MULTI-DIMENSIONAL MODELING OF THE COWLITZ-COLUMBIA CONFLUENCE

Dan Gessler, PhD, PE, Vice President, Alden Research Laboratory, Fort Collins, CO dgessler@aldenlab.com; David Biedenharn, PhD, PE, Principal Investigator, Biedenharn Group, Vicksburg, MS, biedenharngroup@yahoo.com; Chester Watson, PhD, PE, Principal Investigator, Biedenharn Group, Fort Collins, CO, chester@chesterwatson.com Chris Nygaard, PE, USACE Portland District, Portland, OR, Christopher.J.Nygaard@usace.army.mil; Mitch Peters, PE, Alden Research Laboratory, Fort Collins, CO, mpeters@aldenlab.com

Abstract The Portland District of the U.S. Army Corps of Engineers is evaluating measures to manage sediment deposition in the Cowlitz River downstream from Mount Saint Helens. As part of this effort, one and two dimensional models are being used to predict the long term channel evolution and how it might respond to channel training structures. An initial study was launched using a 2-dimensional model to evaluate the impact that a dike field would have on sediment transport within the lower reaches of the Cowlitz River. The downstream end of the reach is tidally influenced and experiences significant changes in water level

Two fully coupled and fully dynamic 2-dimensional hydrodynamic models were created of the lower 4.5 miles of the Cowlitz River: one of the existing channel and one with a series of 36 dikes placed throughout the lower portions of the river. Two six month Cowlitz River hydrographs representing conditions above base flow for water years 1992 and 1994 simulate high flow and average flow periods. The WY 1992 and WY 1994 hydrographs were run through both models to evaluate the effectiveness of the dike field in encouraging sediment movement through the Lower Cowlitz River.

The study area was discretized into four reaches that were compared for the two flow periods extracted from water years 1992 and 1994. Sediment deposition and scour volumes were compiled and compared for the existing river configuration versus the proposed dike scenario.

Preliminary results indicate that at low flow the dike field performs similar to the existing condition, peak flow periods of typical Cowlitz flow years can transport up to 150% of the sediment compared to the existing condition, and at high Cowlitz River flows the dikes can also significantly increase sediment transport to the mouth of the Cowlitz River. Further work is needed to quantify the effects of the pile dikes on flood flows and how those effects are expected to change over time as the channel evolves.

INTRODUCTION

The Cowlitz River is a tributary to the Columbia River near Longview, WA. After the 1980 eruption of Mount Saint Helens, the reach became aggredational due to the increase sediment load from the mountain. Construction of the SRS after the eruption reduced the depositional nature of the. In the late 1990's, the trap efficiency of the SRS decreased as the stored sediment reached the spillway. As a result, sediment reaching the lower Cowlitz River increased and the

reach has become aggredational. The deposition of sediment in this reach is undesirable because it potentially reduces the flood protection level for the adjacent communities.

A number of options are being considered reduce the sediment deposition in the Lower Cowlitz. Generally they can be categorized as decreasing the inflowing sediment load to the reach or increasing the sediment transport capacity of the reach. Ultimately, it may be a combination of options which are used to manage sediment deposition. Options are being individually and jointly evaluated using several different numeric modeling tools to quantify their effectiveness in reducing sediment deposition. This paper focuses on the use of a two dimensional model to evaluate the potential effectiveness of a dike field in reducing sediment deposition in the Lower Cowlitz. Figure 1 shows an aerial view of the area of interest and shows the two dimensional model domain.

To evaluate the potential effectiveness of the dike field, two continuous 6 month simulations of the existing and proposed condition were run. The model can simulate wetting and drying of computational cells and can therefore simulate dikes which are exposed during low flow periods and fully submerged during high flow periods. Model resolution was sufficient to resolve each individual dike and the local flow fields it creates rather than simulating the net effects of an entire dike field as is more typically done.

