needed to simulate sediment transport processes.

We propose to develop a model of the Lower Willamette River extending from the confluence with the Columbia River (RM 0) to the Willamette Falls (RM 26.5), and including the Multnomah Channel to its confluence with the Columbia River near St. Helens. Sensitivity analysis should assess whether the upstream boundary can be moved downstream to the vicinity of Ross Island (about RM 18). The model can simulate a wide range of sediment transport processes. Dredging operations can be simulated by stopping the model just prior to the dredging operation, modifying the bed geometry and sediment types to reflect the dredging operation, and re-starting the model. Currently, the sediment transport models do not simulate the erosion seen from prop wash during tugboat and vessel maneuvering activities. These could be incorporated into a model code if there are sufficient data to quantify the rate of sediment erosion.

Examining the bathymetric change data and distributions of sediment chemistry, leads us to conclude that the model should be able to resolve processes at about 50 m across the river, and about 200 meters along the river. We propose an initial model grid with a resolution of about 50 m across and about 100 m along the river. The model resolution can be coarsened upstream and downstream of the main study area (River Miles 2-11) and along the Multnomah Channel. We believe that the resolution of about 50 m across the river is sufficient to model the variability of geometry and sediments, including the navigation channel and shallow nearshore areas. The resolution could be increased in areas of special significance.

4 MODEL SELECTION

The selection of an appropriate model, and modeling approach, depends on a number of factors including:

- Physical characteristics of the system
- The type and detail of the answer required
- Data availability and quality
- Regulatory and agency perspectives
- Acceptance of the model selected

It is clear from even a cursory evaluation of the system and the problem to be solved that at least a two-dimensional model is needed. We must model the length of the river, and also its breadth to resolve the observed lateral distributions of processes. The need to include vertical resolution over the water column depends on the transport dynamics of the system, which may change during the course of the spring-neap tidal cycle and the annual hydrologic cycle. The study team will assess whether the hydrodynamic and sediment transport model is adequate for the study purposes following initial model calibration.

We decided to consider only non-proprietary models for this application for two reasons. First, we wanted to use a model in common and open use, without licensing restrictions for potential non-model-team reviewers. Second, the model team was selected, in part, because of our experience with various non-proprietary models. Walton et al. (1998) reviewed 13 models and modeling systems to simulate hydrodynamics, sedimentation and contaminant transport and fate in the Elliott Bay/Duwamish River system in Seattle, Washington. Of the non-proprietary models available, there seemed to be three clear candidates. The situation today is very similar. The three models ranked the highest were EFDC, CH3D/ICM and RMA-10/RMA-11 (Table 4-1). Dr. John Hamrick (now with Tetra Tech) developed EFDC. The other models were developed largely with funding from the Corps of Engineers, Engineering research and Development Center (ERDC – formerly the Waterways Experiment Station). ERDC generally is continuing their development and support.

Table 4-1 Comparison of Models

EFDC	CH3D/ICM	RMA10/RMA11
EPA supported	Corps supported	Corps supported
2 or 3-D	2 or 3-D	2 or 3-D
Officially released	Still under development	Still under development
All needed processes	All needed processes	All needed processes
John Hamrick	WES	RMA/WES

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All of these models will simulate the range of processes identified as being important in the Lower Willamette River. However, EFDC offers some additional advantages and the other two models have a significant disadvantage:

- EDFC will simulate multiple sediment class sizes and processes such as bed armoring.
- EDFC is supported by EPA, and has been used to simulate hydrodynamic and sedimentation at Superfund remediation sites. Examples include the Housatonic River (MA) PCB superfund site; and arsenic transport and fate in the Aberjona River (MA). EFDC has also been used to simulate water quality transport and fate for a number of EPA TMDL studies.
- The sediment processes in CH3D and RMA-10/RMA-11 are still somewhat under development, and are not yet generally released.

