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LOWER WILLAMETTE GROUP

INTEGRATION OF SEDIMENT TREND ANALYSIS (STA®) SURVEY RESULTS WITH HISTORIC BATHYMETRY IN THE LOWER WILLAMETTE RIVER

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1.0 INTRODUCTION

1.1 OVERVIEW OF THE INTEGRATION REPORT

This report presents an integration of the results of an historic bathymetry analysis of Portland Harbor prepared by Parsons Brinckerhoff (Parsons Brinckerhoff 2001) with a Sediment Trend Analysis (STA®) of the lower Willamette River prepared by GeoSea® Consulting Limited (GeoSea 2000). The report is a required deliverable under the Stipulated Agreement for Portland Harbor which was incorporated by reference into the Administrative Order on Consent for the Portland Harbor CERCLA Site.

Understanding the physical dynamics of Portland Harbor is a fundamental step in the overall remedial investigation/feasibility (RI/FS) process. The goal of integrating the historical bathymetry evaluation prepared by Parsons Brinckerhoff (Appendix A) with the STA® prepared by GeoSea (Appendix B) is to begin to understand sediment transport in the Lower Willamette River (Figure 1). These two data sets are not considered to be definitive but rather establish a starting point for the understanding of sediment transport. This information will be made part of the physical conceptual site model for the site, and will lead to the identification of RI/FS data gaps that can be addressed during subsequent phases of the RI/FS.

In September 2000, GeoSea® conducted field sampling for the STA® in the lower Willamette River. A total of 836 surface sediment samples were collected from stations located between River Mile (RM) 0 at the river's confluence with the Columbia River and RM 26.5 at Willamette Falls. The resulting grain size distributions were compared, using a proprietary statistical model, from sample location to sample location to deduce patterns of net sediment transport along the riverbed. Their report describes the character of the river bottom sediment at each sample location, and the results of the STA® modeling process.

An historical analysis of navigation channel bathymetry from RM 0 to RM 11.7 was prepared by Parsons Brinckerhoff (2001) to begin to understand sedimentation and erosion patterns in the lower Willamette River. Their analysis used United States Army Corps of Engineers (USACE) bathymetric survey data collected from 1983-2001, hydrology data obtained from the USGS and USACE, and dredging activity during that time period. The integration of the STA® analysis with the bathymetric data provided in this report will concentrate on the length of the Willamette in the Initial Study Area (ISA) from RM 3.5 to RM 9.2.

1.2 HYDROLOGICAL REVIEW OF THE LOWER WILLAMETTE RIVER

The physical setting of the Willamette River and its basin are detailed in Rickert et al. (1977), Wentz et al. (1998), and Uhrich and Wentz (1999). In the area of interest, the Willamette River flows predominantly north/northwest before turning to the northeast at RM 3. The channel cuts through Pleistocene Missoula Flood deposits varying in grain size from coarse- to fine-grained, and Miocene Columbia River Basalt (CRB) flows. Geologic processes have restricted the migration of the river channel from RM 8 to RM 11.7 where the river flows through the center of a down-dropped, fault-bounded graben block. The channel is also largely restricted to the southwest by cliff-forming CRB flows.

The majority of the channelization of the lower Willamette was performed since the arrival of non-Native Americans. These settlers in the region made the channel narrower, deeper, and straighter (Tetra Tech 1995). Subsequent development of Portland Harbor has widened the river resulting in an overall decrease in water velocity and stabilization of the channel. Channel stabilization has also occurred due to the construction of shoreline bulkheads, riprap and armoring.

Water flow downstream in the Willamette is influenced in several important ways as it reaches its confluence with the Columbia. Although the change in relief in the lower Willamette is largely insignificant, very significant changes in river stage occur in response to both natural conditions (e.g., snowmelt, dry summers, wet winters) and associated regulation of dams on both the Willamette and Columbia Rivers. Additionally, the lower Willamette from RM 0 to RM 26.5 is defined in Rickert et al. (1977) as the Tidal Reach. This portion of the river is affected twice daily by tides, which can cause flow reversals when water levels are low.

2.0 BATHYMETRY REVIEW

An analysis of historic bathymetric records from the navigation channel in Portland Harbor from RM 0 to RM 11.7 was performed in early 2001 by Parsons Brinckerhoff. Hydrographic difference contour plots of the navigation channel utilizing data obtained from the USACE for the period 1990 through 2001were produced initially. Subsequently, difference contour plots were made to incorporate survey data from 1982 to 1989. This summary report focuses on the changes over the last decade; changes in the 1980s were strongly affected by dredging projects.

Hydrographic difference contour plots illustrate the change in depth between each survey. Although this analysis imparts some error (discussed in Section 2.2), it is a useful way to look at the gross change in bathymetry over time. As the time interval between successive surveys varied, the amount of change noted in the difference contour plots does not reflect change over a consistent period of time.

The bathymetry review showed that the river bottom is generally stable to depositional in areas, but has shown some areas of erosion in the last decade, as discussed below. The synoptic data show that large changes in water depth can occur over short period of time. This result indicates that the bottom depth is susceptible to episodic hydrologic events.

2.1 RIVER BOTTOM TOPOGRAPHY

The most recent USACE bathymetric survey was conducted in May of 2001. The USACE bathymetric contours were classified by 10 ft contour intervals (Figure 2). The data are concentrated in the navigational channel because the purpose of data collected was to evaluate the need for dredging in the channel. The data show that depths generally range from 40 to 50 feet (green contours) throughout much of the ISA. There is a large borrow pit area between RM 4 and 5 with maximum depths of approximately 80 feet. In addition, there are several areas where depths reach to 60 feet (blue areas), especially between RM 7 and 8. Outside of the ISA there is another borrow pit area between RM 9 and 10.

River bottom topography reflects both natural and man-made phenomena. Some areas, such as along the downtown seawall and at Post Office Bar (Figure 1), are natural shoaling areas that must be dredged periodically to maintain navigable depths. Other areas, such as the basin off Swan Island, reflect extensive historical dredging (Figure 1). Last, bridge supports result in localized water current perturbations that may result in scour (e.g., near RM 6).

Alternatively, some topographically high areas along the riverbed may be explained by variations in the bedrock beneath the river sediment. For instance, segments of the Columbia River Basalt Group may be exposed within the

Willamette channel. This rock is significantly more resistant to both physical and chemical weathering than other material exposed in the region. Consequently, any basalt exposed within the river channel would likely form topographic high spots. Within the ISA, there were few grain size samples collected that indicated hard ground (grab failure), so exposure of basalt in this area is unlikely.

2.1.1 Effects of Dredging on River Bottom Topography

Navigational channel dredging records for the period 1982-2001 were obtained from the USACE and compiled by Parsons Brinckerhoff (Appendix A, Table 1). Dredging in the lower Willamette navigation channel over the last two decades has primarily been conducted to maintain the authorized channel depth of 40 feet, and has been concentrated in the reach from RM 8 to RM 10 where the river naturally shoals (Figure 3). USACE maintenance dredging volumes from 1982-2001 are provided in Table 1. Private dredging in the last two decades, some of which has been done to obtain fill for upland development rather than as maintenance projects, is not volumetrically significant compared with channel maintenance dredging (Parsons Brinckerhoff 2001). Evaluation of Port of Portland surveys for some berthing areas, however, shows significant changes in sediment elevations over time resulting in the need for periodic maintenance dredging. Differences in depths obviously due to dredging and subsequent fill will be noted where appropriate.

2.2 BATHYMETRIC DIFFERENCE CONTOUR PLOTS

Bathymetric difference contour plots were created by comparing two different surveys over the same areas, and subtracting one from the other (Figures 4 through 7). These plots are intended to spatially illustrate the change in elevation between two USACE hydrographic surveys. In all depth difference graphics shown in this report, positive values, indicating net deposition, are shown in shades of red, and negative values, indicating net erosion, are shown in shades of blue (Figures 4 through 7). Some of the scour and depositional contours are due to dredging/filling activity, especially in the area between RM 8 and 10 (Figures 4 and 6). In the ISA, dredging has been limited in the last ten years, so the depositional and erosional patterns noted in these data are most likely not related to dredging (Figure 4).

2.2.1 Error of the Bathymetric Difference Contour Plots

The error in a single USACE bathymetric survey for recent surveys is generally quite small because of improvements in horizontal positioning systems. This error will increase with older data sets; in addition, the surveys from 2000 were considered to have low accuracy, and are therefore not discussed here (Parsons

Brinckerhoff 2001). Because each dataset will contain some error (for more recent surveys, commonly less than one foot), comparisons of two data sets will increase that error because of data processing. For single beam bathymetry, individual depth measurements are collected. In order for two surveys to be compared, the data must be gridded; this process breaks up the survey area into small cells, and an average depth is calculated from all of the measurements taken in that cell. For the purposes of this report, a minimum threshold of ± 4 feet was selected as indicative of a real elevation change, depth changes less than 4 feet were considered to be within the noise associated with data collection and processing.

The error in the difference plots will be greatest in areas of rapidly changing slope. An average depth in a grid cell over a sloping area can be quite different depending on where the boat was over the slope when collecting depth information. For example, if hydrographic survey points are at different locations along a steep slope, the average depth from one survey will be different than the that of the other, although no sedimentation or scour actually occurred. Therefore, large depth changes on a slope were interpreted with caution.

2.2.2 Erosional and Depositional Trends in the ISA

Because the length of time between surveys was variable, some of the plots showed patterns that may be attributed to short term, perhaps seasonal, variations. These patterns can be significant, however, because any net change (either positive or negative) shown over a relatively short time period may not be revealed in a long-term comparison. The ten-year difference plots are highlighted to most effectively reveal long-term sedimentation/scour patterns.