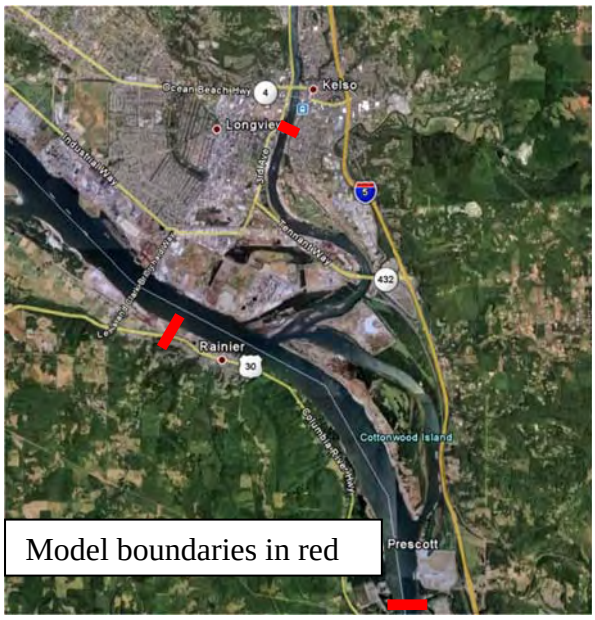

Figure 1 Model domain over view.

MODEL DESCRIPTION

The numeric model MIKE21-C (DHI Software) was used for the depth averaged hydrodynamic simulations. MIKE21-C is a two dimensional, depth averaged hydraulic model well suited to modeling water and sediment transport through sandbed rivers. The hydrodynamic module simulates water surface level and lateral and longitudinal velocity variations in response to a variety of forcing functions, including upstream Cowlitz River flow, tributary Coweeman River

inflow, downstream Columbia River water surface elevation (which is a function of tide and incoming Columbia River flow in this system), bottom shear stress, and other possible influences including wind shear, barometric pressure, Coriolis acceleration, momentum dispersion, sources and sinks, evaporation, flooding and drying, and wave radiation stresses. Since the point of this study was to evaluate the effect of a change in bed geometry (existing channel vs. existing channel with a dike field), wind shear, barometric pressure variation, evaporation, and wave radiation stresses were not included in the simulations.

Model Grid MIKE21-C operates exclusively in SI units and is based on a curvilinear grid. The grid for the Lower Cowlitz River Study includes the lower 4.5 miles of the Cowlitz River and about 6 miles of the Columbia River (1.5 miles downstream and 4.5 miles upstream from the Cowlitz including Carol's Channel). The 97,950 cell grid (653 cells in the Cowlitz River direction x 150 cells in the Columbia River direction) is shown in Figure 2. A small section of the model mesh is shown at an exaggerated scale (inset) to illustrate the density and orientation of the 2-dimensional grid layout.

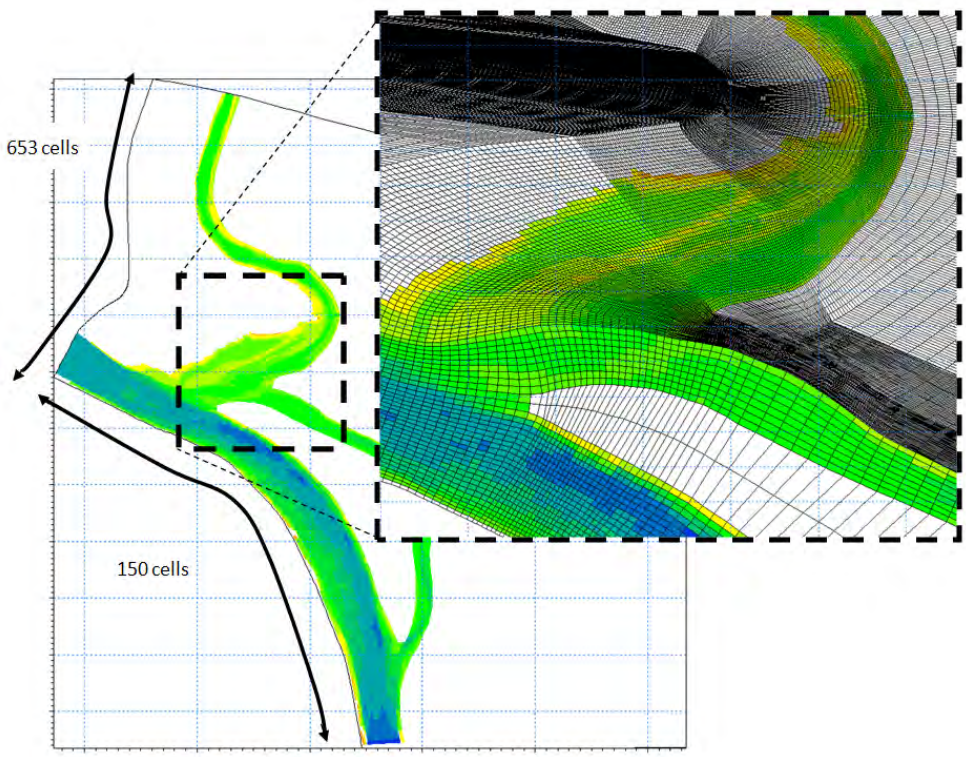

Figure 2 Lower Cowlitz Model Mesh.

