MEMORANDUM CH2M HILL

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DATE:	May 9, 1995
SUBJECT:	Smith & Bybee Lakes Tidal Exchange Analysis
PROJECT:	OPW40024.A0.02

Following is a description of the approach to modeling the water exchange between Smith & Bybee Lakes and the Willamette River along with results of the model runs.

Background

The Lower Columbia Slough is a nine mile-long, tidally-dominated tributary to the Willamette River. Smith & Bybee Lakes are connected to the Lower Columbia Slough by the North Slough at a point approximately 1-1/2 miles upstream of the Willamette River. A discharge structure between the North Slough and Smith & Bybee Lakes allows water exchange between the slough and the lakes when water levels in the Willamette River and the sloughs are greater than 10.5 feet above mean sea level (MSL). No water is exchanged between the lakes and the North Slough for river levels less than 10.5 feet MSL.

A suggestion has been made to remove this control structure in order to return the lakes to their historical condition, opening them to the tidal influences of the Columbia River. Removing the control structure can impact the lakes in two ways: (1) Present habitats within the lakes may be affected by changes in water levels, and (2) Water exchange between the lakes and Willamette River may affect the water quality in the lakes. Potential water quality affects could be to improve water quality due to better flushing of the water in the lakes or negatively impact the quality of water in the lakes due to introduction of leachate from St. John's landfill that leaches into the North Slough..

Another option is to improve the flushing of the system by discharging additional water into both the Smith & Bybee Lakes. With the discharge structure removed, this augmentation flow would be used to further increase flushing of the lakes. If the discharge structure were left in place, the flow would improve flushing and could be used to manage lake water levels.

Scope

The Port of Portland has requested the development of a first approximation model for indicating the tidal exchange between the Smith & Bybee Lakes and the Columbia Slough due to the removal of the existing control structure. The scope of work requires that the model

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predict water levels within each of the lakes as well as the volume and extent of tidal mixing. The model should consider:

- Tidal movements in the Columbia Slough, to which lakes (in series) discharge
- Groundwater infiltration/exfiltration, controlled by the Columbia River level
- Bathymetry of the lakes
- Cross-sectional areas of the inlets between the Columbia Slough and the lakes, and between the lakes, and geometry and roughness of connections
- Surface water elevations and areas within the lakes
- Precipitation
- Evapotranspiration

General Approach

The modeling described below focuses on predictions of water surface elevations inside the lakes and the exchange of water between the lakes and the Willamette River resulting from removal of the control structure. The water exchanged between the Willamette River and Smith & Bybee Lakes and, consequently, the water surface levels in the lakes will be driven primarily by changes in the water surface level of the Willamette River.

Semi-diurnal, periodic variations in water surface elevation occur due to tides with mean tidal ranges in the Willamette River of approximately 1.8 feet (NOS. 1993). Variations in the water surface elevation of the Willamette River also occur due to changes in river flow. Time scales of these changes can be on the order of days to weeks. Their magnitudes vary. A summary of river stage data from 1988 through 1994 are shown in the attached Figures 1 through 8.

Three groups of model runs were made to evaluate the influence removal of the discharge structure and optional management strategies such as flow augmentation would have on water surface elevations and flushing in Smith & Bybee Lakes. These runs are grouped as follows:

- **Tidal fluctuations**, where the response of the lakes to mean tidal fluctuations in the Willamette River was evaluated,
- **River stage variations**, where the responses of the lakes to longer term variations in river level resulting from increases or decreases in flow were analyzed, and,
- **Flow augmentation**, where the influence of discharging additional augmentation flow into the lakes is assessed.

The model used for this evaluation considers flows resulting from water surface elevation changes and from user defined augmentation flows. Groundwater flows, precipitation, and evapotranspiration will generally not be significant compared to these flows and were not analyzed.

Model Description

The following analysis is based on the use of a hydraulic model, INBAYS, that has been used to predict the response of a number of tidally influenced systems (San Dieguito Lagoon, Indian River Lagoon, Humbolt Bay, Agua Hedionda Lagoon, Bataquitos Lagoon). INBAYS will predict water surface elevations and channel velocities for a series of basins connected by channels with the final basin connected to the ocean (or in this case, to a tidally influenced river or slough).

It should be considered a screening level model. This model is relatively unsophisticated compared to other hydrodynamic models (such as one and two dimensional finite-element or finite-difference models) that could be used to model this system. It will predict overall system responses to tidal inputs, but will not predict detailed localized currents or water levels.