Two long-term depth difference data sets are highlighted in this discussion: the depth difference between 1990 and 2001, and between 1990 and 1999. Both data sets show similar depositional and erosional trends on a decade scale. The difference between them highlights the variability on a smaller scale (e.g., changes to the river between 1999 and 2001). The reason for reviewing the more recent data is because dredging in the 1980s was more extensive and tends to obscure natural processes in the river. The figures shown and discussed below are concentrated in the lower ISA (RM 3.5 to 6) and upper ISA (RM 6 to 9.2). Finally, in order to highlight depth differences of greater than four feet (or less than negative four feet), the contour lines from – 4 to + 4 feet were given a white color so they would not obscure the major trends.

The depth difference between 1990 and 1999 in the lower ISA area shows a pattern of overall stability, with some accretion along the right bank (east side), and erosion along the left bank (west side; Figure 4). These data are presented as contour lines ranging from –4 to 4 ft. The bathymetry data are consistent with the hydrological pattern; that is, the outside curve of the river (left bank) may be an area of erosion in the long term, while the inside curve would tend to accrete. The contoured data suggest that most of the accretion was less than ten feet except in the dredging area (attributable to fill of a previously dredged area), and a small but dramatic area of accretion near RM 5. This area is consistent with the 1990-2001 depth difference (Figure 7), and overlaps with the southern end of the borrow pit area, as discussed further below.

The depth difference between 1990 and 1999 in the upper ISA also shows a pattern of overall stability (Figure 4), with no discrete pattern of accretion or sedimentation. Some of the apparent changes in depth are associated with slopes, although it appears that there has been sedimentation in some of the channel depressions. It is likely that some of the patches of erosion are due to the presence of the railroad bridge abutments at RM 6.8 (Figure 5).

A small depression of approximately 52 feet located just upstream from RM 7 was plotted by combining the depth difference with the most recent bathymetry (Figure 5). This small depression is associated with a positive depth difference of up to five feet, consistent with a model of more rapid sedimentation in the lower elevations of the channel. Although the data indicate thicker accumulations (up to ten feet) along the slopes of this depression, some of this change may be error associated with slopes, as discussed above. Assuming a maximum of five feet of additional sediment deposited between the two surveys (nine years), this equates to a sedimentation rate of approximately 6.7 in/year.

A large flood event occurred in the Willamette River in February 1996. Significant deposition occurred with this flood as the Columbia River stage was also high resulting in low water velocities in the Willamette and subsequent deposition of the sediment load. As discussed below, the changes in sediment volume calculated over the period April 1995 to August 1996 demonstrate anomalously large positive changes in sediment volumes for most river reaches during the time period encompassing the flood. Therefore it is useful to evaluate the depth difference after the flood event (1997 to 2001; Figure 6); this data show small areas of net deposition and erosion, but the majority of the ISA shows no change in depth over the last four years greater than four feet.

The depth difference between 1990 and 2001 was processed from the data directly into a grid file (rather than a contour file), which tends to filter more of the noise out of the data. This data set is consistent with deposition in the deepest areas of the river as demonstrated by assessing sedimentation in the borrow pits of the lower Willamette. The pattern of deposition in the borrow pit near RM 5 indicates that sediment is being deposited by bedload transport, that is, by sediment moving along the bottom from upstream to downstream, and being deposited on the upstream slopes of localized depressions (Figure 7). Although the large depth difference on the southern extent of the borrow pit probably is a function of error associated with the depth difference, the comparison does suggest that up to ten feet of sedimentation has occurred in the relatively flat floor of the pit, equating to a sedimentation rate of approximately one ft/year.

2.3 CHANGES IN SEDIMENT VOLUMES

The Parsons Brinckerhoff report presents relative changes in sediment volumes by river mile over 13 time periods (Table 2). Their calculations are averages, by river mile, of the change in volume between two successive bathymetric surveys. Positive changes indicate net deposition whereas negative changes indicate net erosion.

Large positive changes in volume were observed from RM 8 to RM 10 in the years following dredging events (Table 2). The volume of dredged material removed was accounted for by Parsons Brinckerhoff (2001) in the volume calculations in the years the dredging occurred thereby eliminating an artificially negative net change in volume.

A large flood event occurred in the Willamette River in February 1996. The effect of this flood on river discharge can be seen on the hydrology graph presented in the Parsons Brinckerhoff report (2001) (Appendix A, Figure 7). Changes in sediment volume calculated over the period April 1995 to August 1996 demonstrate large positive changes in sediment volumes for most river reaches during the time period encompassing the flood (Table 2).

2.4 BATHYMETRY REPORT OVERVIEW

Although there are regions in the Willamette that have experienced net erosion over the period August 1990 to May 2001, the overall pattern in the Willamette throughout the study area is one of either net deposition or equilibrium (defined here as elevation changes of less than 4 feet). Deposition of greater than four feet is concentrated in bathymetric depressions, commonly the result of dredging (e.g., borrow pits) (Figures 4 through 7). Sedimentation rates in these pits are on the order of one half to one ft/year. Because of the uncertainty of the depth difference comparisons, it is not possible to evaluate patterns of deposition or erosion of less than four feet.

The areas of net scour can be interpreted in the overall context of stream dynamics. Many of these areas coincide with changes in topography along the riverbed as previously discussed. Some areas of net scour may be accounted for in the context of localized changes in water velocity associated, for example, with narrowing and/or turning of the river channel. For instance, a pattern of erosion along the west bank can be seen in the Willamette beginning at about RM 6 along the outside of the channel as it turns to the north (Figure 4). A theoretical increase in water velocity would occur along the outside of a river bend, resulting in a pattern of scour.

3.0 STA® REVIEW

In September 2000, GeoSea® Consulting Ltd. completed a Sediment Trend Analysis (STA) in the lower Willamette River (Appendix B). For this study, a total of 836 grab samples were collected from RM 0 at the confluence with the Columbia (and for one mile in either direction within the Columbia) to Willamette Falls (RM 26.5). Grain size analyses were conducted on a cross section of the grab in order to characterize the sediment at each sample location. Based on these analyses, sediment in the region was classified based on percent gravel, percent sand, and percent mud (silt and clay). Where sediment could not be collected after three unsuccessful casts of the grab, the sample location was characterized as "hard ground". Anything that prevented the jaws of the grab from closing (e.g., cobbles, wood debris, bedrock) would lead to the characterization of a sample location as "hard ground." The results of the grain size analyses were then used to model sediment transport paths within the Willamette.

3.1 GRAIN SIZE ANALYSES

Grain size analyses of sediment collected in the lower Willamette and Columbia reveal a distinctive distribution pattern of bottom sediment in the region. Coarser-grained sediments from sandy gravel to sand dominate the bottom sediments in the upper reaches of the lower Willamette from RM 26.5 to about RM 11. These coarser-grained assemblages grade into finer-grained muddy sand, sandy mud, and mud from RM 11 to nearly RM 0 (Figure 8).

Several important factors influence the distribution of sediment in the lower Willamette, including: type of sediment present, fluid dynamics (e.g., river discharge, water velocity), channel characteristics (e.g., channel depth and width, channel shape), river bottom topography, Columbia River backwater effects, tidal influences, and man-made effects. It is likely that some of these factors are locally more important than others, but overall a combination of each probably contributes to the distribution of sediment within any given reach of the river in the region.

Generally, the distribution of a volume of sediment having mixed grain sizes should show a pattern that becomes finer downstream. This pattern is roughly evident in the lower Willamette. There are, however, exceptions from this pattern that bear discussion. Most occurrences of very fine-grained sediment (mud) in the lower Willamette appear in lagoon-type settings where water flow is minimal. Very fine-grained sediments in a fluvial setting are predominantly transported in suspension and tend to settle out where water velocity decreases to a point where the sediment can no longer be held in suspension. In the lower Willamette very fine-grained, muddy sediment is present in primarily three locations where water flow is minimal: the basin between Ross Island and Hardtack Island (RM 15), Swan Island basin (RM 6-7), and Terminal 4 in the Port of Portland (between RM 4 and RM 5; Figure 8). The initial appearance of finer-grained material (muddy sand and sandy mud) at approximately RM 11 may be explained by a widening of the channel in this region along with a concurrent reduction in water velocity that allows for sediment deposition (Figure 13, Hill and McLaren, 2001).

There is a collection of coarser-grained sediment, largely sand, between RM 5.5 and RM 7 (Figure 8). This area is anomalous because it is surrounded by finer-grained muddy sand and sandy mud. Between RM 6 and RM 7, the Willamette intersects coarse-grained Missoula Flood deposits. These deposits may be a source of sand to that portion of the river, whereas much of the finer-grained sediment in the channel is being transported from further upstream.

Coarser-grained sediments are evident at about RM 1 as the Willamette approaches its confluence with the Columbia (Figures 15 and 17, Hill and McLaren, 2001). The reappearance of coarser-grained sand at the downstream end of a reach predominated by finer-grained muddy sand and sandy mud can probably be attributed to tidal influences causing the backing up of water from the Columbia into the Willamette, carrying coarser-grained Columbia-transported sediments into the area.

3.2 SEDIMENT TREND ANALYSIS

Sediment trend paths in the lower Willamette were derived from patterns of sediment types along the riverbed by GeoSea® Consulting Ltd. using proprietary statistical analysis software. A complete description of the mathematical procedure used to determine these transport paths is included in the STA® report (Hill and McLaren, 2001). In summary, sediment at each sample location was compared to sediment at each neighboring sample location in order to characterize the sediment transport regime along the riverbed. This statistical analytical approach to the representation of river bottom sediment activity provides a unique insight into river sediment dynamics in general.