The resolution of the grid cells in the main flow channel of the Cowlitz river is approximately 10 meters by 10 meters (33 x 33 ft). This level of detail was necessary to simulate individual dikes in the model. The large number of cells (almost 100,000 cells) within the grid requires about 2 days of computer time to run a 190 day hydrograph with a one second hydraulic time step.

Bathymetry The model bathymetry was developed from USACE cross sectional surveys. Channel bed data was interpolated between cross sections using the Grid Generator interpolation

routine. By emphasizing topographic detail in the direction of Cowlitz River flow, a smooth interpolated channel was created. Figure 3 shows the Lower Cowlitz baseline bathymetry.

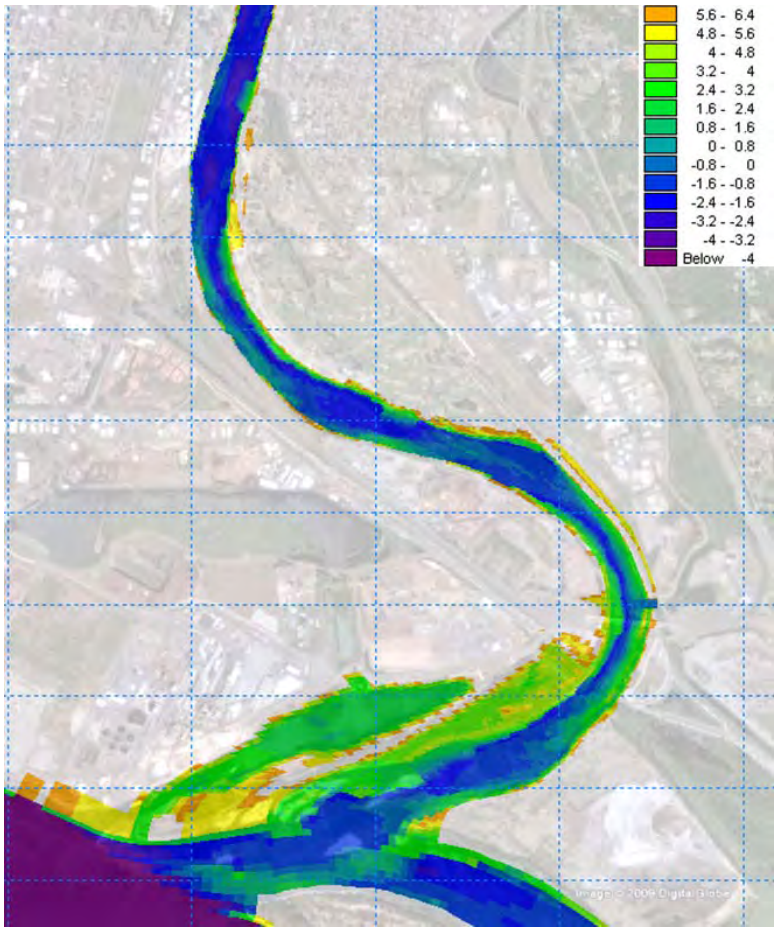

Figure 3 Lower Cowlitz Baseline Bathymetry (color coded elevations are in meters).

The proposed bathymetry is the same as the existing bathymetry with the addition of the dikes. Dikes can be used as tools to improve the local sediment transport capacity of the channel, reducing sediment deposition. Dikes are designed to convert a wide shallow channel to a deeper channel (which is more efficient for transporting sediment). The hydraulic effects of the dikes are most noticeable with stages at or below the top of the dike. As the increases above the top of the dike, the relative impacts of the dikes are diminished, particularly at overbank conditions. A key aspect of dike design is to balance the need for increased sediment transport capacity at the low to intermediate stages with the requirement that flood stages not be significantly increased at higher flows. For this reason the top elevation of dikes are generally constructed well below the top bank elevation (typically less than 1/2 to 2/3 of the bank height) to insure that their hydraulic impacts are negligible at the higher flows. Ultimately, a properly designed dike system will result in lower stages at lower flows, with minimal changes in stage at the higher flows. Over time, the dikes should promote reduced deposition or promote scour and increase the overall channel capacity at all flows.