The advantage of INBAYS is that the level of effort required for model setup and running is significantly less than that required of more sophisticated models. It has proved accurate and reliable for predicting overall basin water surface levels and water velocities within the channels connecting the basins. This approach is adequate for providing a first approximation of the tidal exchange between the Smith & Bybee Lakes and the Columbia Slough.

INBAYS will model up to three basins connected in series by channels to the ocean or another tidally influenced water body. The first basin is connected to the ocean by a channel with defined geometry and roughness. The second basin is connected to the first by a second channel with defined characteristics, and the third basin is, likewise, connected to the first.

Basins are defined in terms of their surface areas and the rate of change of the surface area with changes in water surface elevation. Channels are defined by their overall geometry (length and average cross-sectional dimensions) as well as coefficients for calculating head losses for the water flowing between the basins.

The model calculates channel flows and basin elevations in response to defined tidal elevations at the boundary of the model. Addition flow from other sources such as discharges or minor tributaries may also be defined into any of the basins individually.

Modeling Approach

INBAYS is designed to analyze series systems (i.e. systems with basin and channel elements connected "inline"). The analysis of Smith & Bybee Lakes requires that the model consider tidal movements in the Lower Columbia Slough as well as exchange between the Columbia Slough and the Smith & Bybee Lakes. This system, consisting the Lower Columbia Slough, the North Slough, and the Smith & Bybee Lakes, is <u>*not*</u> a series system.

The Lower Columbia Slough system is shown in Figure 9. The North Slough runs into the Lower Columbia Slough at a juncture approximately 1-1/2 miles from the mouth of the

Columbia Slough. The water surface elevation in the Smith & Bybee Lakes is a function of the water surface elevation at this junction and head losses in the North Slough due to flow between the Lakes and the Columbia Slough. The water surface elevation at the junction is in turn a function of the water elevation in the Willamette River and the head losses in the section of the Columbia Slough below this junction due to the *combined* flows from North Slough *and* from the portion of the Lower Columbia Slough upstream of this junction.

For each model run, the model was set up and run in two parts or phases. The first phase was used to predict the water surface elevations at the junction due to the combined flows from the water bodies upstream of the junction. For this phase, the model was set up with a single basin representing the combined volumes of the Smith & Bybee Lakes, the North Slough, and the upstream portion of the Lower Columbia Slough. This basin is connected to the Willamette River by the downstream portion of the Lower Columbia Slough. The results give predicted water surface elevations at the junction.

The second phase was used to calculate the response of the water levels in the lakes based on the predicted water surface elevation changes at the junction. Resulting water surface elevations from phase 1 were used to drive the phase 2 model. For phase 2, the Smith & Bybee Lakes were modeled as a single basin connected to the Columbia Slough by the North Slough.

The bathymetry of the Smith & Bybee Lakes show a distinct channel connecting the lakes at elevations below about 7 feet MSL. For water elevations above the 7 foot contour, the channel broadens and the lakes soon merge together. As a first approximation, the lakes were assumed to act as a single basin

Model Input

As indicated above, the model was run to evaluate the influences of tides, changes in river stage, and augmentation flow on the water surface response and flushing for the Smith & Bybee Lakes. Input used for each of these three sets of model runs are described below.

Tidal Exchange

The first model was run for a mean tidal range of 1.8 feet in the Willamette River (NOS, 1993) at mean river levels of 6, 7, 8, and 10 feet MSL. These mean river levels were selected based river stage data collected on the Willamette River near Portland between 1988 and 1993. These data, shown in Figure 1, indicate the average river stage on the Willamette River ranges from approximately 4 feet MSL during October to a maximum of approximately 11 feet in June. These represent average daily river stages, river levels may be higher than 11 feet or lower than 4 feet at a particular time during the day. Flow into the Smith & Bybee Lakes will be limited by the depth of the North Slough. Contour maps of the North Slough (from Wells, 1992b) indicate maximum bottom elevations in the channel of higher than 5 feet MSL. Also, the base of the existing control structure is at approximately 6 feet MSL. For the

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purposes of this analysis, it was assumed that water would not exchange between the Columbia Slough and Smith & Bybee Lakes at levels lower than 6 feet MSL.