In addition, EFDC can parameterize and include the effect of increased friction due to small structures (such as pilings), and it has a parametric wave prediction sub-model that can compute the increase in bed shear due to wind-driven waves. This may be important in near-shore areas. EFDC can also simulate wetting and drying cells, so that the lateral extent of large events (for example, the 1996 flood) can be adequately simulated.

The use of a model such as EFDC, which is can be quickly reconfigured from two-dimensional depth-averaged mode to multiple vertical layers, will allow the required vertical resolution to be determined early in the course of the study. For some systems, even the use of two layers in the vertical can result in significant enhancements in the model's performance with marginal impact on run time performance.

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5 MODELING APPROACH

5.1 Model Setup

One of the biggest uncertainties in selecting a modeling approach is whether the system can be adequately simulated using a 2-D model and still achieve the project goals. The Lower Willamette River has relatively weak tides with little or no significant density structure. Therefore, we propose a "two-tier" approach where we first apply EFDC as a 2-D model and evaluate whether this adequately captures site processes and meets study objectives (Phase 1). If it does, we would use the 2-D model(Phase 2A). If it does not, then we would add the vertical dimension, recalibrate the model, and continue (Phase 2B). A recommendation will be made at the end of the first modeling phase in a review meeting with modeling and LWG staff. EPA and its partners will be consulted before a decision is made.

5.1.1 <u>Extent of Model</u>

The Willamette River is tidal to the Willamette Falls, but only sees reversing flows to about RM 18 during low Willamette River flows. The recent WEST Consultants study of the Ross Island reach (WEST, 2002) used a 2-D model extending from RM 11.8 to RM 18. This was found to be a satisfactory upstream boundary to describe sedimentation processes in this region, but for a steady-state, river flow model. As we intend to develop an unsteady model, including tidal and wind forcing, we propose to initially extend the model from the confluence with the Columbia River (RM 0) to the Willamette Falls (RM 26.5).

Currents measured in the vicinity of the confluence of the Willamette River and the Multnomah Channel indicate that the Multnomah Channel should be included in the model.

The remaining question is whether part of the Columbia River (perhaps from Bonneville Dam upstream to St. Helens downstream) should also be modeled. To consider this, the results of the CE-QUAL-W2 model of the Willamette and Columbia River were analyzed for the simulation of 2002. The computed flows were processes to develop cumulative "excursions" (the sum of velocity multiplied by time) to examine the tendency of the flows to be predominantly into or out of the Willamette River and Multnomah Channel. The results (Figure 5-1) show Columbia River water can flow into the Willamette River below the confluence with the Multnomah Channel during summer low flows (days 150-270, or June-September). However, they do not extend beyond the Multnomah Channel, rather the difference in tidal elevation causes even the flood to turn down the Multnomah Channel. Upstream of the confluence with the Multnomah Channel, upstream currents can be found during flood tide, but their duration is very short and excursions limited to only a few hundred meters.
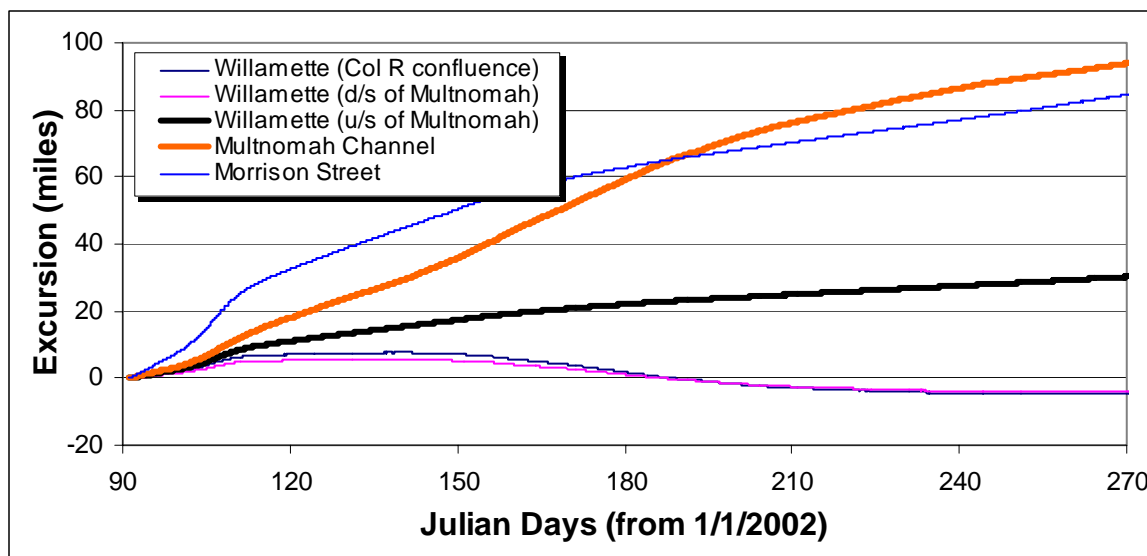
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Figure 5-1 Excursions Calculated from CE-QUAL-W2 Model Results

