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The Columbia Slough

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The Columbia Slough

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Technical Report EWR-2-97

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Table of Contents

List of Figures

List of Tables

Foreword

This report was written in an attempt to provide the public and Bureau of Environmental Services Staff with a summary of work accomplished on the Columbia Slough system by Portland State University and other consultants working on the Slough over the last 6 years. An attempt was made to create an easy-to-read report with important overviews of the "big picture", glossary of definitions, index, and further details to assist in technology transfer.

Acknowledgments

The Columbia Slough Watershed Manager, Mary Abrams, and the MCDD1 director, Tim Hayford, were instrumental in providing support and information for this report. Chris Berger, graduate student at PSU, has also been instrumental in providing modeling of the Slough system over the last few years. There are many individuals who have

contributed to our understanding of the Slough system over the years and they include (not in order of importance): David LaLiberte, Montgomery Watson, Inc.(formerly PSU research assistant); Lianne Scull and Steve Hawkins (formerly Columbia Slough Watershed Managers); Mike Eberle, Robert Annear, Michael Staats, and Greg Savage, all graduate students at PSU; David Collins, CH2MHill (former PSU student); Joanna Karl, Jim Morgan, and Dennis O'Neal at METRO; Lori Faha, Unified Sewerage Agency (formerly COP/BES Columbia Slough manager); staff at CH2MHill: David Crawford, Dawn Sanders, Shelley Wei (former PSU graduate student), Mark Laswell; staff at HDR Engineering: such as Bruce Willey; staff at Brown and Caldwell: such as Claudia Zorchak; Tom Davis, Montgomery Watson (formerly COP/BES); Paul Fishman; Ogden Beeman Associates staff; and other COP/BES staff: Susan Barthell, Dwane Leanards, Amy Chomowitz, Nancy Hendrickson, Linda Schaeffler, Lester Lee, Holly Juza; and State of Oregon DEQ staff: Bob Baumgartner, Sonja Biorn-Hansen, Neil Mullane, Steve Snurbush, Marilyn Fonseca; MCDD1 staff: David Hendricks and others; Woodward-Clyde staff: Eric Strecker, Mike Fowler; Parametrix staff including Dave Morten; PSU faculty and staff involved in the sediment study: Dr. ShuGuang Li, BinHong Wu, Min Chen, and Dr. Y. Shen; Roger Sutherland, formerly at OTAK; Stan Geiger, of SRI-Shapiro; and Molly Aldolfson of Adolfson and Associates. This list is by no means all-inclusive, but they represent some of the individuals who have been involved in the Slough over the years and have contributed to our understanding of this unique system.

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1. The Columbia Slough

The Upper and Lower Columbia Slough are each long (about 9 miles) and narrow (from 50 ft to 200 ft wide) water bodies in the Portland metropolitan area in Multnomah County. The Lower Columbia Slough, as shown in Figure 1, is connected to the Willamette River where it experiences a tidal fluctuation of its water surface of between 1 to 3 ft. Inflows to the Lower Columbia Slough include *combined-sewer-overflows (CSOs), storm water (from storm water pipes and from pump stations on the Northern side of the Lower Slough called Penn-1 and Penn-2 pump stations), water from Smith and Bybee Lakes*, *leachate from the St. John's Landfill*, *and inflows (both pumped and gravity inflows) from the Upper Columbia Slough at MCDD1*.

The Upper Columbia Slough, shown in Figure 2, was historically maintained to provide irrigation water to agricultural and commercial users in the summer months. The Upper Slough is connected by pipes and an overflow weir during the Fall, Winter, and Spring to Fairview Lake. During the summer, Fairview Lake is connected to the Upper Slough only by flow over and leakage through the weir. Water is also pumped from the Upper Slough to the Lower Columbia Slough at a pump station at *MCDD1 (Multnomah County Drainage District #1*) and from the Upper Slough to the Columbia River at *MCDD4 (Multnomah County Drainage District #4*). At MCDD1, pipes also allow gravity flow from the Upper Slough to the Lower Slough. Other inflows to the Upper Columbia Slough include groundwater and storm water from the Portland International Airport and other industrial, commercial, and residential neighborhoods in the area.

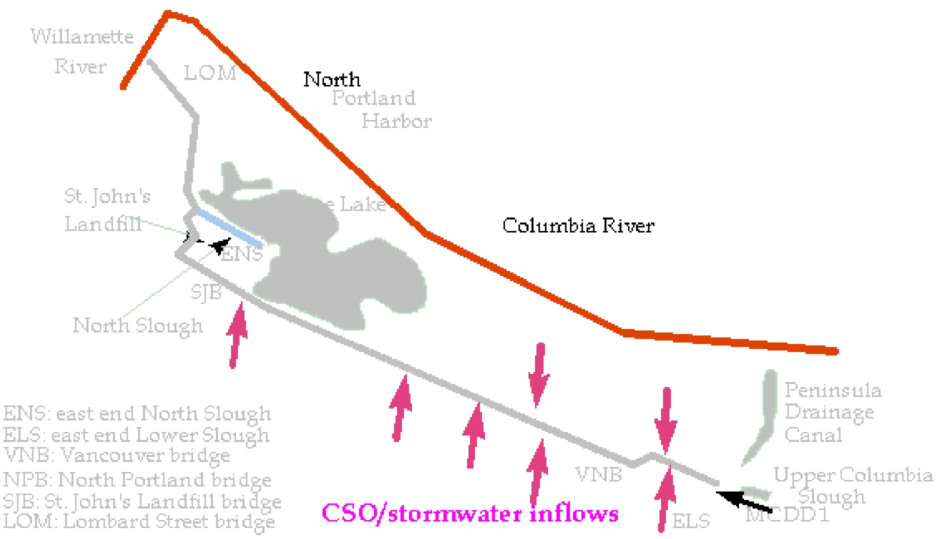

Figure 1. The Lower Columbia Slough.

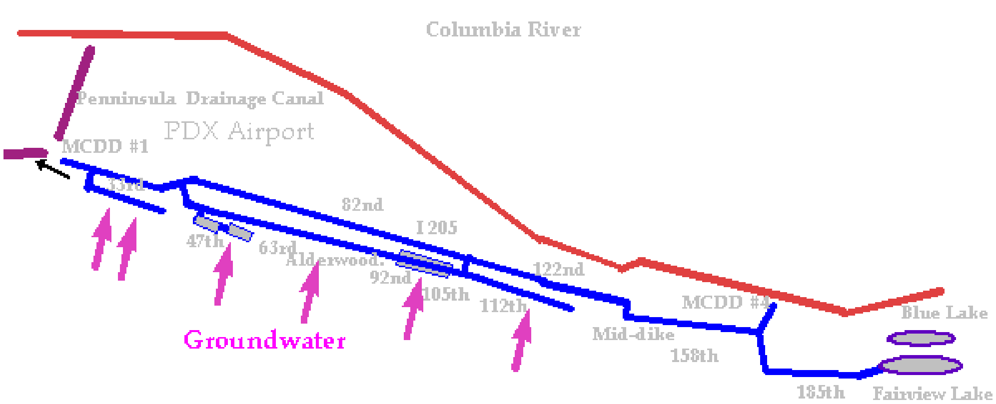

Figure 2. The Upper Columbia Slough.