For the phase 1 model, tidal water surface elevations for the Willamette River at the mouth of the Columbia Slough were approximated as sinusoidal water level oscillations around the mean water surface elevation. For example, for the model runs for an 8 foot mean water level, the water surface was varied sinusoidally from a maximum of 8.9 feet MSL to a minimum of 7.1 feet MSL. Because it was assumed that water would not be exchanged with the Smith & Bybee Lakes at levels below 6 feet MSL, a truncated curve was used for the 6 foot mean water level case with water levels held at 6 feet during the time the tidal elevations were below 6 feet. Curves representing these tidal fluctuations are shown in Figure 10.

Input used to define the models are summarized in Table 1 below. Geometric data used to define these models are based on data of bathymetric contours, and surface area and capacity versus water surface elevation for the components of the system presented in Wells (1992b).

Willamette River Changes

Magnitudes and duration of water level changes in the Willamette River vary with changes in river flow. Figures 2 through 8 show daily variations in river stage for the 1988 through 1994 water years. As can be seen in the figures, much of the time, the river level will be near or below 6 feet with periods of elevated water level over 6 feet.

To evaluate the general affects of water level changes on the elevations and flushing inside Smith & Bybee Lakes, general river level changes were characterized as periodic water level fluctuations of with peaks between 8 and 12 feet and periods of approximately 1 to 2 weeks. The water level fluctuations were modeled as sine-waves with mean water levels of 7, 8, 9, and 10 feet MSL, amplitudes of 1 or 2 feet (measured from the mean water level to the crest), and periods of 1 or 2 weeks.

Geometric input used to define the channels and basins are the same as water surface elevation models for the tidal exchange runs. Water surface elevation variations used to drive the models are presented in Table 2. Preliminary runs of the phase 1 model showed relatively little muting of the water surface fluctuations between the Willamette River and the junction at the North Slough. As a result, the input shown in Table 2 were applied directly to the phase 2 model.

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Table 1. Model Input, Tidal Exchange

Water Surface Elevation (ft, MSL)	Parameter	Units	Phase 1 Model (1)	Phase 2 Model (2)
6	Basin Surface Area	acres	614	430
	dA/dH (basin) [(3)]	acres/ft	186	167
	Channel Mean Depth	ft	6	2
7	Basin Surface Area	acres	803	600
	dA/dH (basin) [(3)]	acres/ft	186	167
	Channel Mean Depth	ft	7	3
8	Basin Surface Area	acres	1022	800
	dA/dH (basin) [(3)]	acres/ft	186	167
	Channel Mean Depth	ft	8	4
10	Basin Surface Area	acres	1301	1050
	dA/dH (basin) [(3)]	acres/ft	89.5	72.5
	Channel Mean Depth	ft	10	6
ALL	Channel Bottom Width	ft	50	60
	Channel Side Slope (Left)	--	3.5	3.5
	Channel Side Slope (Right)	--	3.5	3.5
	Channel Length	ft	8800	4590
	Tidal Amplitude	ft	0.9	from phase 1 results
	Tidal Period	hrs	12.4	12.4

(1) Phase 1 model combines the Smith & Bybee Lakes, North Slough, and Columbia Slough east of the North Slough together as one basin. Channel dimensions are based on the geometry of the Columbia Slough west of the North Slough.

(2) Phase 2 model considers the Smith & Bybee Lakes as a single basin. Channel dimensions are based on the geometry of the North Slough.

(3) dA/dH = the change in surface area of the basin with changes in water surface elevation.

Table 2. Model Input, River Stage Changes.		
Water Surface Elevation (ft, MSL)	Amplitude (1) (ft)	Period (days)
7	1	7
7	1	14
8	2	7
8	2	14
9	1	14
9	2	14
10	1	14
10	2	14

(1) Total range is 2 times the amplitude. (i.e. for a mean water level of 7 feet with an amplitude of 1 foot, the range is from 6 to 8 feet)

Flow Augmentation

The effects of flow augmentation were evaluated by adding an additional 32 cubic feet per second (cfs) of flow to the basin in the phase 2 models described above for the tidal exchange analysis.

Model Results

Table 3 presents a summary of results of the model runs in terms of the response of the system to water surface elevation changes in the Willamette River. The fifth and sixth columns present the results from the phase 1 and phase 2 models respectively. The amplitudes from the phase 1 results were used as the input tides at the end of the North Slough for the phase 2 models. These results are shown graphically in the attached Figures 11 through 25.