In summary, trends in sediment transport are displayed as transport vectors. Transport vectors represent one of six possible transport behaviors, only five of which are present in the lower Willamette STA® study:

- **Dynamic Equilibrium**: The relative probability of finding a particular grain in the deposit is equal to the probability of its transport and re-deposition (i.e., there is a grain by grain replacement along the transport path). The bed is neither accreting nor eroding and is, therefore, in dynamic equilibrium.

- **Net Accretion**: Sediment becomes finer in the direction of transport; however, more fine grains are deposited along the transport path than are eroded, with the result that the bed, though mobile, is accreting.
- **Net Erosion**: Sediment coarsens along the transport path, more grains are eroded than deposited, and the bed is undergoing net erosion.
- **Mixed Case**: A Mixed Case trend is one where the sequence of samples produces significantly acceptable statistics for both Net Erosion and Net Accretion. Such a finding is usually taken to be analogous to the case of Dynamic Equilibrium, but it may be more correctly interpreted to mean that the environment undergoes periodic accretion followed by periodic erosion, and both events have been "captured" in the samples used to make up the trend.
- **Total Deposition (I)**: Sediment becomes more fine-grained in the direction of transport; however, the bed is no longer mobile. Rather, it is accreting under a "rain" of sediment that fines with distance from the source. Once deposited, there is no further transport.

The category of Total Deposition (II) is not present in the lower Willamette. Any given transport vector represents not only a direction of sediment transport, but it is assumed that sediment samples used to derive transport vectors belong to a single facies, i.e., the sediment is related not only in space, but in time. Sediment transport vectors then, are grouped into transport environments. Transport environments are bundles of transport lines representing reaches in the river that are behaviorally similar. A discussion of transport environments in relationship to the bathymetric results and overall morphology of the river is included in Section 4.

3.3 STA® REPORT OVERVIEW

While Sediment Trend Analysis of the lower Willamette provides a unique perspective on river bottom sediment behavior, it is in essence a model. It portrays a 'snapshot in time' of the sediment dynamics during the time of sediment collection, so it is less useful in determining long-term sedimentation and erosion trends. Like any model, accuracy increases with an increase in sampling density. The sediment samples used to construct the model were all collected over a two-week period in September 2000. Conceivably, a new model constructed from sediment samples collected over the same period in 2001 could show different transport patterns.

Based strictly upon the results of the STA® study, the reach of the lower Willamette with the most active sedimentation (particularly finer-grained sedimentation) is the area in the nearest vicinity of the Portland Shipyard between RM 10 and RM 7 (Figure 9). This does not imply, of course, that no other significant areas of sedimentation are suggested by the STA® results. In addition, it cannot be determined with accuracy where within the RM 10 to RM 7 reach sedimentation is most likely.

The category of Dynamic Equilibrium is common throughout the ISA, representative of "conveyor belt" sediment transport, suggesting that there is little net deposition or erosion occurring. To support the STA® results, the patterns of sediment transport in the lower Willamette are largely predictable based on the type of sediment present along the riverbed, and the bathymetric and hydrologic data presented in the bathymetric report (Section 4).

4.0 INTEGRATION OF BATHYMETRY AND THE STA® REPORTS

The historical bathymetric evaluation and STA® studies each provide an initial step in understanding sediment transport in the lower Willamette River. However, each study used a different approach towards reaching this understanding. The bathymetric study compares multiple years of bathymetric survey data based upon 13 individual bathymetric surveys without reference to sediment grain size. The STA® study presents a view of sediment transport based upon a single 2-week grain size sampling study without reference to bathymetric data. The bathymetric study is strictly empirical; the STA® study, while based upon field sampling, is fundamentally theoretical. In some respects, these two studies converge and support each other's conclusions. In other ways, they diverge and provide different insights.

Although it is possible to compare these studies anecdotally it is likely more useful to compare them synoptically within the ISA (RM 3.5-9.2). However, the two studies use different methods of describing sediment transport, erosion and accretion, and specify their results by referencing locations along the lower Willamette River using different methods. Thus, comparison of their results is only possible by simplifying the conclusions of each study and geo-referencing the data in a similar way.

4.1 DEVELOPING A BASIS FOR DATA COMPARISON

4.1.1 Bathymetric Study

The bathymetric study (Parsons Brinckerhoff 2001) compares 13 individual bathymetric survey events. Each survey event covers slightly different areas with varying time periods between surveys. The difference contour plot between any pair of surveys shows the resultant erosion and accretion under varying conditions of flood and drought conditions, flow rate, river stage, tidal influence, sediment load, dredging activities, and Columbia River flow rate integrated over variable time periods between surveys. Thus, in viewing difference contour plots from sequential pairs of surveys some areas that show erosion on one plot may show accretion on another. This is not surprising because each difference contour plot is the result of integration of widely varying environmental parameters. As a result, it is somewhat difficult to characterize sediment transport from one comparison of two sequential surveys to the next pair.

One way to understand sediment transport is to view bathymetric changes over an extended period. The bathymetric report presents a difference contour plot, using the survey data from August 1990 and November 1999 (Figure 4). (The report suggests that the March and August 2000 surveys included in this study may be suspect and are not included in their long-term difference plot). Although these data do not show the direct effects of episodic events such as floods, they do represent the long-term depth changes in the lower Willamette over nearly a decade. Thus, the contour difference data from this plate will be used to compare to the STA® results.

The bathymetric study also presented a table of changes in average depth for sequential river miles for each pair of surveys during the study period (Table 3). The table shows the change in average depth per mile between 13 surveys from river miles 3 through 9, including an average change between the August 1990 survey and the November 1999 survey. The data were normalized for RM 3 through 9 representing the approximate range of the ISA. Because the time intervals between surveys is variable it is difficult to compare the differences between pairs of surveys. To compare the change in average depths between pairs of surveys the data were normalized to total depth change per month for river miles 3-9. This was done by summing the changes in average depth per river mile and dividing by total number of months between surveys. Although this is an artificial construct it provides a normalized basis for comparison of data between survey pairs.

To compare these data with the results of the STA® study, a further revision of these data was made. These changes were made to accommodate the method that the STA® uses to relate the physical proximity of its results along the river and will be discussed in a subsequent section.

4.1.2 STA® Study

The STA® results are organized by dividing the lower Willamette into reaches and, within each reach, transport environments. The ISA is included within transport environments 9 through 13 (Figure 9). Note that transport environments don't match river miles exactly. Therefore, several accommodations were made to compare the results of the studies. First, only a small, downstream section of transport environment 9 is within the ISA and was not included in comparison of results. Second, transport environment 11 is located completely within the Swan Island ship basin, not in the main flow of the river, and was not included in the bathymetric study area. Consequently, the STA® results from this area were not used in comparison to the bathymetric study. The third accommodation is that only the upstream half of transport environment 13 falls within the ISA. Fortunately, the results for both the upstream and downstream part of transport environment 13 look very similar.

Therefore, classification of transport environments (TE) for the purposes of this discussion is:

- TE 10 = approximately River Miles 7-9

- TE 12 = approximately River Mile 6-7
- TE 13 = approximately River Mile 3-6

4.2 EVALUATION OF TRANSPORT ENVIRONMENTS WITHIN THE ISA

Transport environments were interpreted while concurrently considering the sediment present at each reach, and building on previous bathymetric interpretations. Additionally, because it is helpful to consider bathymetric analyses, interpretations of sediment trends will largely be limited to the ISA (RM 3.5 to RM 9.2). The sampling density of the STA® study was also increased in this general area, likely increasing the precision of the sediment trend lines.

Sediment transport environments are relatively predictable in the Willamette. Areas with an Erosion STA-trend are not present in the ISA. Erosion patterns occur further upriver, and are generally consistent with a shallow, narrow channel. Conversely, areas of deposition (Accretion, and/or Total Deposition) are largely consistent with a relatively deep, wide channel. Reaches having either Dynamic Equilibrium or Mixed Case trends are the most difficult to interpret. In both cases the riverbed is experiencing neither net accretion nor net erosion. Spatially, Mixed Case trends are also closely associated with Dynamic Equilibrium trends. There are no obvious bathymetric or morphological patterns present that could be used to separate the two transport behaviors. For these reasons, a cause and effect interpretation of any reach classified as having a Dynamic Equilibrium or Mixed Case sediment transport trend is difficult to make.

Approximate areas of different transport behaviors within each transport environment were estimated from the STA® report. The STA® results show that TE 10, not including the Swan Island ship basin, is roughly 70% depositional. This depositional area is composed of about 58% total deposition (type I) and about 12% net accretion. This is consistent with the bathymetric depth difference over this area (Figure 10). There are large patches of accretion to the right of the channel between RM 7.2 and RM 7.5, and between RM 7.8 and RM8.5. Based upon available documentation (Parsons Brinckerhoff 2001), this reach of the river has a history of periodic dredging. This fits well with the physics of this reach of the river noting that this area is much broader, deeper and slower moving than the narrower and faster moving reach just upstream. The balance of the TE 10 area, 30%, is split between dynamic equilibrium (23%) and mixed case (7%). Generally, both studies support the same conclusion that there is a trend towards deposition in this transport environment

Based on the STA® results, TE 12 is reported to be an area of dynamic equilibrium showing no long-term erosion or accretion (Figure 9). The sediment sampling in TE 12 showed a higher percentage of sand in the samples than adjacent reaches (Figure 8). This may be due to a narrowing of the river in this reach causing fine-grained suspended sediment to move further downstream and exposing coarse-grained Missoula Flood deposits as mentioned previously. The bathymetry data comparison suggests that this reach is a mosaic of mixed erosion and accretion. Near RM 6.2-6.3 there are areas of erosion and accretion. It is likely that some of the patches of erosion are due to the presence of the railroad bridge abutments at RM 6.8 (Figure 5). In general, there are no large areas of erosion or accretion (greater than four feet) suggesting general agreement between the two studies (Figure 10).