During high Columbia River flows, the tide is damped out, and even small flows in the Willamette River flow to the Columbia River. And high flows in the Willamette River also generally flow to the Columbia River.

We believe that the confluence with the Columbia River can be used as the downstream boundary for a hydrodynamic and sediment transport model of the Willamette River for the following reasons:

- Columbia River Water generally does not extend above the confluence with the Multnomah Channel.
- Under this condition, sediment transport loads in the system are generally small.
- The GeoSea (2001) study characterizes sediment even in the lowest reaches of the Willamette River as Willamette River sediments.
- Sediment concentrations in the Columbia River are small, as numerous dams reduce upstream loads. There are no tributaries on the Columbia River upstream of the Willamette River that contribute major sediment loads downstream of Bonneville Dam. The major supply to the Columbia River is from the Cowlitz River (derived from Mount St. Helens) located downstream.

5.1.2 **Development of Grid**

The purpose of the numerical model is to simulate hydrodynamics and sediment transport. Bed sediment chemistry data were included in the analysis purely to identify potential remedial scales for capping, dredging and natural recovery processes.

From an analysis of the data, we believe that major processes can be resolved in the RM 2 to 11 reach using a grid that is nominally 50 m across the channel and 100-200 m along the channel. We propose to model the near-bank regions using a lateral

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resolution of 25 m to provide more detail in areas with greater bed elevation changes and greater sediment chemical concentrations. We would coarsen the lateral resolution to about 75 m near the center of the river where more gradual variations are seen.

From Ross Island to the confluence of the Columbia River, it would contain about 2,000 computational cells. We would propose to model the Willamette River upstream of Ross Island using larger (longer) cells, and along the Multnomah Channel using fewer than 100 one-dimensional elements to enable a tidal boundary condition to be imposed at the downstream extent using data from the NOAA gauge at St. Helens.

We will use available overbank topographic data to extend the grid laterally to include the area estimated to be covered during the 100-year flood (nominally the 1996 event). The extended lateral resolution is expected to be 50-100 m, depending on the lateral extent of flooding. The recommended model should be capable of simulating wetting and drying cells.

5.1.3 **Boundary Conditions**

Tidal boundary conditions will be assigned at the confluence of the Willamette and Columbia Rivers, using tidal data from the NOAA Vancouver, Washington, gauge, and at the confluence of the Multnomah Channel and Columbia River, using tidal data from the NOAA St. Helens, Oregon, gauge. River flows will be assigned at the upstream extent of the model using observed flows at the USGS streamflow gauge in Portland.

Sediment inflows will be assigned to the Willamette River using the regression relationships between river flows and sand/fine sediments developed in this report. Observed sediment concentration in the Columbia River will be used to develop a boundary condition at the confluence with the Willamette River to allow inflows during flood tide.