2. Water Quality Problems in the Columbia Slough

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ater quality problems in the Slough affect how fish and aquatic life and we use the resource. Table 1 shows a list of water quality problems in the Columbia Slough along with potential sources of pollution.
Table 1. Water quality problems in the Columbia Slough.

Water quality problem	Potential sources of problem	Description of impact - why is this of concern ?
pHpH levels above 8.5	excessive algal growth due to high nutrient levels of N and P; these nutrients could be coming from groundwater in the Upper Slough, St. John's LandfillSt. John's Landfill leachate, CSOCSOs, and stormwater inflows	High pHpH levels create a poor environment for fish and aquatic life; a summer problem
dissolved oxygendissolved oxygen levels below 4 mg/l	high organic loading from PDX International Airport's winter deicing activities, CSOCSOs, storm water, *sediment oxygen demand*, and groundwater	all fish and *aerobic* organisms require oxygen to live in the water environment, water deprived of oxygen will cause aerobic organisms to die or relocate, a summer and winter problem
algaealgae levels above 15 g/l chlorophyll a	excessive algal nutrients, N and P from groundwater and St. John's LandfillSt. John's Landfill leachate, CSOCSOs, and stormwater inflows	high algaealgae levels create high pHpH levels (see above) and create nuisance, aesthetic concerns by forming algal mats on the surface of the water, reducing water clarity (water looks muddy) and contributing to sediment oxygen demand by the settling of dead algal cells to the bottom muds, a summer problem
coliform bacteriabacteria levels above 200 colonies/100 ml	CSOCSOs and storm water inflows, as well as illicit sewer discharges	coliform bacteriabacteria themselves are harmless and exist in our intestines, but they indicate that there is some fecal contamination in the water - either from human or animal waste, a summer and winter problem
high water temperaturetemperatures	lack of shading and impounding water, lack of natural water level fluctuation	to support cold water fish such as Salmon, temperaturetemperatures of 14^{o}C (52.7^{o}F) are an optimal upper limit, this is only a summer issue
toxic metals and organics in sediments, water column, and fish tissue	unregulated and illegal discharges into the Slough, storm water and CSOCSO discharges, landfill leachate	Toxic compounds can be consumed by fish and other aquatic life that bioaccumulate the toxins in their tissue. This becomes a health hazard when humans consume the contaminated tissue and a health hazard to aquatic organisms.

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3. The Big Picture - Sources of Water Quality Problems

W here does the water come form in the Upper and Lower Columbia Slough ? The source of the water quality problems in the Slough can be traced to inflows to the system or historical activity in the area, such as building dikes and installing culverts.

Excessive Algae Growth

For example, what causes the high algae growth in the Slough in the summer months ? Excessive nutrients for algae growth - such as nitrogen (ammonia, NH_3-N, nitrate, NO_3-N) and phosphorus compounds (orthophosphate, PO_4-P), sunlight, and detention time in the system (the time a parcel of water stays in the Upper or Lower Slough before exiting into another water body) allowing enough time for algal growth. What is the source of the nutrients ? In the Upper Slough, the only significant source of water inflow during the summer is groundwater (this usually averages between 50 and 80 cfs). The groundwater comes from E. Multnomah County and contains high concentrations of nitrate (about 6 mg/l) and orthophosphorus (about 0.1 mg/l). Phosphorus limits algae growth since nitrogen is in such. Figure 3 shows the inflows (the relative volume of water over the summer period) from different sources during the summer of 1992 for the Upper Slough. (The Boeing source is water from a groundwater pump-and-treat system that discharges to the Upper Columbia Slough. There was no inflow from Fairview Lake in 1992 except leakage through a weir.) To show the source of orthophosphorus which causes excessive algae growth, Figure 4 shows which sources are the primary contributors for orthophoshorus. These figures show clearly that groundwater is the primary source of phosphorus during the summer months.

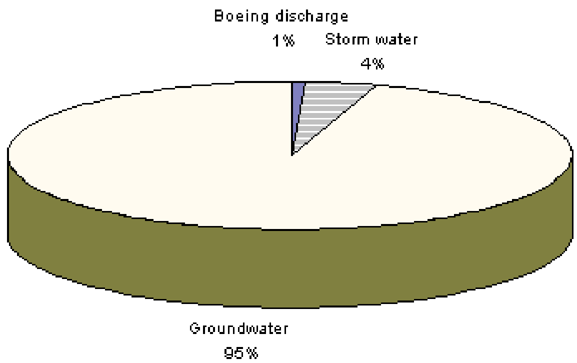

Figure 3. Percentage of average flows into the Upper Slough for the summer of 1992 (May-October).

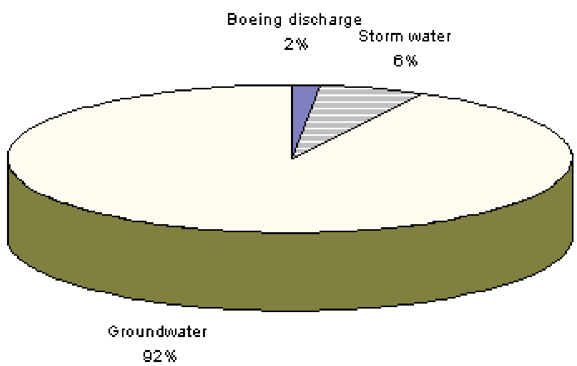

Figure 4. Percentage of orthophosphorus (PO_4-P) loading into the Upper Slough for the summer of 1992 (May-October) (The term loading refers to the rate of mass of phosphorus that is being discharged to the Slough.)

What about in the Lower Slough ? Figures 5 and 6 show the distribution of inflows and orthophosphorus mass loading to the Lower Slough during the summer of 1992. These show that the Upper Slough contributes most of the flow into the Lower Slough in the summer. Hence, inflows from the Upper Slough are the primary source of phosphorus for the Lower Slough in the summer.