For the ISA section of TE 13, the STA® results showed that this reach of the river is split nearly equally between dynamic equilibrium and mixed case transport paths. The dynamic equilibrium transport paths tend more to the right bank of the river (east side) while the mixed case paths tend more left bank (west side, Figure 9). The depth difference analysis shows that there is a slight trend toward erosion on the left bank and a slight trend towards accretion on the right side (Figure 10). This suggests that the outside curve of the river (left bank) is not in complete equilibrium, in conflict with the STA® results. Similarly, the right bank, the inside curve, that is showing accretion as suggested by the bathymetry study, is perhaps in an accretion 'phase' of the Mixed Case category. At any rate, within this TE, the two studies are incompatible, suggesting that this area may be one of the more hydrologically complex areas of the ISA.

4.3 COMPARISON OF THE STA® RESULTS TO DEPTH CHANGE CALCULATIONS

Parsons Brinckerhoff presented the change in average depth per river mile with an additional column showing the total average depth change per month for RM 3-9, the approximate area included in the ISA (Table 4). The data were normalized to show depth change in terms of transport environments instead of river miles. These data show the results for RM 7-9 to approximate TE 10, RM 6-7 to approximate TE 12, and RM 3-6 to approximate TE 13 (within the ISA). A column of average depth difference per month is also presented for each transport environment. The last row of Table 4 shows total depth difference and the average depth difference per month for each transport environment comparing the August 1990-November 1999 survey pair.

The table shows that TE 10 has the highest average depth difference per month over the 9-year comparison with an accretion rate of 7.5 in/year. This compares qualitatively favorably with the STA® report as well as the history of dredging in this reach of the river. The next highest accretion rate, 4.6 in/year or roughly 60% of TE 10, was shown in TE 13. This is a different conclusion than that of the STA® results. The STA® study shows no total deposition or net accretion in TE 13.

TE 12 has the lowest accretion rate of all the transport environments in the ISA (Table 4). An accretion rate of 0.23 in/year is more than an order of magnitude less than the lowest accretion rate of 4.6 in/year in TE 13. This can be considered a negligible rate of accretion relative to the other transport environments. Thus, this agrees well with the results of the STA® which considers this transport environment a region of dynamic stability.

4.4 SUMMARY

- The Willamette from RM 9.2 to approximately RM 7 is a net depositional area, hence the requirement for periodic dredging. The rest of the ISA area (from RM 7 to RM 3.5) is predominantly a system that is in equilibrium, with some localized areas of deposition and erosion.
- Deposition rates in depressions and in TE 10 (RM 7-9) consistently fall between the range of ½ to 1 ft /year; most of this deposition occurs in bathymetric lows (commonly associated with dredging areas), and along the inside bends of the river.
- Erosion is most consistent outside of the ISA, but occurs in localized areas such as along the outside bends of the river. Episodic erosion occurs based on short-term hydrologic events, however, periodic dredging can obscure actual events of erosion in the bathymetric depth difference analysis.
- The results of two studies show inconsistencies in predicting sediment movement in TE 13 (RM 3-6), which suggests that this is the most hydrologically complex part of the ISA.

5.0 REFERENCES

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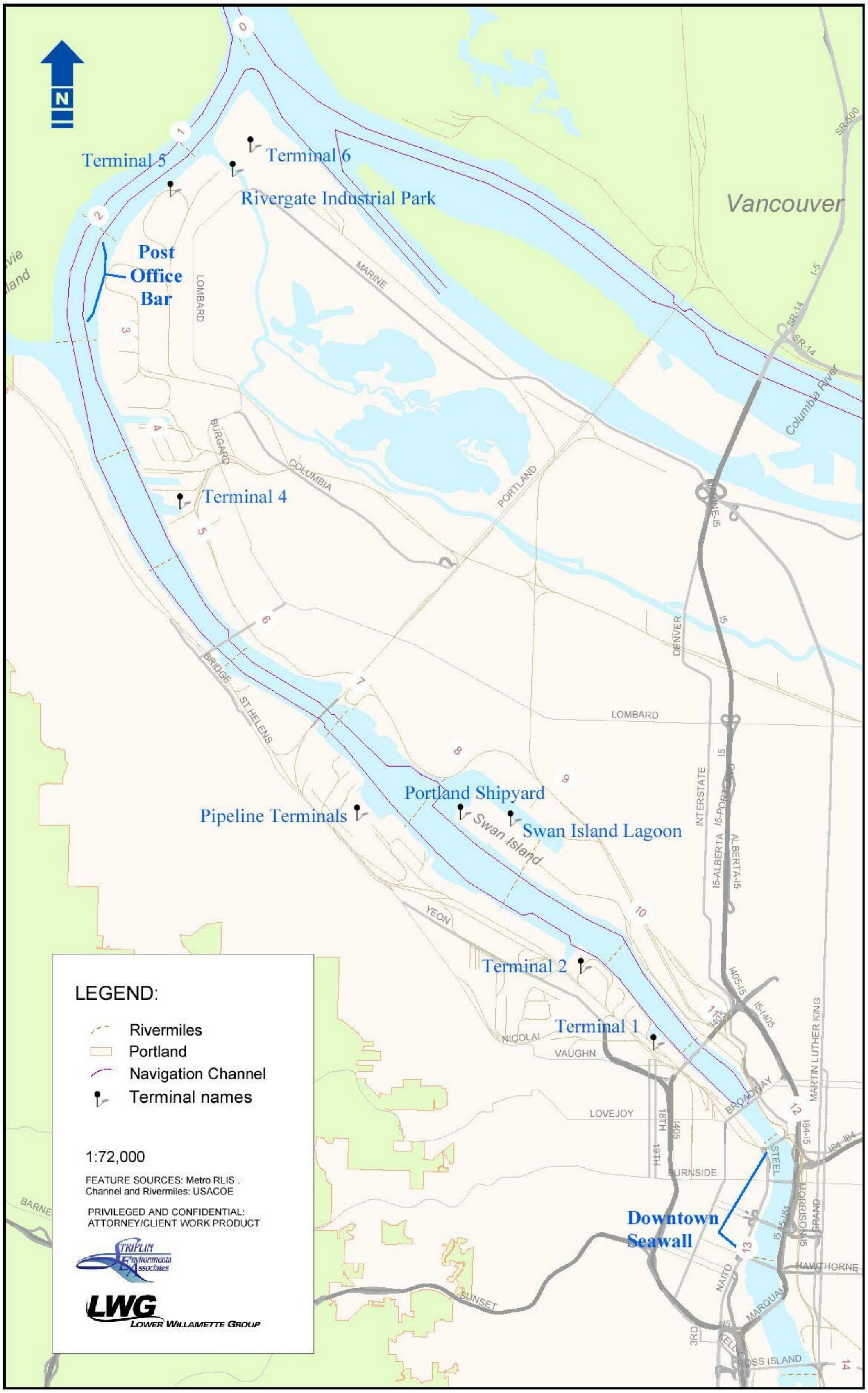