At approximately 36 locations throughout the study reach, dikes were added by raising mesh cells to a level of 2.3 meters in the upper 3 reaches and 1.5 meters in the lower reach (approximately the 50% exceedence discharge water surface elevation) so that they would train flow into a smaller active channel. The model with dikes is shown in Figure 4 (the dikes are shown in black). The upstream dikes are about 300 feet in length effectively constricting flow to about half of the original channel width. The initial dike placement was intended to illustrate the effect of dikes on sediment movement. Further study is necessary to refine dike locations, maximizing their ability to concentrate and mobilize sediment while minimizing impact on flood water elevation.

Figure 4 Dikes added to the Lower Cowlitz Model.

Hydrodynamic Simulation Period River data for the Cowlitz (flow), Coweeman (flow), Columbia (flow and downstream stage) are all necessary as inputs for the 2-dimensional flow model. An overlapping period of record with hourly Columbia River flow and downstream water surface elevation (hourly data is necessary to account for tidal influences within the Columbia River), and mean daily Cowlitz and Coweeman River flow values was available between water years 1990 and 1996. Cowlitz sediment inflow values (in cubic meters per second for 6 size fractions ranging from 0.04 mm to 1.41 mm) was developed from available Cowlitz River sediment sample data for this period. A high flow period and a typical flow period on the Cowlitz River were selected to investigate the dike impacts. The time series period from September 20, 1991 to April 1, 1992 is a high Cowlitz River flow period and from October

1, 1993 to April 1, 1994 is a typical flow period. These two water years (1992 and 1994) within the available hydrologic records (Figure 5), were selected for the purpose of this study.

Model Boundary Definitions At each model boundary, either a water surface elevation or a flow is specified. Models must include at least one boundary where water surface elevation is defined and one boundary where flow is given. The remaining boundaries can specify water level or flow. This model has 4 model boundaries: the starting water surface elevation in the model is defined on the Columbia River about 1.5 miles downstream from the Cowlitz confluence, incoming flow from the Columbia River is input approximately 4.5 miles upstream from the Cowlitz confluence, Cowlitz inflow and incoming sediment is defined at a boundary 4.5 miles upstream along the Cowlitz River, and Coweeman River inflow is entered upstream from the Highway 432 Bridge.

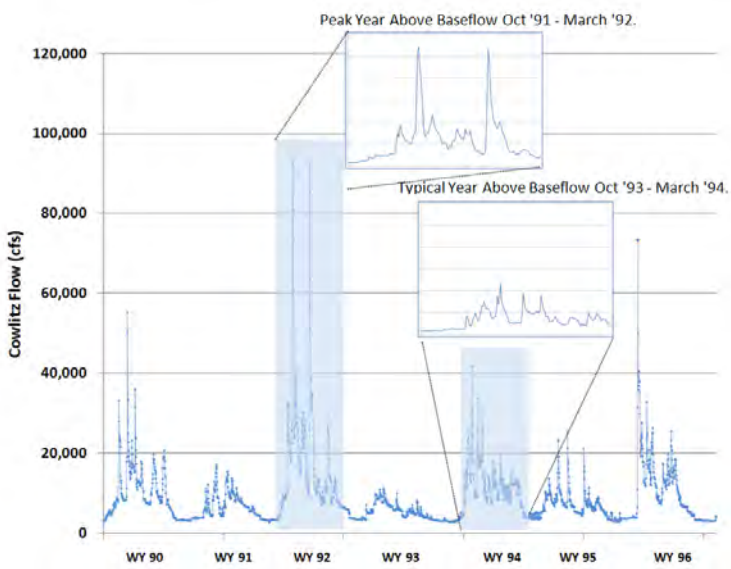

Figure 5 Cowlitz Flow (Water Years 1990 to 1996).

RESULTS

Preliminary model results are presented and discussed. It is important to note that the placement and height of the dikes has not been optimized using the numeric model. Rather, it has been shown that the model can serve as an effective tool in measuring the potential benefits a dike field.

<u>High Flow Water Year – 1992</u> Sediment transport effectiveness of the dike system was evaluated for a high Cowlitz River flow year by comparing deposition volumes within four reaches of the Lower Cowlitz River for five observation periods within the 1992 water year hydrograph. Figure 6 shows the spatial reach breakdown of Reaches 1 through 4 (upstream to downstream). These reaches were defined for geomorphic reasons: Reach 1 is the initial dike field at the upstream end of the model, Reach 2 includes a large radius left bend with long dikes, Reach 3 is a long right bend with small dikes, and Reach 4 is the downstream most area near the mouth of the Cowlitz, Carol's Channel, and the confluence with the Columbia River.