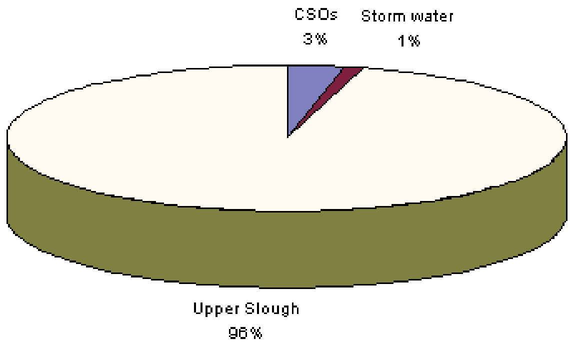

Figure 5. Average distribution of inflows to the Lower Columbia Slough during the summer of 1992 (May-October).

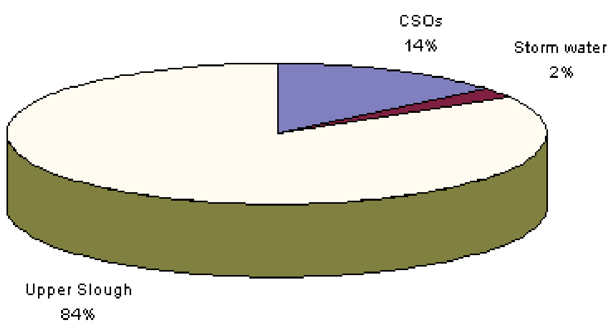

Figure 6. Percentage of orthophoshorus (PO_4-P) loading to the Lower Columbia Slough during the summer of 1992 (May-October).

Low Dissolved Oxygen

Low dissolved oxygen concentrations have been recorded in the summer near MCDD4. This was a result of stagnant water conditions when the mid-dike levee was closed and little or no pumping was made at MCDD4 into the Columbia River. The decaying algae in the water caused low dissolved oxygen conditions. The dead algae settle into the sediment and decay. The bacteria and zooplankton consume algae and oxygen, thus depleting the water if oxygen for fish and other aquatic life.

In the winter, low and zero dissolved oxygen has been recorded in the Slough system after warm rains following very cold conditions. The low dissolved oxygen is caused by bacterial breakdown of biodegradable organic material or of ammonia compounds. Sources of these compounds are storm water, CSOs, sediment accumulation from summer algae decomposition, urea (a deicier applied to the airport and to roads and bridges during freezing conditions, this compound readily breaks down to ammonia), and deicing chemicals from the Portland International Airport applied to airplanes to prevent ice formation on wings. These deicing compounds are called ethylene and propylene glycols and have an organic strength (when not diluted with water) over 10,000 times that of CSOs and storm water.

All storm water runoff from the PDX International Airport either infiltrates into the groundwater or runs off into the Upper Columbia Slough. During periods of CSO and storm water inflows when there were no antecedent cold weather conditions (when the airport would not usually be deicing aircraft), dissolved oxygen conditions in the winter were not below DEQ minimum standards of 4 mg/l. But following cold weather conditions (when aircraft and runway deicing were being used) and a warm rain (washing the deicing material into the Upper Slough), dissolved oxygen concentrations in the Slough often dipped below 4 mg/l. In an estimate of the loading of BOD (a measure of the biodegradable organics in the water), Figure 7 and 8 show the estimated loadings from storm water, the airport, and CSOs for the Upper and Lower Slough, respectively. [These estimates were made

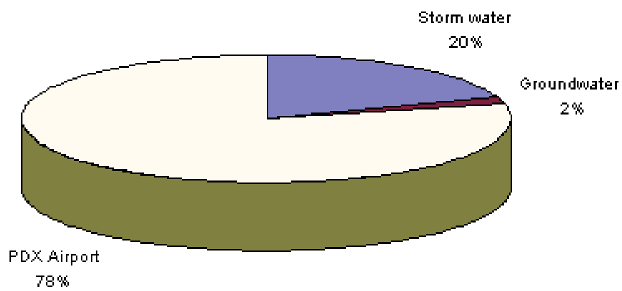

Figure 7. Estimated organic loading into the Upper Slough during the winter for a situation where the mid-dike levee was closed and all inflows from Fairview Lake were discharged into the Columbia River at MCDD4 for winter of 1995.

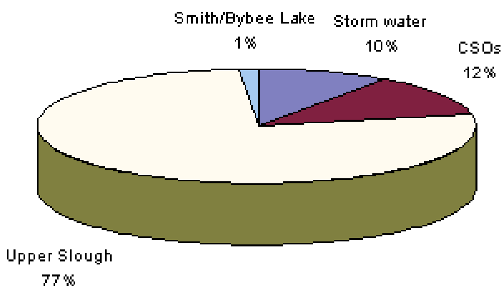

Figure 8. Estimated organic loading into the Lower Slough during the winter of 1995.

by using a model of the system to reproduce water quality data in the Slough and not from measurements.]

In these figures, the Upper Slough predominant source of biodegradable organics is the PDX Airport during periods following deicing of aircraft. In the Lower Slough, the primary source is the Upper Slough discharge.

Figure 9 shows measurements of dissolved oxygen in the Lower Slough and meteorological data before and during a low dissolved oxygen event during 1996. The discharge of high BOD waste, such as deicing materials, is acerbated by increases in the stage of the Willamette River because the Lower Columbia Slough stagnates (see Wells, et al., 1996).