5.1.4 **Model Inputs**

Model data and inputs will include:

- Geometry – the December 2001 bathymetry will be used as an initial condition for model calibration and validation.
- Locations of structures (including docks, piling and bridge supports).
- Initial bed sediments grain size distribution – data from the GeoSea (2001) and SEA surveys will be used to define initial bed distributions of sediments.
- Tide data at downstream boundaries – observed tides at St. Helens (at the downstream end of the Multnomah Channel) and Vancouver (at the confluence with the Columbia River) will be used for model calibration and validation simulations.
- River flows at upstream boundary – the observed daily flows at Portland, the Falls and the Clackamas River will be used to define upstream river flows.

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- Sediment inflows (sands and fines) – will be estimated for the Willamette River as functions of river flows using the regression equations developed for the Ross Island study (WEST, 2002). Observed sediment concentrations in the Columbia River will be used to estimate flood tide loads at the downstream boundary. Sediment loads at the downstream end of the Multnomah Channel are not important, as the excursion distance upstream in the channel is very small.
- Wind speed and direction will be assumed to be uniform over the modeled area.

5.2 Model Sensitivity

Model sensitivity is a process of determining the major variable and coefficient influences on model results. It can be performed either before model calibration and validation, to determine which processes and coefficients most affect the results, or afterwards, to determine how much the model results could change. Generally, we recommend that the sensitivity analyses be performed prior to model calibration to determine which processes and parameters most affect model calibration.

In the data analyses, several issues were left unresolved. A major purpose of the sensitivity analyses is to consider and resolve these issues. In the model study, we would perform "linear" sensitivity analyses, in which we propose to vary one parameter or variable at a time (and not look at the complex interaction between variables). The sensitivity analysis will include all key parameters and variables, and specifically address the following:

- Effect of including wind shear and wind waves.
- Determine what combination of river flows and tides most influence sediment deposition and erosion. This will include:
  - ➤ Low flows in the Willamette and Columbia Rivers,
  - ➤ High flows in the Willamette River and low flows in the Columbia River, and
  - ➤ Low flows in the Willamette River and high flows in the Columbia River.
- Influence of sediment inflows from the Columbia River.

In each case, we would compare the results to a "base" case in which all the processes are included. The final simulation would compare the base case with a case in which all the "insensitive" processes were not modeled. This comparison would determine the configuration of the model to be calibrated.

5.3 Model Calibration and Validation

"Calibration" is the process of adjusting model coefficients, using reasonable values, to best match a set of observations. "Validation" is the process of comparing model results with a second, preferably much different, set of observations without further adjustment of model coefficients. The intent of model calibration and validation is to demonstrate that the model can simulate the range of site conditions anticipated for the

study objectives. In practice, it is often necessary to re-calibrate the model following model validations to better fit the model to both sets of observations. The structures present in the Lower Willamette River will be included by either adjusting the grid element description for very large structures that block flow, or adjusting the bottom friction to include the added resistance ("drag") of smaller structures such as pilings.

We propose to calibrate the model to the period December 2001 to September 2002, to include the changes between the first two bathymetric surveys. Calibration measures would include:

- Comparison of computed water surface elevations with observations at the USGS streamflow gauge near the Morrison Street Bridge.
- Comparisons with the magnitude and distribution of the vertically-integrated results of the ADCP data collected April 19, 2002 (DEA, 2002b).
- Comparison between the computed bed elevations and surveyed data during the summer of 2002.
- A comparison between the modeled and observed bathymetric changes.

Calibration measures will include qualitative comparison of distributions; tabulated statistics (mean error, mean absolute error, RMS, etc.); and frequency distributions of the bed elevations and their changes (see Figure 3-3, for example). Rather that define strict quantitative limits for model statistics (which are always difficult to estimate beforehand because of the uncertainties in the model data), we propose that the statistics of the calibrated model be used to assess whether the model is sufficiently accurate for the study purposes. Grossly, we would hope that both the final calibrated and validated model would simulate water surface elevations within 0.5 feet, velocities within 0.25 feet/second, and bed elevations within one foot.