Figure 6 Lower Cowlitz Dike Study Reach Delineation.

The high flow period of interest included flows above base level for water year 1992 and was divided into 5 key observation periods. The first period (Observation Period 1) is characterized by low flow leading to a large peak flow period (Observation Period 2), a medium high flow period (Observation Period 3), another large peak (Observation Period 4), and the receding limb of the hydrograph (Observation Period 5). These temporal divisions can be seen in Figure 7.

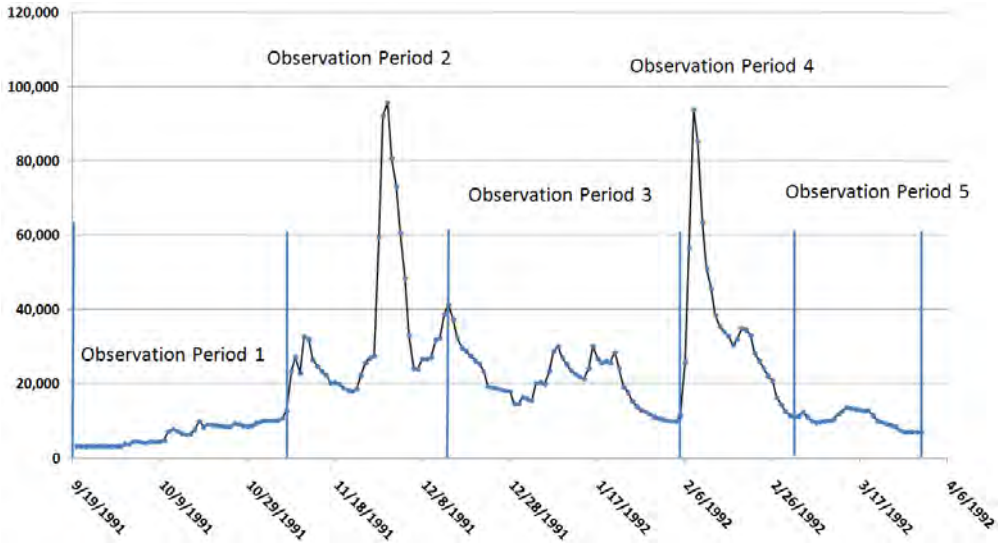

Figure 7 Observation Periods within the WY 1992 Cowlitz River Flow Hydrograph

Sediment volumes were calculated per reach by subtracting individual cell bed elevations at the end of an observation period from the initial bed elevations at the beginning of that observation

period and multiplying by individual cell areas. The incremental changes were combined for the reaches within the active channel, or the area where dredging would be anticipated.

Existing Case - Baseline Model For the existing condition model, the model domain is generally degredational by about 500,00 cubic yards for the high flow period. The most significant scour occurs during the high flow event of period 2. Interestingly, the second high flow event during observation period 4 is generally aggredational. Because of necessary assumptions for the inflowing sediment load, it is best to consider these results in a relative sense to the with dike condition. Results for the high flow water year existing condition are summarized in Table 1.

Table 1 Scour and Deposition by Reach and Observation Period - Baseline Case (cubic yards).

Baseline Case without Pile Dikes (***scour is negative**)

Obervation Period	<----------Reach----------> 1	2	3	4	
1	33	(1,895)	(72,321)	38,060	(36,125)
2	224,200	(241,586)	(418,334)	(249,868)	(685,587)
3	136,428	(4,528)	3,238	(14,741)	120,397
4	70,371	123,485	(102,212)	(39,422)	52,222
5	2,726	13,526	219	(91)	16,379
	433,758	(110,998)	(589,410)	(266,062)	(532,714)

Proposed Case - Dike Model The dike model of the Lower Cowlitz shows the same trends for scour and deposition throughout the Observation Periods, except for a notable difference during Observation Period 4. The dike model encourages a large overall scouring trend during the second peak (Observation Period 4), whereas the baseline case showed deposition during this period. Results for the dike model are summarized in Table 2. Based on the relative results of the model, it is expected that the dikes will reduce the sediment deposition trends observed in the lower Cowlitz

Table 2 Scour and Deposition by Reach and Observation Period - Dike Case (cubic yards).