Figure 1. Lower Willamette River Vicinity Map

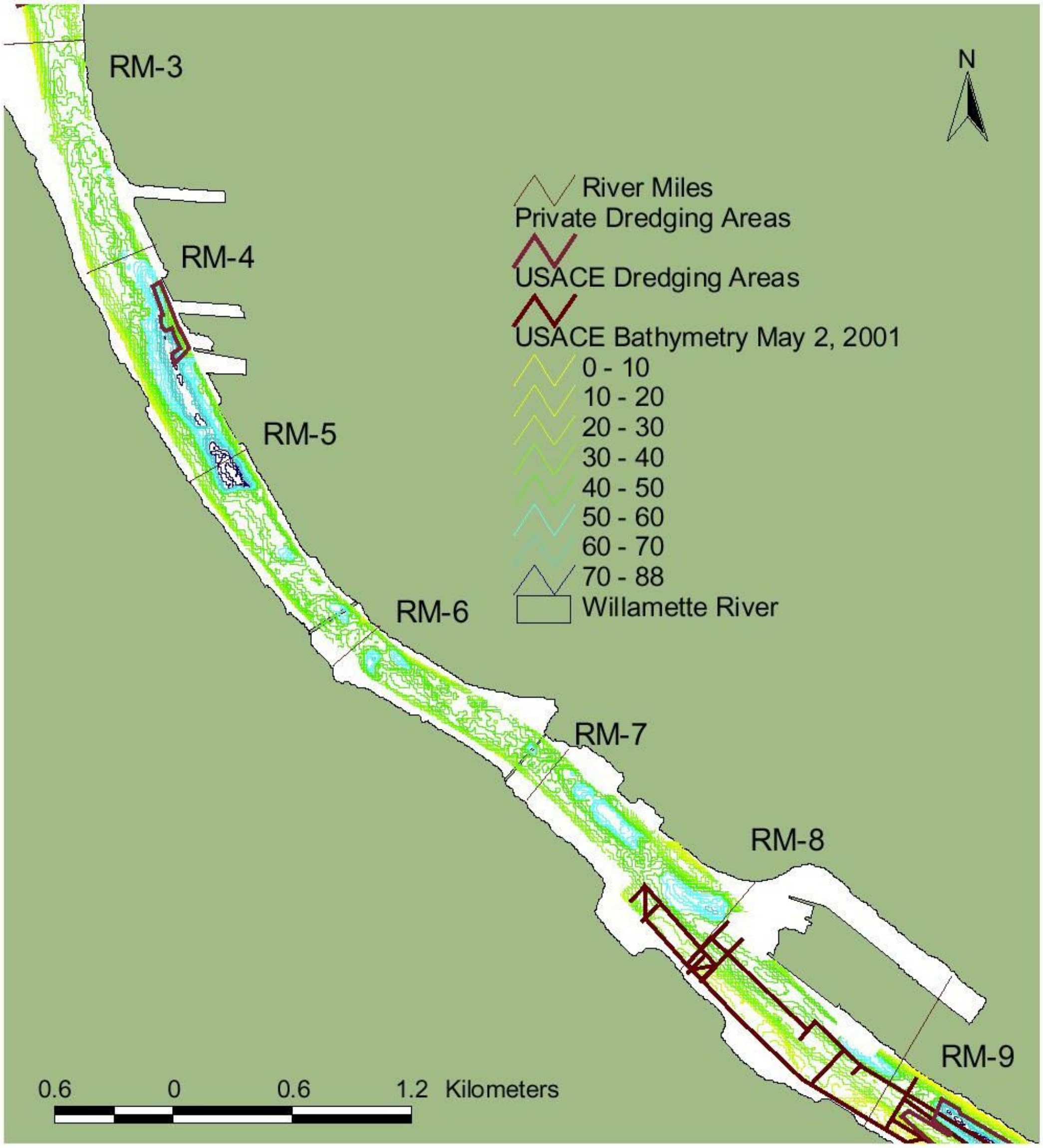

Figure 2. USACE bathymetric contours (10 ft contour interval) in the ISA collected May 2001

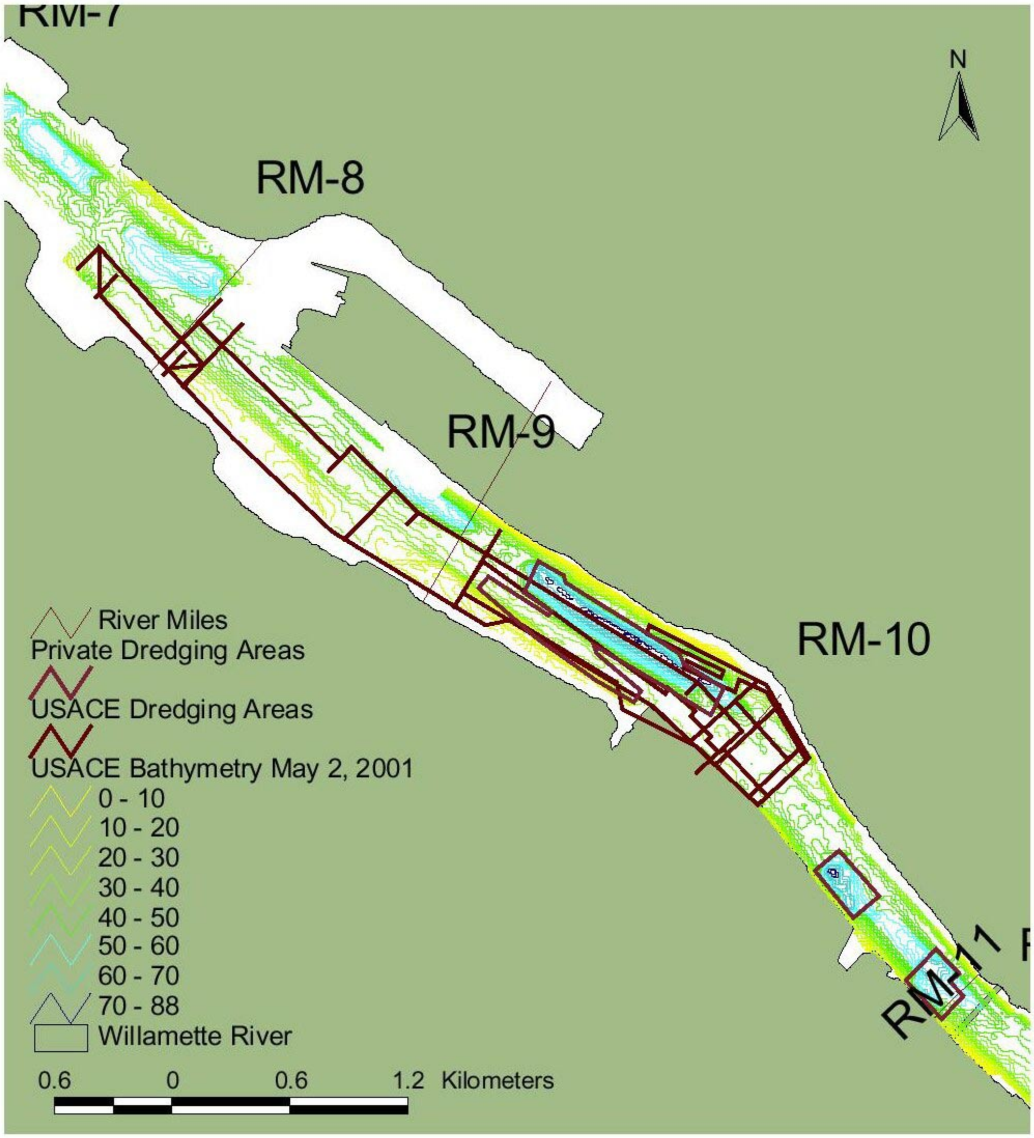

Figure 3. Bathymetric contours (10 ft contour interval) between RM 8 and 11, shown with USACE dredging areas

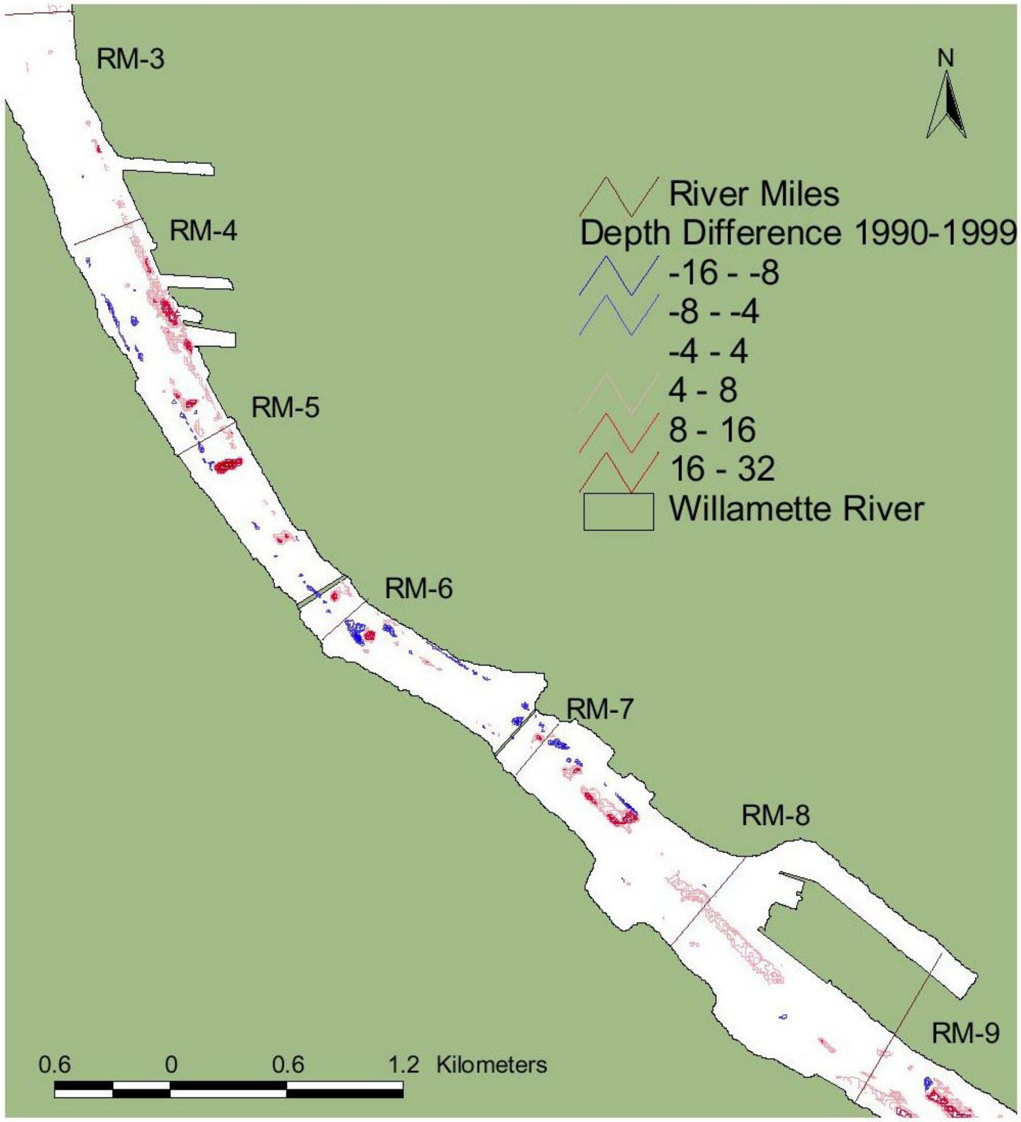

Figure 4. Depth difference contours (in ft) in the lower ISA, between 1990 to 1999 USACE surveys