Another bathymetric survey was conducted in May 2003 and currents and bathymetry are being surveyed during a large flow (about 140,000 cfs) in February 2004. We propose to validate the model over the period summer 2002 to February 2004, and make the same comparisons as for the model validation. We understand that additional ADCP data were collected in this time frame. We would include them in the model validation.

5.4 Approach to Model Application

There are two possible ways to simulate future conditions in the Lower Willamette River. The first is to perform simulations based on a long historical record or repeating a shorter historical record (perhaps one year). The second method is to use a "piecewise event" approach.

For the Duwamish River/Elliott Bay system, EFDC was run continuously for 10-year simulation periods by repeating one year of observations ten times. While this has the

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merit of looking like "real" conditions, future conditions will not repeat in the same historical manner, and we rarely see successive years of such similar hydrology and meteorology. In addition, there is uncertainty is some model inputs and overall system variability. Figure 3-14 showed the relationship between flows and sediment concentrations developed for the Ross Island study (WEST, 2002). However, closer examination of the data for 1964 shows that there is not a "one-to-one" relationship (Figure 5-2).
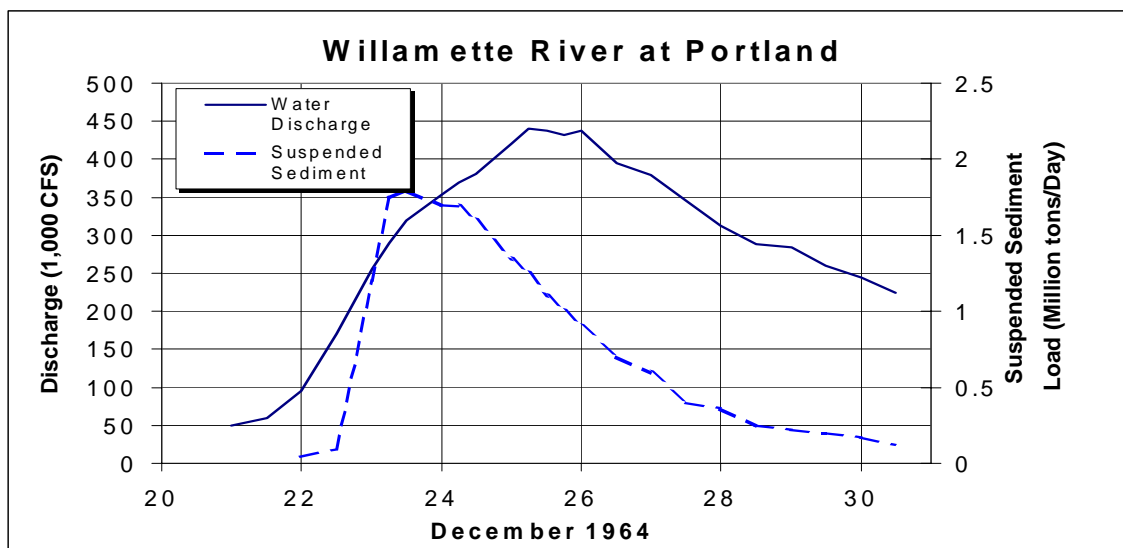

Figure 5-2 Flow and Sediment Hydrographs at Ross Island

A second approach is to use a "piecewise event" approach. The Ross Island study (WEST, 2002), for example, divided the flow-duration curve into intervals, simulated each flow, and then estimated total deposition and erosion as an integration of the results over the frequency-duration curve (Figure 5-3). This study used a steady-state model and steady flows.