Flushing Times

Flushing time is a measure of the rate of water exchange between the water in the lakes and the water from the Willamette River. The flushing time represents the amount of time required for the water inside the lakes to be replaced with "new" water from outside. For the

Table 3. Model Results - Response of Smith & Bybee Lakes to Water Surface Elevation Changes in the Willamette River.

Mean River Level (ft, MSL)	Water Surface Fluctuation Frequency	Augmentation Flow to Lakes (cfs)	Amplitude at Willamette River (ft)	Amplitude at Junction (ft)	Amplitude in Smith & Bybee Lakes (ft)
Tidal Exchange					
6	12.4 hrs	0	0.9	0.15	0.035
7	12.4 hrs	0	0.9	0.21	0.05
8	12.4 hrs	0	0.9	0.23	0.07
10	12.4 hrs	0	0.9	0.27	0.11
Willamette River Level Changes					
7	1 week	0	--	1.00	0.93
7	2 weeks	0	--	1.00	1.00
8	1 week	0	--	2.00	1.72
8	2 weeks	0	--	2.00	1.96
9	2 weeks	0	--	1.00	1.00
9	2 weeks	0	--	2.00	2.00
10	2 weeks	0	--	1.00	1.00
10	2 weeks	0	--	2.00	2.00
Tidal Exchange with Flow Augmentation					
7	12.4 hrs	32	0.9	0.21	0.05
8	12.4 hrs	32	0.9	0.23	0.07
10	12.4 hrs	32	0.9	0.27	0.11

Note: Amplitude designates the distance of the peak/trough from the mean water level. The total water surface elevation range is 2 times the amplitude.

purposes of this analysis, the flushing time was taken to be the number of days required to replace 95% of the water in the lakes assuming complete mixing within the lakes during each cycle.

For water exchange driven by water level fluctuations in the Willamette River, the rate at which "new" water is introduced to the system is a function of the volume exchanged during each cycle and an exchange coefficient which tells what fraction of the exchanged water is "new" water and what fraction is water that exited the lakes during the previous cycle.

For the system modeled, as the river level falls, water flows from the lakes, through the North Slough into the Lower Columbia Slough and then to the Willamette River. At the end of this "ebb" cycle, the water remaining in the North Slough is "old" water that was previously in the lake. As the Willamette River rises again, this "old" water is reintroduced into the Smith & Bybee Lakes followed by the "new" water from the Willamette River and Lower Columbia Slough. The exchange coefficient is therefore calculated as:

$$C_E = 1 - (V_{NS}/V_i)$$

where:
- C_E = Exchange Coefficient
- V_{NS} = Volume of water in the North Slough
- V_i = Volume of water entering the lake from the North Slough during each cycle.

The concentration of "new" water in the lakes was calculated as a function of time based on the water exchange across the lake boundary and the exchange coefficient. The flushing times resulting from these calculations are shown in Table 4.

Discussion

Removal of the control structure between the North Slough and the Smith & Bybee Lakes would result in changes in the water surface elevations within the lakes as well as increasing flushing with water from outside the lakes.

Water Surface Elevations

The depth of the North Slough will limit the times that water will be exchanged between the Willamette River and Smith & Bybee Lakes to times where the Willamette River stage is greater than about 6 feet MSL. Review of historic river stage data (Figures 1 through 8) indicate that the Willamette River is rarely higher than 6 feet MSL between July and November. The water levels are higher between December and April but periodically drop below 6 feet MSL. The water levels in the Willamette River were observed to be consistently above 6 feet during the months of April, May, and June. For the periods at which the water level drops below 6 feet, removal of the structure will not result in result in greater flushing of the lakes and water levels inside the lakes will be limited to a maximum elevation of about 6 feet MSL.

Table 4. Flushing Times for Smith & Bybee Lakes Model Runs.