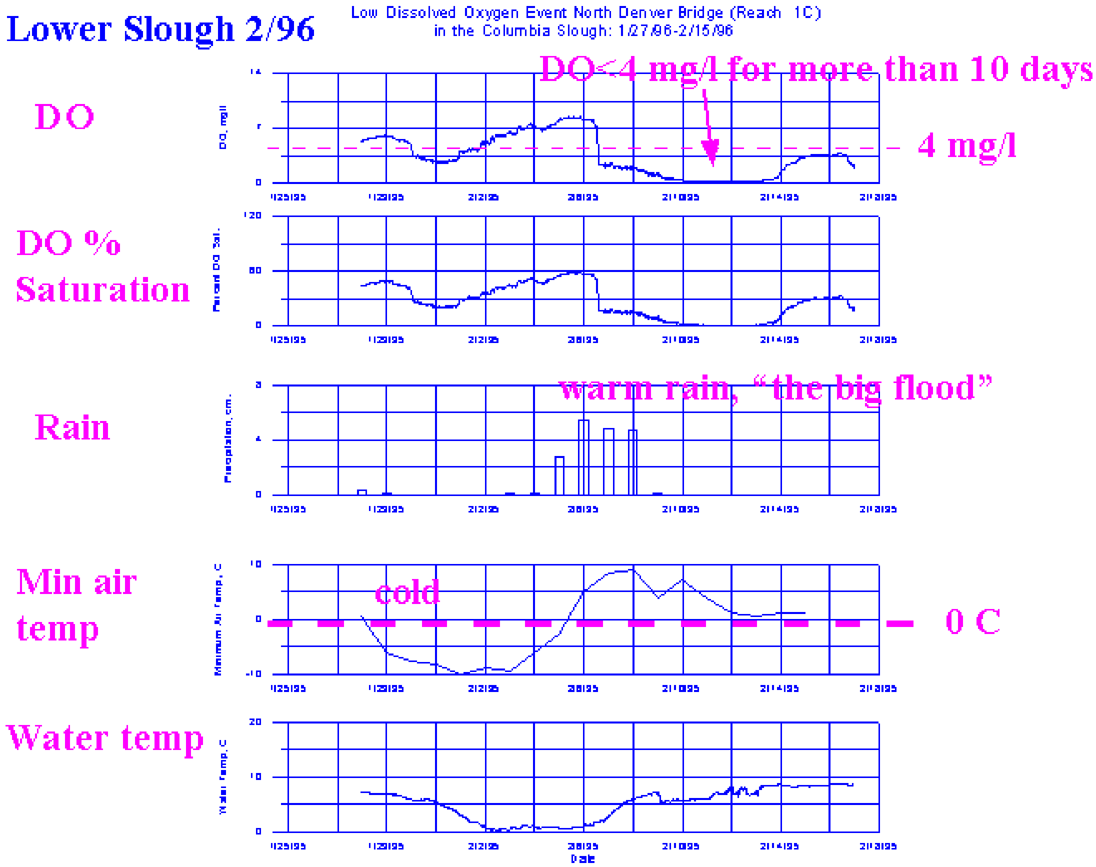

Figure 9. Winter dissolved oxygen concentrations and percent saturation, minimum air temperatures, rainfall, and water temperatures during the "flood of '96" in the Lower Slough at N. Denver bridge.

Bacteria

During summer and winter rain events, the Portland sewage treatment plant cannot take all the water from sanitary and storm water and some spills untreated into the Columbia Slough as a combined sewer overflow (CSO). The bacteria loading from CSOs is the primary source of pathogenic bacteria in the Lower Slough in the summer and winter. In the Upper Slough, storm water and unknown sources contribute to coliform levels above the standard of 200 colonies/100 ml sample, but these violations are usually small compared to the CSOs which contribute bacteria concentrations usually greater than 100,000 colonies per 100 ml sample.

Temperature

Temperatures above the optimum range for Salmon are caused by pooling of water in the Upper Slough and removal of shade trees along the banks of the Slough system. The optimum upper temperature for cold water fish such as Salmon is about 14^{o}C (52.7^{o}F), with an upper lethal temperature of 26^{o}C (78.8^{o}F). In the Upper Slough and Lower Slough, temperatures above 25^{o}C (77^{o}F) are common. Other fish species, such as warm water fish like crappie, bass, enjoy the warmer waters. For example, the impoundment of Smith and Bybee Lake in 1982 had led to increases in water temperatures such that warm water fish now reside in those lakes.

Toxic Compounds

Toxic compounds have been found in some sediment locations in the Lower and Upper Slough, as well as in fish tissue. These compounds can impact human health when

- fish are eaten that have high concentrations of toxins in their tissue
- sediments are ingested during swimming or by handling the sediments.

Currently, a separate study by the City of Portland is underway to determine how significant a problem toxics are and what level of caution the public should exercise. The source of these toxics is industrial discharges and storm water.

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4. Approaches to Solving Water Quality Problems

olving water quality problems involves (i) cutting off the source of the problem and (ii) managing the system to minimize the impact of the problem if source control is not

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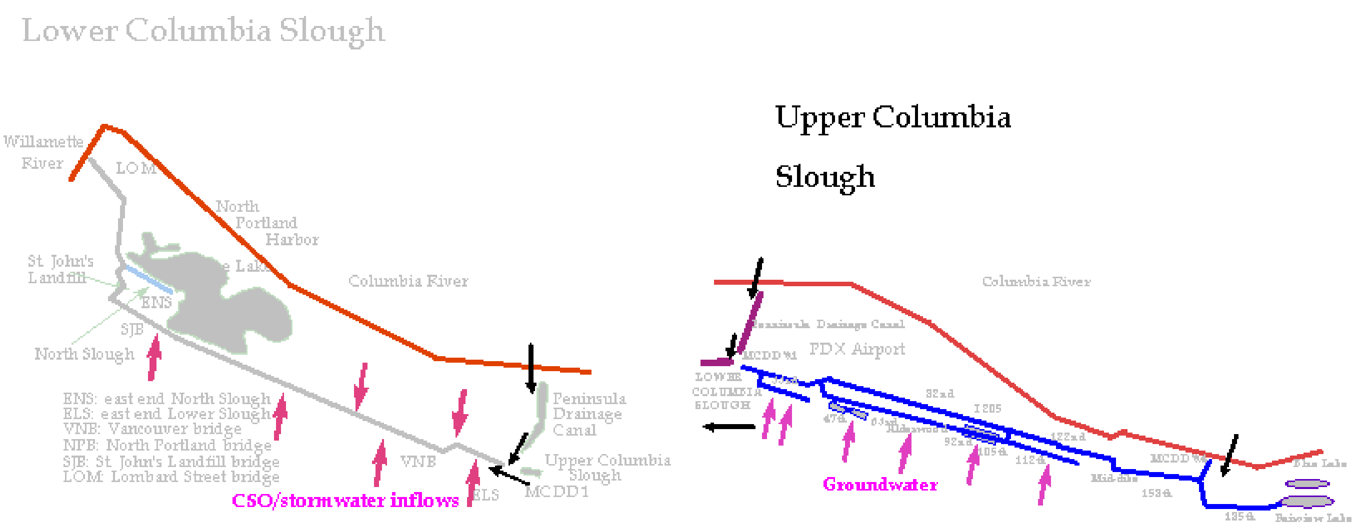
possible. Sometimes a combination of the two approaches is the most cost-effective.

In 1989 an environmental study of methods to improve water quality in the Slough for the City of Portland recommended flow augmentation of Columbia River water into the Lower Slough at the end of the Peninsula Drainage Canal or at MCDD4 in the Upper Slough. Figure 10 shows how this alternative would work. The goal was to reduce the impact of CSOs by diluting the CSO inflow with Columbia River water and to reduce algae concentrations by reducing the detention time of algae in the Lower Slough. If the inflows were to be directed through the Upper Slough they could also, it was thought, reduce algae growth in both the Upper and Lower Slough. The estimated capital costs were thought to be between $6,000,000 and $8,500,000, depending on whether the location was through the Peninsula canal or through the Upper Slough at MCDD4. This first study though did not anticipate the higher costs associated with this proposal because of fish passage, flood control, and pipe size problems. Later studies showed that the algae growth problem would not be solved with flow augmentation as it was proposed and that bacteria standards for CSOs could not be met. Hence, the City decided on another approach for CSO control - construction of wet-weather storage facilities to contain most events rather than discharging directly into the Slough. This construction project will be completed by the year 2001.