We propose to use a variation of this second approach. We would divide the Willamette River hydrograph into a low-flow period, and a series of "characteristic" high-flow events, including typical annual floods, less frequent larger floods, and the major flood of February 1996. During low flow, we expect relatively small sediment loads in the Willamette River and that larger materials will be quickly deposited below the Willamette Falls as the river velocities slow down. During river flood events, we expect significantly more sediment in the river, and that these events will cause a redistribution of sediment in the system as sediment is scoured upstream and moved downstream, and the larger sediments now in the river flow are also deposited.
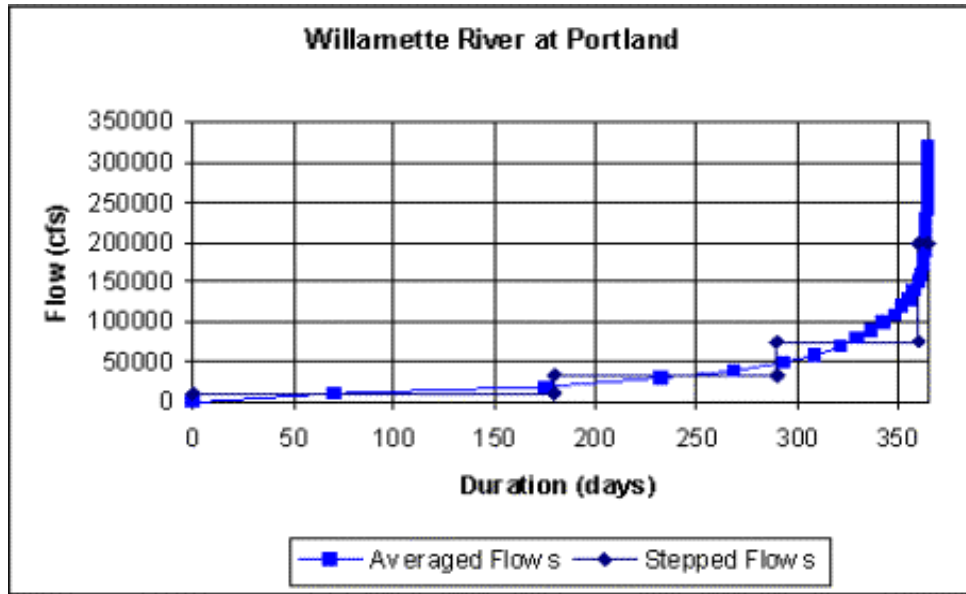
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Figure 5-3 Piecewise Flow Distribution

We would validate the approach by performing a continuous simulation of the Willamette River for the calibration and validation period. We will then simulate the "piecewise" events, and superimpose the results of simulations that characterized this period, and compare with the results of the continuous simulation.

Once the "piecewise event" approach has been validated, the observed flow record can be analyzed to identify sequences of events that have occurred historically or plausible future sequences, and superimpose the solutions to obtain a number of synthetic sediment transport regimes. The results from these regimes, developed for with and without various remedial alternatives, can be used to assess the performance of various alternatives for a wide range of possible flow conditions.

This approach has the advantage of being more efficient, and we believe it is consistent with the accuracy and availability of data, particularly sediment and contaminant inflow concentrations. If successful, we would use this approach to simulate general sediment transport conditions for various project conditions, including the simulation of remedial alternatives. We would also assess these alternatives for major flood events, such as the 1996 flood, which was approximately the 100-year event.

5.5 Model Results

The following types of results would be available from the application of the calibrated EFDC model to the Lower Willamette River:

- "Snap shots" or time histories of water surface elevations and current velocities.

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- "Snap shots" or time histories of the horizontal distributions of water surface elevations and current velocities.
- "Snap shots" or time histories of water column sediment concentrations.
- "Snap shots" of time histories of bed sediment concentrations.
- "Snap shots" or time histories of the horizontal distributions of water column sediment concentrations.
- "Snap shots" or time histories of the horizontal distributions of bed sediment concentrations.
- Horizontal distributions of cumulative and net sediment deposition and erosion.