Input					
Mean River Level (ft, MSL)	Water Surface Fluctuation Frequency	Amplitude at Willamette River (ft)	Amplitude in Smith & Bybee Lakes (ft)	Exchange Coefficient	Flushing Time (days)
Tidal Exchange					
6	12.4 hrs	0.9	0.035	0.05	411
7	12.4 hrs	12.4 hrs	0.05	0.33	70
8	12.4 hrs	12.4 hrs	0.07	0.52	51
10	12.4 hrs	12.4 hrs	0.11	0.93	37
Willamette River Level Changes					
7	7 days	1.00	0.93	0.96	17
7	14 days	1.00	1.00	0.97	32
8	7 days	2.00	1.72	0.98	13
8	14 days	2.00	1.96	0.98	24
9	14 days	1.00	1.00	0.96	67
9	14 days	2.00	2.00	0.98	32
10	14 days	1.00	1.00	0.96	79
10	14 days	2.00	2.00	0.98	38
Tidal Exchange with Flow Augmentation					
6	12.4 hrs	0.9	0.035	0.00	18
7	12.4 hrs	0.9	0.05	0.08	38
8	12.4 hrs	0.9	0.07	0.43	39
10	12.4 hrs	0.9	0.11	0.65	33

Note: Amplitude designates the distance of the peak/trough from the mean river or lake water level. The total water surface elevation range is 2 times the amplitude.

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For given river levels above 6 feet MSL, tidal fluctuations will have relatively small effects on the water surface elevations within the lakes. Lake levels do not respond quickly to changes in river level because of the constrictions to flow caused by the North and Lower Columbia Sloughs and the relatively large volumes of water that must be exchanged per unit change in lake elevation. As a result, tidal fluctuations on the order of 1.8 feet will result in diurnal changes within the lakes on the order of 1 to 2 inches.

Greater changes in lake elevations will occur due to changes in river stage. The lake levels are able to respond more fully to these more gradual changes (on time scales of days to weeks). For example, a 2 foot increase in the Willamette River level over the period of one week would result in an increase in the lake levels of approximately 2 feet.

Review of historic river stage data indicate a river stage range in the Willamette River of from less than 2 feet MSL to greater than 12 feet MSL. This would correspond to lake levels of from less than 6 feet to greater than 12 feet MSL with daily variations due to tides on the order of inches.

Augmentation flows will tend to raise the mean lake levels slightly, but these changes are insignificant compared to the influences of river stage on the mean lake levels.

Flushing

Removal of the control structure alone would not result in increased flushing of the lakes over a large portion of the year. As discussed above in the discussion of water elevations, essentially no water would be exchanged between the Willamette River and the lakes during a typical year between the months of July and November. Between December and April, water levels would typically rise high enough for water to be exchanged and flushing rates would be driven by a combination of tidal pumping and river elevation changes. During this time, however, there is expected to be periods of low water levels in which no exchange occurs. During May and June of a normal year, water levels are high enough for continuous water exchange due to a combination of tidal pumping and river elevation changes.

Based on the model predictions, tidal flushing of the lakes resulting from removal of the control structure would be small for river levels near 6 feet MSL. Relatively small tidal prisms combined with reintroduction of lake water from in the North Slough makes tidal pumping an inefficient mechanism for flushing the lakes at low river levels. The reintroduction of water from the North Slough becomes more significant at low water levels where the volume of water in the North Slough is a large percent of the water exchanged each cycle. This is reflected in the low exchange coefficient for the 6 foot river level case. Exchange rates due to tidal pumping increase at higher river elevations. The combined effects of decreased resistance in the deeper channel and greater surface areas for the lakes (resulting in greater volumes exchanged over each tidal cycle) make tidal pumping a more efficient mechanism for tidal flushing at higher river levels.

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Flow augmentation decreases the tidal component of flushing by reducing the amount of tidal flow into the lake during each cycle. This is reflected by the reduction in the exchange coefficients in Table 4 between the runs with and without augmenting flow. Overall flushing rates, however, are increased due to the constant input of "new" water into the system from the augmentation flows. The greatest increases are seen during periods of low water level where the tidal component is relatively inefficient and the low lake volumes are flushed fairly quickly by the continuous flow. Flow augmentation will have the greatest impact during times of low river stage where tidal flushing is weak or where water would not normally be exchanged between the lakes and the river.

Due to the observed time scales and magnitudes of river stage changes, these changes would be the dominant factor in exchanging water between the Willamette River and Smith & Bybee Lakes during periods of time that the river levels exceed approximately 6 ft MSL. Tidal effects would contribute little to the flushing at low water levels. Tidal effects would have greater relative impacts during times of higher river stage (typically occurring around May) where the contribution of the tidal component can approach that due to typical river level changes. Neither river stage changes or tides, however, would contribute to flushing the system during periods with river levels below about 6 feet MSL.

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