Reducing the groundwater inflow to the Upper Slough was not a feasible solution either. The most practical solution appeared to be lowering water levels in the Upper Slough by pumping out the groundwater - in essence, flow augmentation with groundwater. The idea behind this suggestion was to reduce the residence time of water in the Upper Slough to cut down the possible time for algae growth. This strategy has been tried over the last few summers with some encouraging results (see Section 7).

Figure 10. Flow augmentation alternative through Peninsula Canal or through Upper Slough at MCDD4MCDD4.



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5. A Management Tool - A Computer Model

In order to reduce the trial and error approach to managing the complex Columbia Slough system, a mathematical model of the Columbia Slough system was developed at PSU to help the City, METRO, and other local and State agencies interested in the Slough to evaluate potential management strategies. This model is a computer code that predicts flow in and out of the Slough and water quality changes occurring within the Slough. The model allows water quality managers and interested citizens to estimate the impact of a particular management strategy on the Slough and ask hypothetical questions, such as:

- What flow rate should we pump at MCDD1 to reduce the detention time of a CSO in the Lower Slough during low water events in the summer ?
- How much can we reduce algae growth in the Upper Slough by pumping out groundwater at a given rate ?
- Will reducing the detention time of water in the Upper Slough impact the Lower Slough algal growth problem ?
- How much de-icing fluid material can the Upper and Lower Slough receive without violating water quality standards for oxygen ?
- What if we install stormwater wetland treatment systems in the Upper Slough, would we improve water quality ?
- What impact will planting shade trees along the Southern banks of the Upper Slough have on algae growth and temperature ?

The benefit of such a model is to eliminate alternatives that would not solve the Slough's water quality problems and to focus on those that will have a strong benefit to the system.

What, though, is a water quality model ? What can a water quality model do and not do ?

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6. Water Quality Modeling of the Slough System - What Do Models

Tell Us Are the Best and Worst Methods of Improving Water Quality

In order to explore methods to improve water quality in the Columbia Slough system, several studies have been sponsored by the City of Portland, Bureau of Environmental Services. These studies were undertaken to assess the current state of water quality in the system and to develop a computer model of the Slough system. The steps in development of a computer model are

- Model formulation (selecting the proper mathematical description of the chemistry, physics, and biology of the Slough system)
- Model calibration (ensuring that the model reproduces field data of water quality, water surface elevation, flows and velocities in the Slough)
- Model verification (ensuring that the model year-after-year is a reliable predictor of water quality and hydraulic field data)
- Evaluation of management alternatives (evaluating potential strategies for water quality improvement in the Slough)

What is the model ?

The "model" is a set of computer instructions written in a computer language (FORTRAN) describing the physics, biology, and chemistry of the Lower and Upper Slough. This model predicts the water quality and hydraulic parameters shown in Table 2 as a function of time, vertical and longitudinal location.

Table 2. Water quality variables simulated in the Slough model.

Water quality or hydraulic variable simulated in the Upper and Lower Slough model	Importance of variable in assessing water quality conditions
water surface elevation	affects direction of water movement
water velocity	water movement or water velocity tells us where the water moves and how fast
temperaturetemperature	important for fish survival and affects all biological and chemical processes, affected by meteorological conditions (including shading)
algaealgae concentration	the model predicts algaealgae biomass concentrations, telling us where the algae growth problems are and at what concentration nuisance conditions are encountered
bacteriabacteria	coliform bacteriabacteria are modeled in the Slough, these are indicators of pathogenic organisms
pHpH	if pHpH is below 6.5 or above 8.5 fish and aquatic life could be impaired
dissolved organic matter (soluble)	a measure of the amount of biodegradable organics in the water; as bacteriabacteria consume this organic matter, oxygen is consumed; this is comparable to BOD (biochemical oxygen demand, which is a measure of the amount of oxygen required to biodegrade an organic waste)
refractory organic matter (soluble)	same as dissolved organic matter except that the rate of decay of these organics is very slow
sediment organic matter	determines the rate of oxygen consumption by particulate matter settled to the bottom of the Slough - typically dead algaealgae and particulate organics coming into the Slough
detritus (particulate organic matter)	Particulate organic matter that decays as bacteriabacteria consume detritus as food, an oxygen sink
total inorganic carbon	this is all the non-biological (inorganic) carbon in the system, these components are affected by algaealgae growth and gas transfer across the air water interface, these components affect pHpH
alkalinity	a measure of the water's ability to neutralize acids, affects pHpH

dissolved oxygendissolved oxygen	amount of oxygen in the water; important for fish and aquatic life
soluble phosphate	amount of dissolved phosphorus in the water; an algaealgae nutrient
nitrate	amount of dissolved nitrate in the water; an algaealgae nutrient
ammonia	amount of dissolved ammonia in the water; an algaealgae nutrient and a chemical that consumes oxygen
zooplankton	an organism that consumes algaealgae and detritus, fed on by fish, consumes oxygen and reduces algae
conservative tracer	amount of a conservative, or non-biodegradable, material in the water

Limitations of the model - What it can predict and what it cannot predict

The ability of the model to predict water movement and quality is dependent on the quality of input data available for the model. When the water quality model does not predict water quality conditions well, that means the following could be true:

- the model does not correctly account for the proper physics, biology, or chemistry of the system
- input data at the model boundaries (for example, water coming in from Fairview Lake, the Willamette River, storm water inflows, or combined sewer overflows) is unknown or poorly understood
- measurements of water quality in the Slough were incorrect because of unknown sampling errors

Generally, the model can predict the parameters in Table 2 throughout the Slough system when good input data to the Slough are known. These model input data include

- meteorological data (air temperature, dew-point temperature, wind speed, wind direction, cloud cover, precipitation)
- storm water inflows and quality
- CSO inflows and quality
- groundwater inflows and quality
- runoff quality and flows from PDX airport in the winter
- leachate flow and quality from St. John's Landfill
- pipe sizes and invert elevations of all pipes in the system
- channel morphology or channel shape
- water level variation at Lombard Street or Willamette River
- MCDD1 and MCDD4 pumping flow rates
- irrigation users flow rates and locations
- Willamette River water quality
- flow rate and quality of all point source discharges (for example, the Boeing site in the Upper Slough)

The model then is only as good as the input data given to it. In some cases other models have to be used to estimate some of the boundary condition data. For example, the storm water and CSO flows into the Upper and Lower Slough have been modeled for flow and quality. Why ? Because we would have to continuously sample almost 50 locations in the Upper and Lower Slough to obtain the data required for the model. These sampling locations would be the outlet pipes as the discharge enters the system. Hence, the approach used was to take measurements at a few locations so that the storm water and CSO models could be calibrated. This means that the storm water and CSO models well represented the measurements. Then those models were used as inflows to the Slough system model at other locations and times.