These types of results, and others requested by the study team members, will be available to understand the existing processes of sediment transport in the Lower Willamette River, and to evaluate both the potential effect of sediment movement on risk estimates and the potential short and long-term effectiveness of a range of physical cleanup strategies.

5.6 Documentation

The model report will include sections describing the development of the grid, preparation of input data, model calibration and validation, and the model outputs. The report will also present information from the sensitivity analyses and will include an uncertainty analysis, to evaluate the sensitivity of model parameters and processes to change and to consider whether the results are reliable within the range of anticipated variability. The uncertainty analysis will encompass potential errors in the model structure and model assumptions; parameter variability and parameterization errors, measurement errors, aggregation errors, and other areas of uncertainty discovered during the modeling process.

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6 DESCRIPTION OF EFDC MODEL

The EFDC (Environmental Fluid Dynamic Code) model is a public domain, multifunctional surface water modeling system, which includes hydrodynamic, sediment-contaminant, and eutrophication components. The EFDC model was originally developed at the Virginia Institute of Marine Science, by Dr. John Hamrick, and is currently maintained by Tetra Tech, Inc. with support from the US EPA. EFDC has been used for more than 80 modeling studies of rivers, lakes, estuaries, coastal regions and wetlands in the U.S. and abroad. The EFDC model is capable of 1, 2, and 3-D spatial resolution. The model uses a curvilinear-orthogonal horizontal grid, and a sigma or terrain following vertical grid. For 1-D applications, an optional "HEC" type cross-section description can be used. Two horizontal grid generation and preprocessing tools, GEFDC (GridEFDC) and VOGG (Visual Orthogonal Grid Generator), both having GIS based interfaces are available.

The EFDC model's hydrodynamic component uses a semi-implicit, conservative finite volume-finite difference solution scheme for the hydrostatic primitive equations with either two or three-level time stepping (Hamrick, 1992; Hamrick and Wu, 1997). The semi-implicit scheme is based on external mode splitting, with the external mode being implicit with respect to the water surface elevation and the internal mode being implicit with respect to vertical turbulent momentum diffusion. Advective and Coriolis-curvature accelerations in both the external and internal modes are represented by explicit conservative formulations. Salinity and temperature transport are simultaneously solved with the hydrodynamics and dynamically coupled through an equation of state. The hydrodynamic component includes two additional scalar transported variables, a reactive variable which can be used to represent dye or pathogenic organisms, and a shell fish larvae variable which includes a number vertical swimming behavior options. Scalar transport options include a number of high accuracy advection schemes including flux corrected MPDATA and flux limited COSMIC. Additional hydrodynamic component features include, the Mellor-Yamada turbulence closure formulation, simulation of drying and wetting, representation of hydraulic control structures, vegetation resistance, wave-current boundary layers and wave induced currents, and dynamic time stepping. An embedded single port buoyant jet module is included for coupled near and far field mixing analysis.

The EFDC model's sediment transport component is capable of simulating the transport of multiple size classes of cohesive and non-cohesive sediment (Tetra Tech, 2002). A sediment processes function library allows the model user to choose from a wide range of currently accepted parameterizations for settling, deposition, resuspension and bed load transport. The sediment bed is represented by multiple layers and includes a number of armoring representations for non-cohesive sediment and a mixed bed material finite strain consolidation formulation for dynamic prediction of bed layer thickness, void ratio and pore water advection. The sediment transport component can operate in a morphological mode, with full coupling between the hydrodynamic

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component, to represent dynamic evolution of bed topography. The EFDC model's toxic contaminant transport and fate model can represent the transport and fate of an arbitrary number of contaminants, including metals and hydrophobic organics, sorbed to any of the sediment classes and dissolved and particulate organic carbon using a three-phase equilibrium partitioning formulation (Tetra Tech, 2002). Dissolved and particulate organic carbon (POC) can be represented as independent state variables (either externally specified or provided by the internal nutrient cycling model) or POC can be fractionally assigned to any of the sediment classes. Water column-bed exchange processes particulate deposition and resuspension, pore water entrainment and pore water advection and diffusion. Bed processes include pore water advection and diffusion and the ability to introduce groundwater contaminant sources at the bottom of the model resolved sediment bed. A contaminant processes function library allows the representation of various degradation and transformation processes.