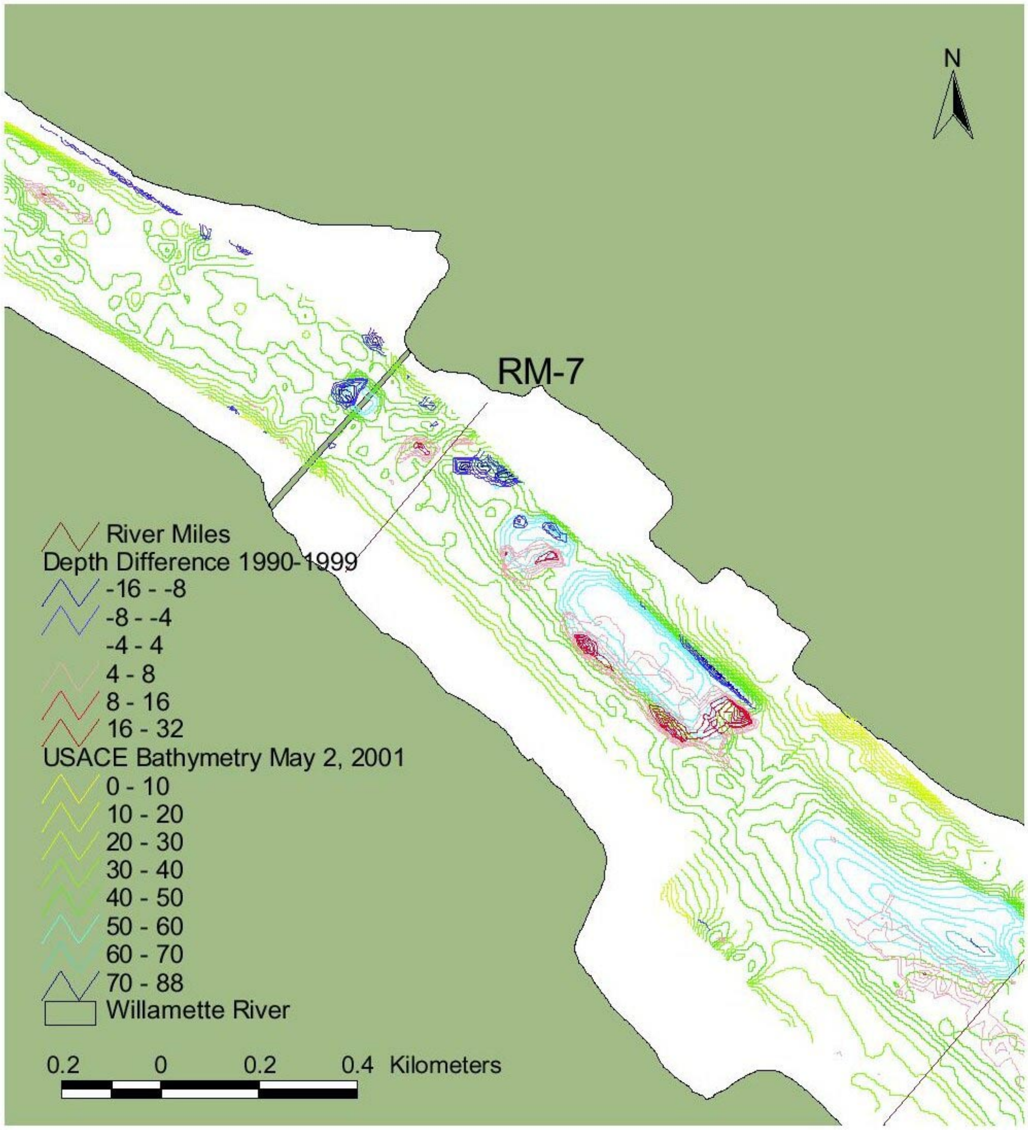

Figure 5. Depth difference contours (in ft) near RM 7, 1990 to 1999, in comparison with USACE 2001 bathymetric survey

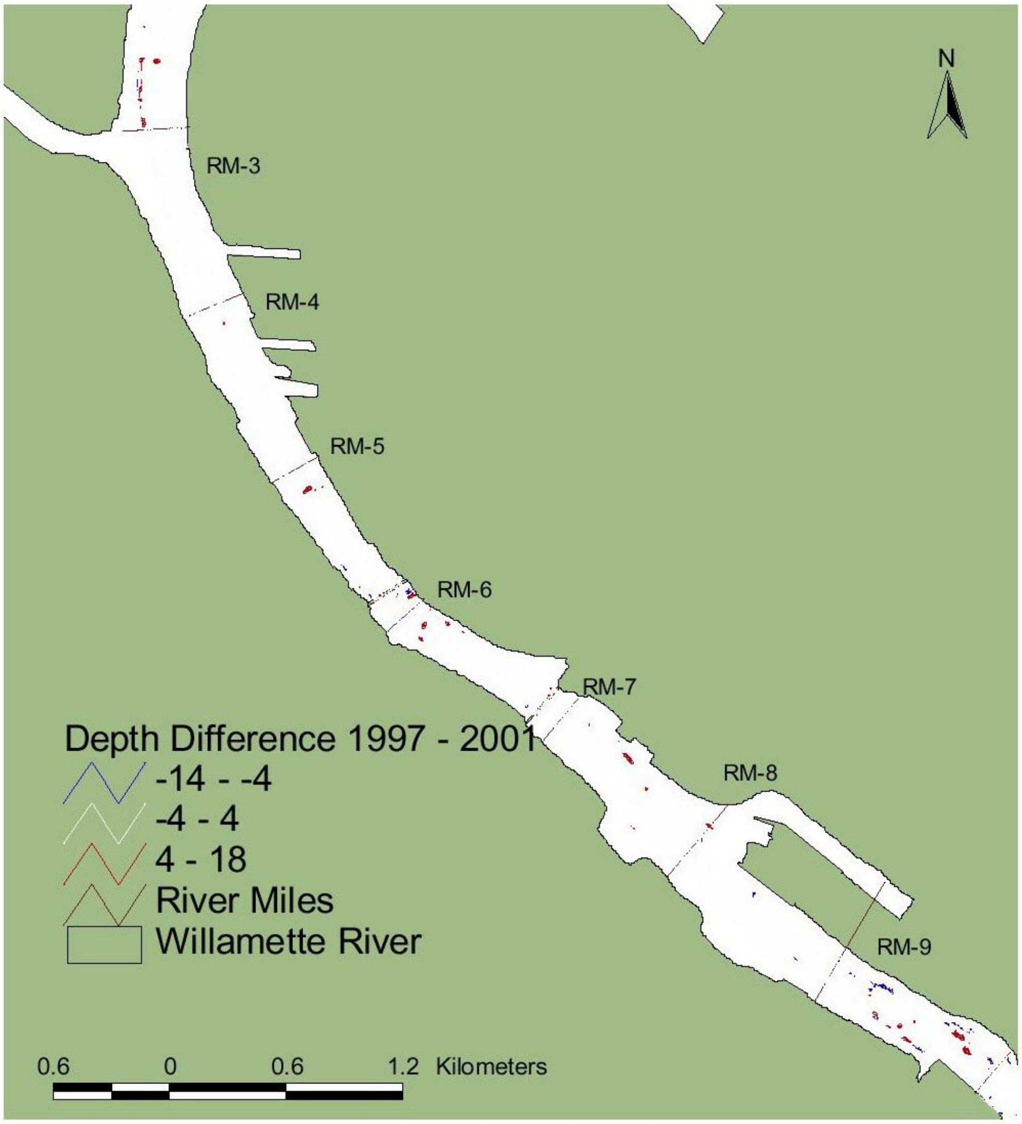

Figure 6. Depth difference contours (in ft) between 1997 and 2001 USACE bathymetric surveys