A weakness in the present model is that Willamette River water quality is measured only every other week in the summer. The Willamette River inflows into the Columbia Slough and causes changes in water quality of the Lower Slough. To reproduce water quality data in the Lower Slough better, continuous water quality data would be required.

The model has been calibrated to both low water and high water hydraulic conditions. But the model is not suited to simulate the flood of 1996 unless further information of the channel shape above 14 ft MSL were known (14 ft MSL is the current "top" of the model). The 1996 flood had water levels above 25 ft MSL.

The model currently includes the domain from Lombard Street bridge in the Lower Slough to the western side of Fairview Lake in the Upper Slough. This is shown in Figure 11. The model includes all "sections" of the Lower (such as North Slough, Smith and Bybee Lakes) and Upper Slough (Whitaker Slough, Buffalo Slough, etc.), including the Peninsula Drainage Canal.

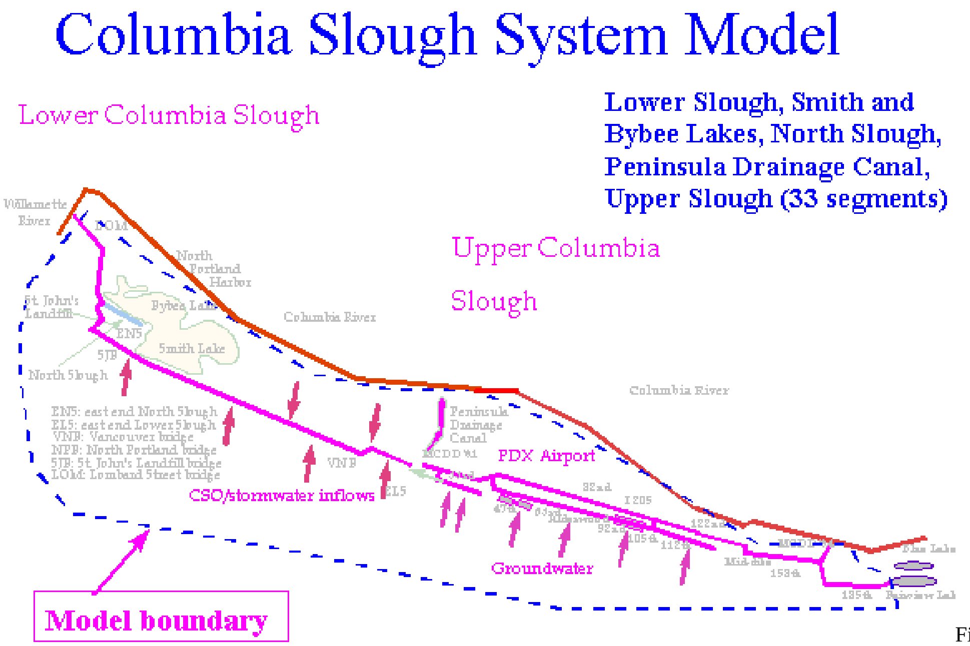

Figure 11. Domain for the Slough system model.

How well does the model predict the hydraulics of the Slough ?

In general, in the Lower Slough the model has predicted water surface elevations and flow rates within 10% of the daily variation.

The water surface in the Upper Slough during a pump test well illustrated the model's ability to predict the "water hammer" effect when the pumping rate at MCDD1 was changed. Note Figure 12 which shows water surface elevations at MCDD1 in the Upper Slough during the summer of 1993. On Julian day 278 the pumps at MCDD1 were turned off and the water level rose. Then on Julian day 281, the pumps were started and the water level dropped. There were small increases in water level as MCDD1 pumping rates were reduced. The model correctly mimicked the physics of the "water hammer".

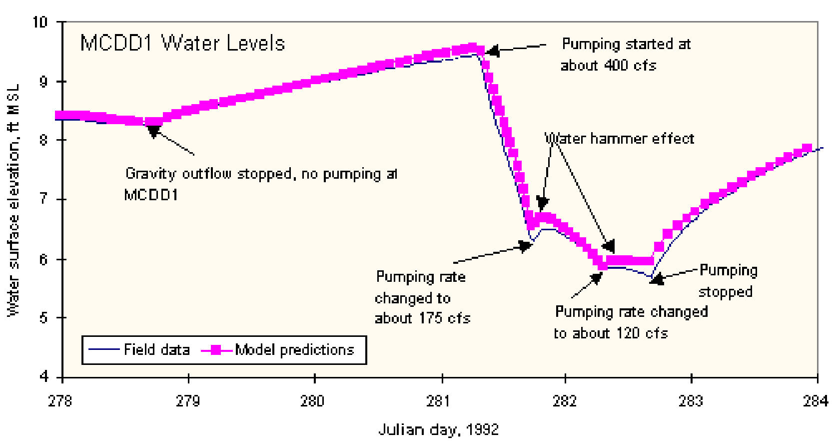

Figure 12. Water levels predicted by the model compared to field data.

Water surface elevations are well reproduced in the Upper Slough also when enough data are available to know the inflow rates. Figure 13 shows predicted flow rates at NE 47th in the Southern arm of the Upper Columbia Slough compared to field data taken at the same location.

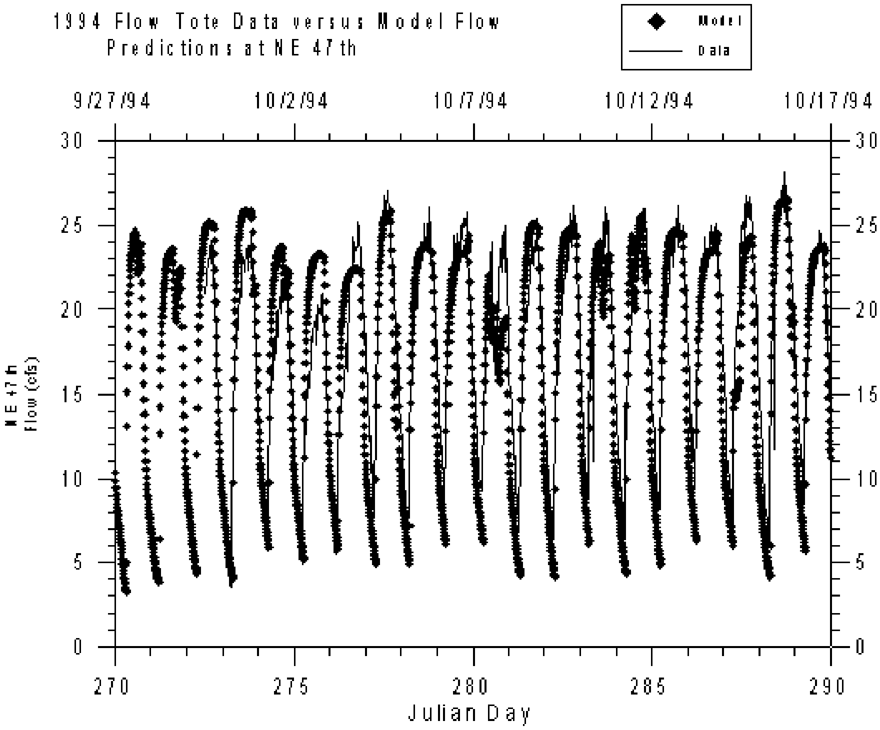

Figure 13. Flow rates predicted by the model compared to field data.