Pier Dike Case Sediment Change per zone (scour is negative)

Obervation Period	<----------Reach----------> 1	2	3	4	
1	149	(33,775)	(61,468)	54,976	(40,118)
2	67,259	(957,300)	(321,785)	(248,416)	(1,460,242)
3	132,378	51,778	(30,808)	(22,711)	130,638
4	4,399	68,851	(61,323)	(219,753)	(207,826)
5	12,853	5,412	(11)	391	18,645
	217,037	(865,033)	(475,394)	(435,513)	(1,558,903)

Comparison - Dike Effectiveness High Flow Year The dikes as initially modeled may extend up to 300 feet from the river bank into the channel through the upper reaches (Reaches 1 and 2). At high flow levels the large dikes in these reaches effectively concentrate flows and enable increased sediment transport. The downstream dikes are not as long, but with the exception of Reach 3, which has very short dikes, they are still effective in their ability to increase sediment transport through the downstream reaches. Table 3 shows a direct comparison between the results of the baseline and dike models.

Table 3 Effectiveness of Dikes to Encourage Sediment Mobility (cubic yards).

Pier Effectiveness
(increased sediment transport efficiency is positive)

Obervation Period	<----------Reach----------> 1	2	3	4	
1	(116)	31,879	(10,853)	(16,916)	3,994
2	156,942	715,714	(96,549)	(1,452)	774,655
3	4,049	(56,306)	34,046	7,970	(10,241)
4	65,973	54,634	(40,889)	180,331	260,048
5	(10,127)	8,114	229	(483)	(2,266)
	216,720	754,035	(114,016)	169,451	1,026,190

Typical Water Year – 1994 The 1994 typical water year study period analysis was completed similar to the high flow year. Table 4 summarizes existing condition model results by reach and observation period and Table 5 summarizes proposed condition results. Table 6 provides a direct comparison of results. Similar to the high water year, it is best to consider result in a relative sense. The with dike condition shows about a 60 percent increase in the scour within the model domain. It is important to note that the absolute quantities of sediment are not validated, and all changes should only be considered in a relative sense. It is generally know that the study reach is aggredational under existing conditions. Changes in the inflowing sediment load and the sediment transport functions can be used to make necessary adjustments to the model.

Table 4 Scour and Deposition by Reach and Observation Period - Baseline Case (cubic yards).

Baseline Case without Pier Dikes (scour is negative)

Obervation Period	<----------Reach----------> 1	2	3	4	
1	0	(40)	(16,628)	2,199	(14,470)
2	11,586	(28,905)	(295,439)	173,096	(139,662)
3	4,435	(22,911)	(10,920)	(43,850)	(73,247)
4	9,027	(20,299)	(2,432)	(25,469)	(39,174)
5	46,340	(13,741)	2,681	(29,682)	5,598
	71,388	(85,896)	(322,739)	76,293	(260,954)

Table 5 Scour and Deposition by Reach and Observation Period - Dike Case (cubic yards).

Pier Dike Case (scour is negative)

Obervation Period	<----------Reach----------> 1	2	3	4	
1	0	(8,008)	(15,359)	5,112	(18,255)
2	9,491	(106,161)	(262,407)	130,141	(228,936)
3	110	(9,053)	4,995	(3,556)	(7,504)
4	12,577	(77,885)	(16,121)	(69,997)	(151,426)
5	57,394	(45,044)	11,044	(32,643)	(9,249)
	79,573	(246,152)	(277,848)	29,057	(415,370)

Table 6 Effectiveness of Dikes to Encourage Sediment Mobility (cubic yards).

Dike Effectiveness
(increased sediment transport effiency is positive)

Obervation Period	<----------Reach----------> 1	2	3	4	
1	(0)	7,968	(1,269)	(2,913)	3,785
2	2,095	77,257	(33,032)	42,955	89,274
3	4,325	(13,858)	(15,915)	(40,295)	(65,743)
4	(3,551)	57,587	13,689	44,528	112,253
5	(11,054)	31,303	(8,363)	2,961	14,847
	(8,185)	160,256	(44,891)	47,236	154,416

CONCLUSIONS

A model has been developed which can be used to evaluate the effectiveness of a proposed dike field on the lower Cowlitz River. Based on preliminary and uncalibrated simulations, it appears the dike field can effectively reduce the sediment deposition. The model will be refined with additional information about inflowing sediment loads and the sediment transport functions will be calibrated such that predicted depositional patterns are consistent with observed patterns.