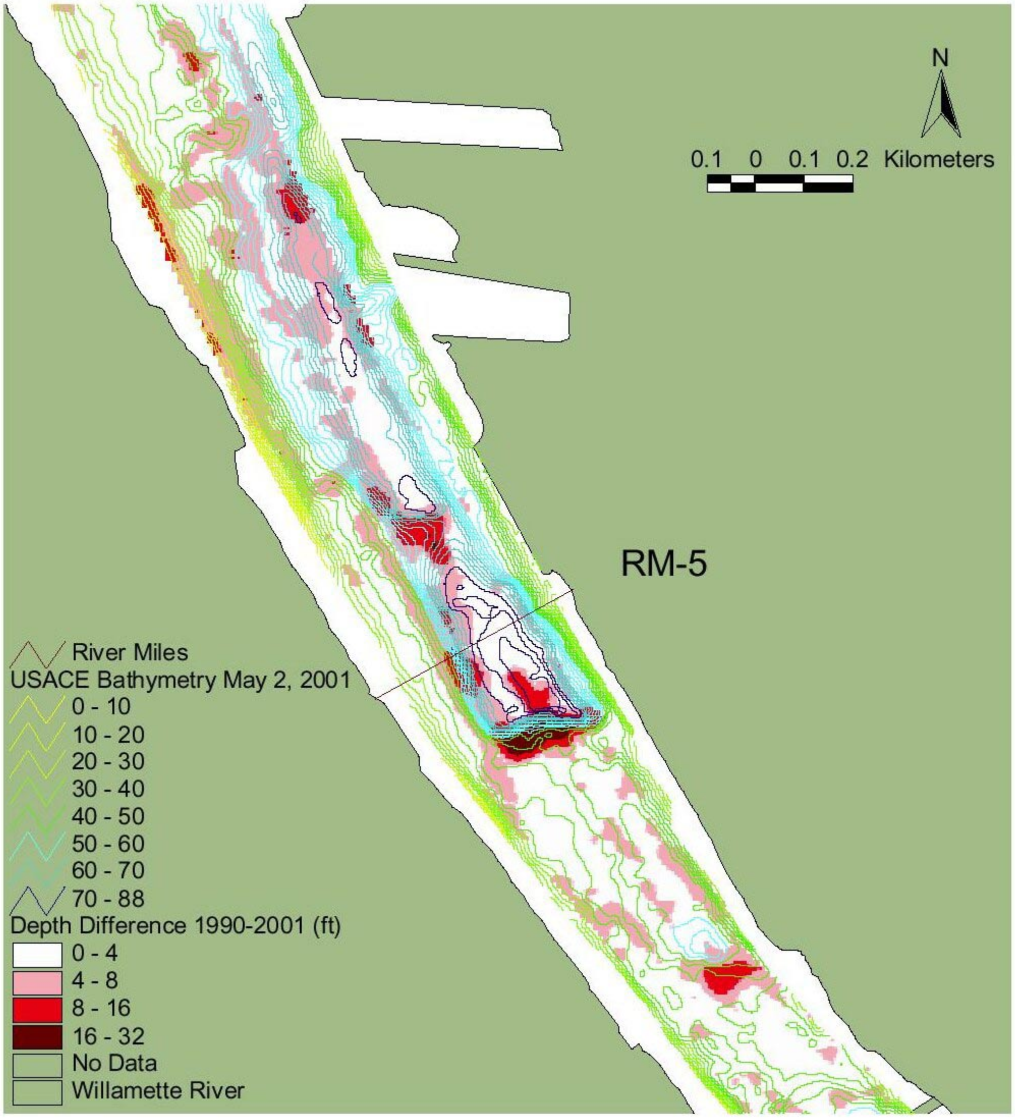

Figure 7. Borrow pit near RM 5 (USACE 2001 bathymetry) showing deposition over 1990-2001 period

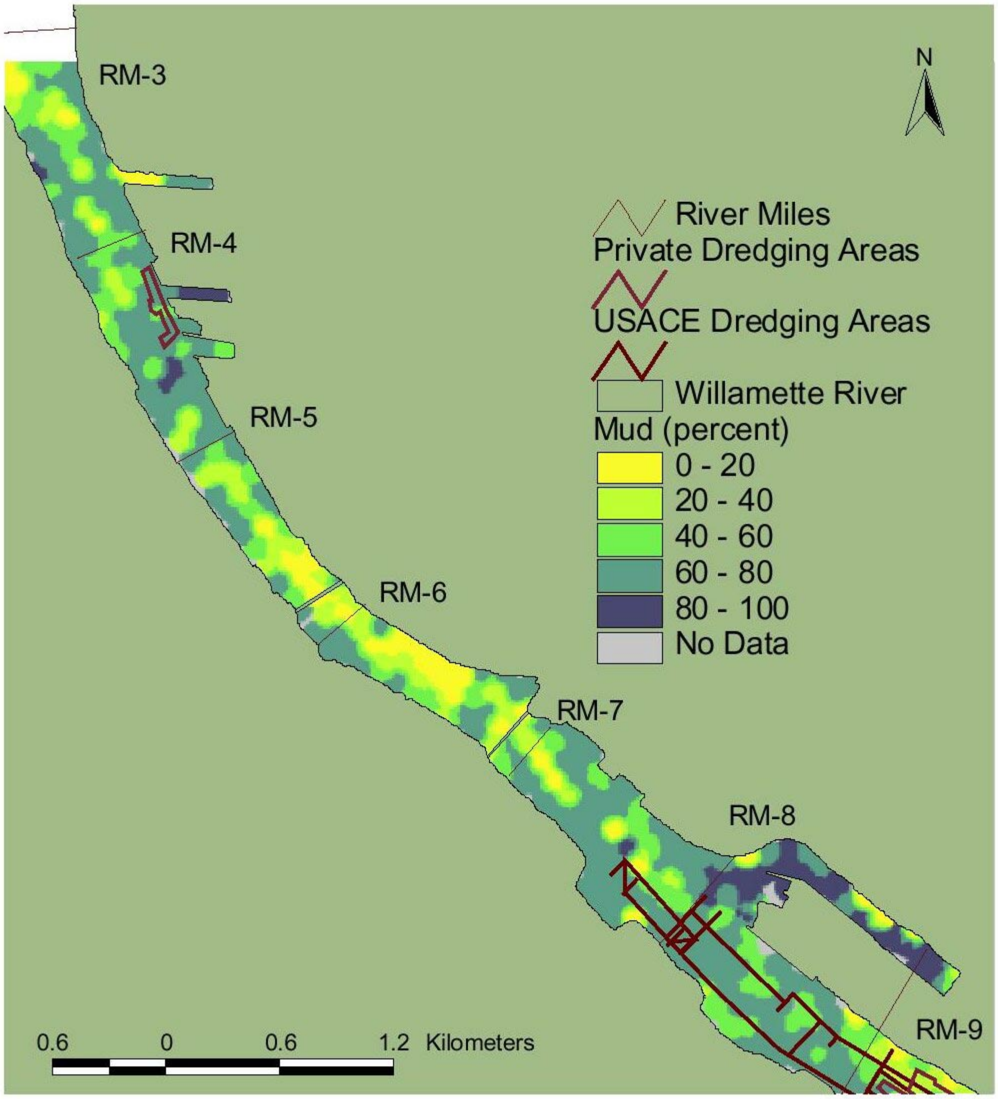

Figure 8. Grain size distribution (percent mud) over the ISA. Individual values of mud (%) gridded to create surface plot.

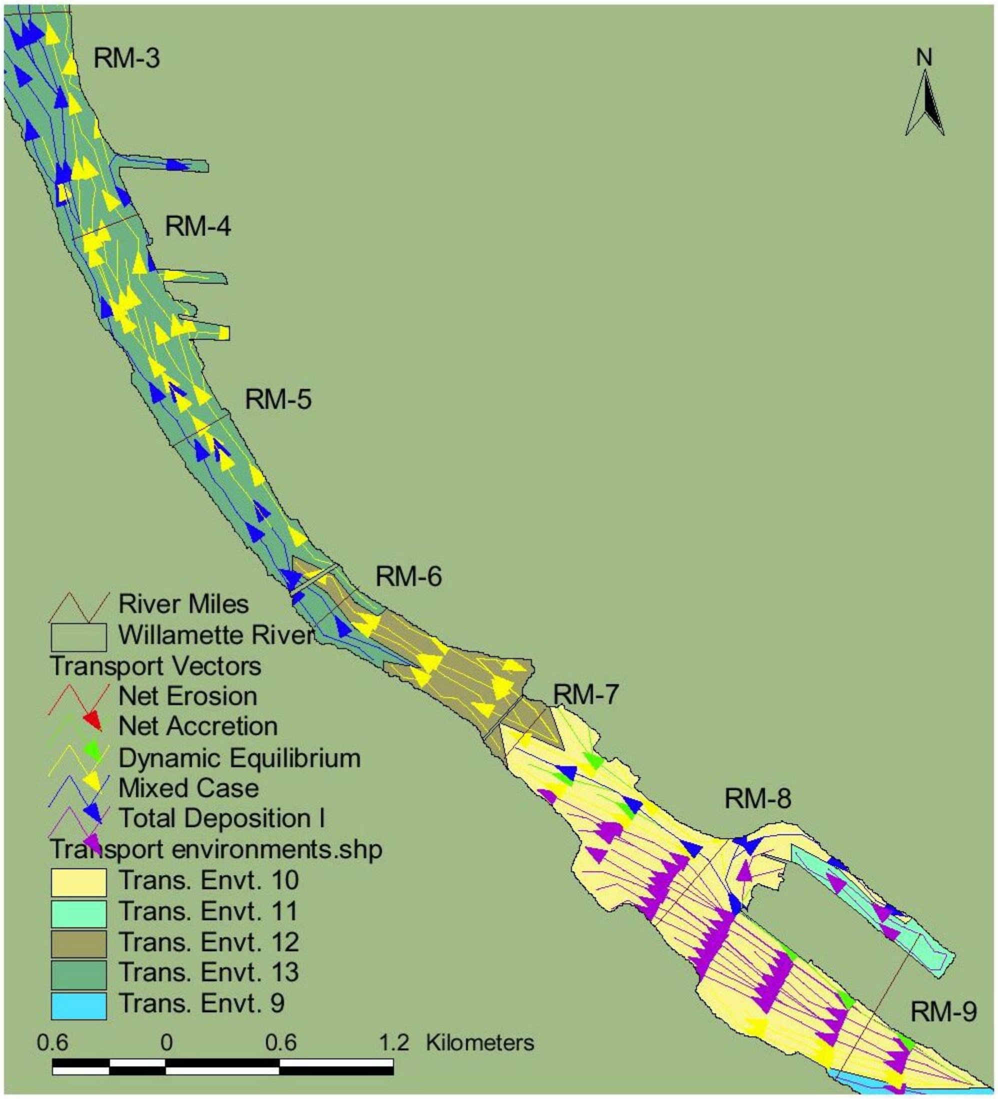

Figure 9. Transport vectors from the STA study in the ISA; transport environments also shown