The EFDC model is widely accepted for management and permitting studies. EFDC has been used in developing Comprehensive Resource Management Plans (CRMP) for three National Estuary Programs; Peconic Bays, NY, Morro Bay, CA, and Mobile Bay Alabama. Total Maximum Daily Load (TMDL) applications include; Charles River, MA, Christina River Basin, MD, Neuse River, NC, Brunswick Harbor, GA, Fenholloway River, FL, St Johns River, FL, Flint Creek, AL, Yazoo River Basin, MS, Arroyo Colorado, TX, Tenkiller Lake, OK, Los Angeles River, CA, South Puget Sound, WA, and Ward Cove, AK. National Point Discharge Elimination (NPDES) permitting applications include Norwalk Harbor, CN, Potomac River, VA, and Cape Fear River, NC. EFDC is currently being applied to several contaminated sediment Super Fund sites; Aberjorna River, MA, and the Housatonic River, MA, and it was previous applied to the Elliott Bay/Duwamish River system in Seattle, WA. The model has been extensively peer reviewed as evidenced by 12 peer reviewed journal articles and 17 peer reviewed conference proceedings articles. The EFDC application to the Housatonic River Super Fund (http://www.epa.gov/region01/ge/thesite/restofriver.html) is being extensively peer reviewed. The application to the Seattle site is important because many of the same modeling team members were involved. The EFDC model was developed at Seattle to simulate the hydrodynamics, sediment transport, and contaminant transport and fate from various combined sewer outfalls and storm drains. The model was the key to the risk assessment by providing information about the concentrations and distributions of contaminants in the water column and sediments resulting for various control strategies.

The EFDC modeling system includes a number of auxiliary tools in addition to the previously referenced grid generation tools. Two Windows based pre- and post-processing tools, EFDC VIEW and EFDC EXPLORER, are publicly available. The EFDC VIEW Tool will be integrated into the US EPA Region 4 TMDL Tool Box. The TMDL Toolbox includes various model interfaces and inter-model communication tools such as watershed to receiving water model linkages, model input and output database management, and graphical and statistical post-processing. A number of currently available post-processing tools support various scientific visualization packages such as MATLAB, IDL, TECPLOT and GRADS.

The EFDC model source code was originally developed in FORTRAN 77 and is currently FORTRAN90/95 compliant. The code is continuously maintained to be compatible with FROTRAN90/95 compilers from commercial vendors including Absoft, Compaq (Visual FORTRAN), Intel, Lahey-Fujitsu, and the Portland Group. The code is highly optimized (Hamrick and Wu, 1997) and structured for automatic vectorization and parallelization by compilers such as Intel FORTRAN Version 7, which support these capabilities. The EFDC model has always supported execution on desktop WINTEL PC's beginning with 15Mhz systems of the late 1980's. The recommend current minimum configuration includes, Intel P3 or P4, AMD Athalon, or Power MAC based processors at 1 Ghz or faster, with a minimum of 256 Mb RAM. A robust operating system such as Windows 2000 Professional, Red Hat Linux or MAC OSX is also recommended. For large applications requiring high performance, the combination of Windows 2000, an Intel P4 or Xeon processor at 2 GHz or faster, 512 Mb RAM and Intel FORTRAN Version 7.0 is recommended for single processor or cluster configurations. For parallel SMP execution of the model, dual or quad processor Intel Xeon based systems are recommended. For information on obtaining EFDC and supporting documentation and auxiliary software tools, and current hardware recommendations, please contact John Hamrick at 703-385-6000 or hamrijo@tetratech-ffx.com.

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