How well does the model predict water quality changes ?

The model predictions in the summer and winter have generally been good. Figure 14 shows a comparison of model predictions and measurements in the Upper Slough at NE 47^{th} on the Southern arm for dissolved oxygen, pH, and temperature for 1993. Figure 15 shows model predictions of dissolved oxygen, temperature, and pH during a winter flood event in 1995 at St. John's Landfill bridge in the Lower Slough. The model typically predicts temperature within 1^{o}C, dissolved oxygen within 1-2 mg/l, and pH within less than a pH unit.

When boundary conditions data were not available, the model predictions were not good. For example, coliform bacteria were at concentrations close to 500 to 600 colonies per 100 ml at one station in the Upper Slough near NE 138^{th}. The model though predicted no coliform bacteria because no source of bacteria was known for the model input. Hence, the model can only predict in-stream water quality well if the boundary conditions are known.

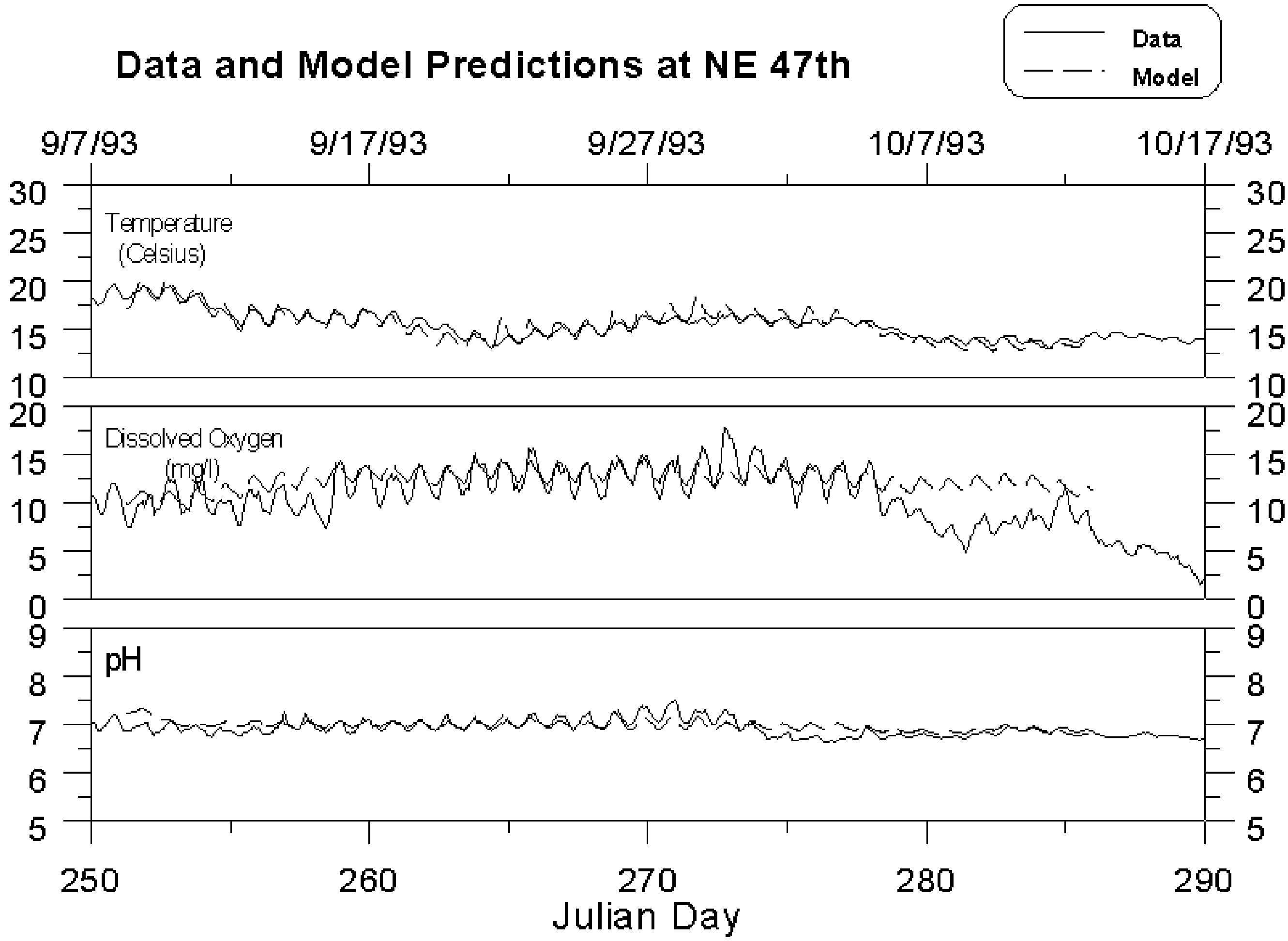

Figure 14. Model predictions compared to field data at NE 47th on the Southern arm during 1993.