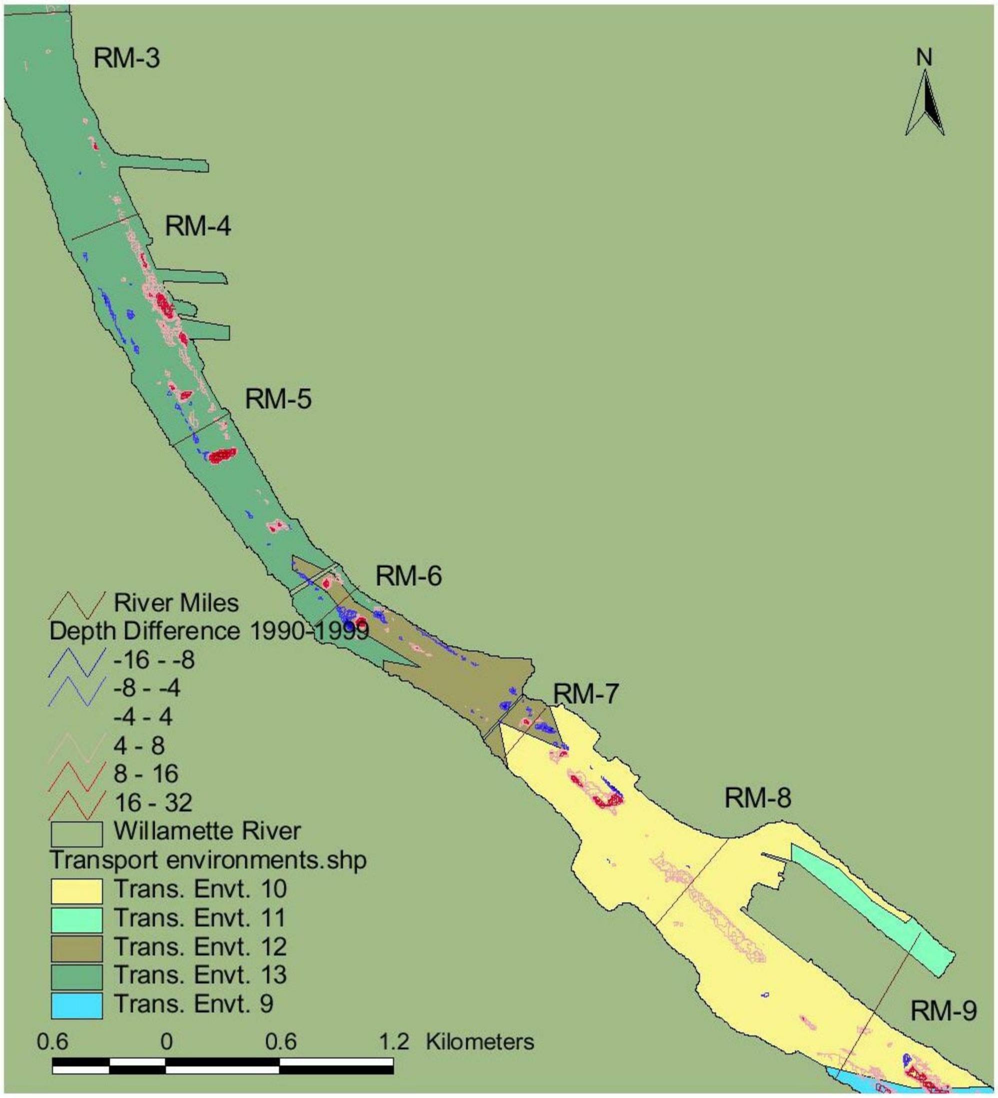

Figure 10. Transport environments within the ISA showing the relationship between transport environment and depth difference

Table 1. USACE Maintenance Dredging in the Lower Willamette River.

Year	Volume (cubic yards)
1984	517,073
1985	890,171
1988	97,808
1989	586,935
1990	1,777
1994	499,897
1996-97	346,069

Table 2. Change in Volume (cubic yards) in Channel Over Survey Periods.

Survey #1	Survey #2	No. of Months	River Mile 3-4	4-5	-5-6	6-7	7-8	8-9	9-10	Total	Total/ Month	Notes
Aug-90	Sep-92	25	134,192	**-37,744**	8,051	**-25,532**	178,098	146,065	288,697	691,827	27,673	
Sep-92	Jul-93	10	**-92,369**	14,130	4,106	**-21,898**	**-178,017**	**-68,600**	76,896	**-265,752**	**-26,575**	
Jul-93	Apr-95	9	**-47,656**	**-33,135**	13,954	28,881	47,200	72,064	161,597	242,905	26,989	
Apr-95	Aug-96	16	155,090	581,951	216,020	67,472	357,710	378,608	375,934	2,132,785	133,299	After Flood
Aug-96	Aug-97	12	96,662	**-299,767**	**-161,785**	**-10,404**	52,623	117,600	30,805	**-174,266**	**-14,522**	
Aug-97	Nov-97	15	**-75,316**	**-20,646**	**-29,860**	**-20,564**	139,856	319,246	307,502	620,218	41,348	
Nov-97	Apr-98	5	**-37,637**	**-15,223**	**-38,517**	**-38,737**	**-119,904**	**-271,410**	**-146,982**	**-668,410**	**-133,682**	
Apr-98	Mar-99	11	44,038	80,963	64,444	52,254	89,849	151,615	153,496	636,659	57,878	
Mar-99	May-99	2	72,519	74,527	49,006	13,763	50,106	97,565	130,870	488,356	244,178	
May-99	Nov-99	6	27,835	31,155	4,878	**-14,548**	**-48,160**	**-99,202**	**-38,206**	**-136,248**	**-22,708**	
Nov-99	Mar-00	4	**-178,571**	**-316,670**	**-175,966**	**-72,229**	**-51,973**	**-28,006**	**-16,149**	**-839,564**	**-209,891**	
Mar-00	Aug-00	5	253,319	428,210	307,596	151,979	220,073	240,665	228,062	1,829,904	365,981	
Nov-99	Aug-00	9	74,748	111,540	131,630	79,750	168,100	212,659	211,913	990,340	110,038	Combo of Previous Two
Aug-90	Nov-99	111	229,647	341,984	112,767	19,627	328,921	756,022	1,254,453	3,043,421	27,418	9 Years

Table 3. Change in Average Depth Per River Mile.

Survey #1	Survey #2	No. of Months	River Mile 3-4	4-5	-5-6	6-7	7-8	8-9	Total Depth (ft)	Total Depth/ Month (ft)	Notes
Aug-90	Sep-92	25	0.78	**-0.16**	0.05	**-0.27**	1.01	0.60	2.01	0.08	
Sep-92	Jul-93	10	**-0.53**	0.06	0.03	**-0.24**	**-0.79**	**-0.28**	**-1.75**	**-0.18**	
Jul-93	Apr-95	21	**-0.27**	**-0.14**	0.09	0.26	0.20	0.29	0.43	0.02	
Apr-95	Aug-96	16	0.89	2.35	1.26	0.60	1.83	1.68	8.61	0.54	After 1996 Flood
Aug-96	Aug-97	12	0.55	**-1.21**	**-0.95**	**-0.09**	0.27	0.52	**-0.91**	**-0.08**	
Aug-97	Apr-98	8	**-0.72**	**-0.19**	**-0.42**	**-0.53**	0.06	0.20	**-1.60**	**-0.20**	Two surveys combined
Apr-98	Mar-99	11	0.25	0.33	0.39	0.47	0.49	0.68	2.61	0.24	
Mar-99	May-99	2	0.41	0.30	0.30	0.12	0.25	0.44	1.82	0.91	Short duration anomaly
May-99	Nov-99	6	0.16	0.13	0.03	**-0.13**	**-0.27**	**-0.49**	**-0.57**	**-0.10**	
Nov-99	Aug-00	9	0.43	0.43	0.67	0.69	0.91	1.23	4.36	0.48	Two surveys combined
Aug-90	Nov-99	111	1.35	1.45	0.75	0.18	2.06	3.76	9.55	0.09	Net Difference over 9 Years

1. Change in average depth shown in feet, based on individual areas for each comparison.
2. Positive change in average depth indicates sedimentation or fill, negative change indicates scour.

Table 4. Change in Average Depth per Approximate Boundary of Transport Environment.

Survey Dates		No. of Months	Approximate Transport Environment No. 13 (RM 3-6)		Approximate Transport Environment No. 12 (RM 6-7)		Approximate Transport Environment No. 10 (RM 7-9)	
			Total Depth Diff. (ft.)	Depth Diff./ Month (ft)	Total Depth Diff. (ft)	Depth Diff./ Month (ft)	Total Depth Diff. (ft)	Depth Diff./ Month (ft)
Aug-90	Sep-92	25	0.67	0.03	**-0.27**	**-0.01**	1.61	0.06
Sep-92	Jul-93	10	**-0.44**	**-0.04**	**-0.24**	**-0.02**	**-1.07**	**-0.11**
Jul-93	Apr-95	21	**-0.32**	**-0.02**	0.26	0.01	0.49	0.02
Apr-95	Aug-96	16	4.50	0.28	0.60	0.04	3.51	0.22
Aug-96	Aug-97	12	**-1.61**	**-0.13**	**-0.09**	**-0.01**	0.79	0.07
Aug-97	Apr-98	8	**-1.33**	**-0.17**	**-0.53**	**-0.07**	0.26	0.03
Apr-98	Mar-99	11	0.97	0.09	0.47	0.04	1.17	0.11
Mar-99	May-99	2	1.01	0.51	0.12	0.06	0.69	0.35
May-99	Nov-99	6	0.32	0.05	**-0.13**	**-0.02**	**-0.76**	**-0.13**
Nov-99	Aug-00	9	1.53	0.17	0.69	0.08	2.14	0.24
Aug-90	**Nov-99**	**111**	**3.55**	**0.03**	**0.18**	**0.002**	**5.82**	**0.05**

1. Change in average depth shown in feet, based on individual areas for each comparison.
2. Positive change in average depth indicates sedimentation or fill, negative change indicates scour.