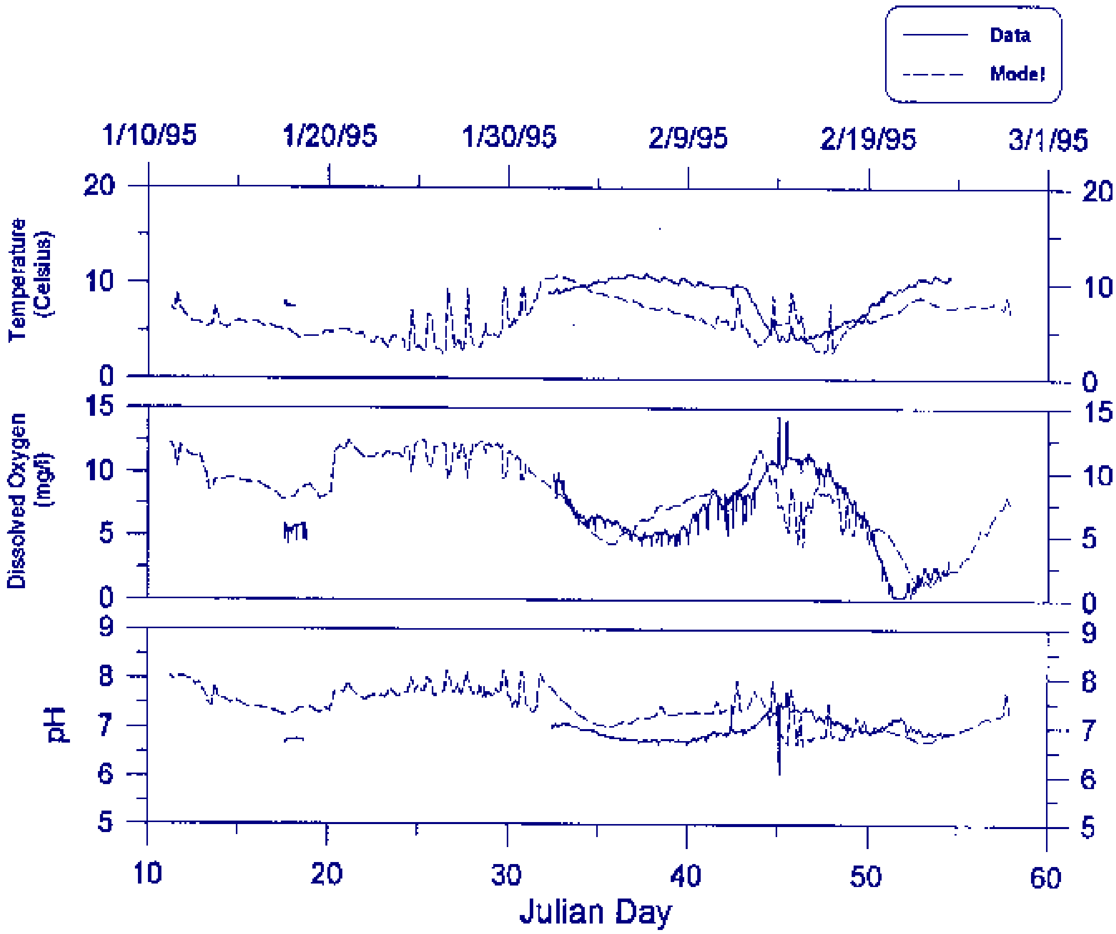

Figure 15. Winter 1995 model predictions compared to field data at St. John's Landfill bridge.

Management Strategies Evaluated with the Upper and Lower Slough model

As the model calibration is improved, management scenarios are simulated with the model. Over the last 5 years, dozens and dozens of management scenarios were evaluated with the Slough models. A representative list of some of these model scenarios is shown in Table 3. Figures 16 through 24 show graphically some of these management scenarios.
Table 3. Representative model scenarios simulated with Columbia Slough model.

Management Strategy	Why Was This Strategy Considered ?
Flow augmentation from Columbia RiverColumbia River	flow augmentationflow augmentation is a method to increase the flow rate of water in the Slough to dilute bacteriabacteria and to reduce the detention time of water to reduce algaealgae growth, the Columbia RiverColumbia River water was chosen since it was considered relatively "clean"
Tree shading in Upper Slough	Reduce the penetration of sunlight to the Slough, thereby reducing water temperaturetemperatures
Flow augmentation in Upper Slough from groundwater	reduce detention time of water in the Slough to reduce the growth of algaealgae, also to lower the temperaturetemperature of Upper Slough water
CSOCSO removal	eliminate pathogenic bacteriabacteria from untreated sewage
Changes in culvert sizes in Upper Slough in conjunction with low-flow test	allow isolated channels in the Upper Slough to become more hydraulically connected to the Upper Slough, this would allow flow augmentationflow augmentation with groundwater to be more successful since the residence time of water in the Slough could then be reduced
Efficiency of wetland treatment in Upper Slough	decrease nutrients and algaealgae biomass in Slough
Storm water treatment	decrease nutrients entering the Slough

Reduce airport discharge of deicing chemicals in the winter	decrease BOD load from deicing chemicals which lower dissolved oxygendissolved oxygen
Removal of barge from North Slough	increase tidal flushing into North Slough
Opening up Smith and Bybee Lakes to North Slough	increase tidal flushing in North Slough and allow Smith and Bybee Lakes to experience full tidal flushing
Opening up Peninsula Drainage Canal to Columbia RiverColumbia River and Columbia Slough	allow discharges from CSOCSOs and from the Upper Slough to short-circuit to the Columbia RiverColumbia River, enhance flow in East end of Lower Columbia Slough

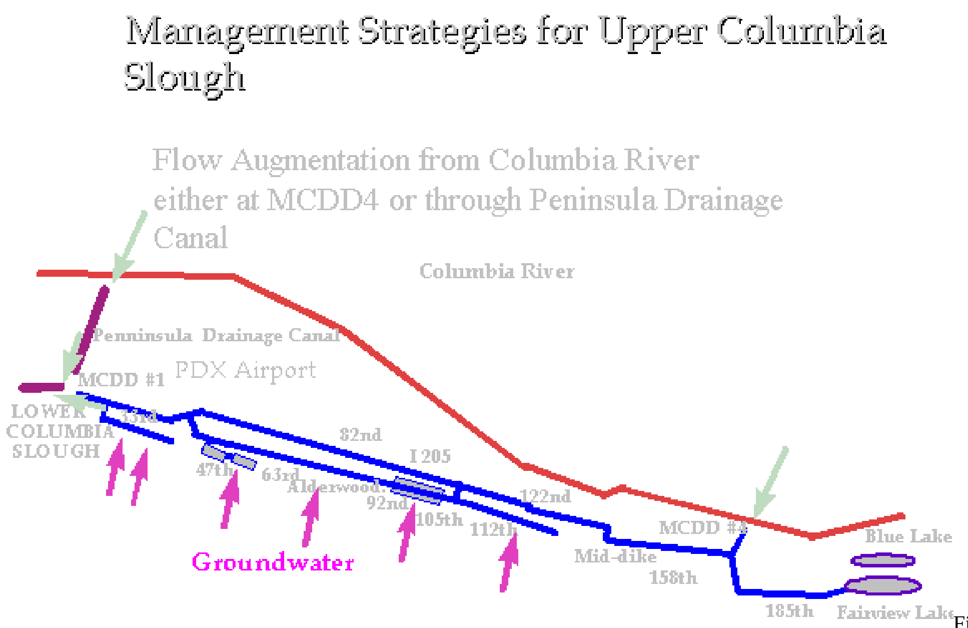

Figure 16. Management strategy for Upper Slough: flow augmentation.

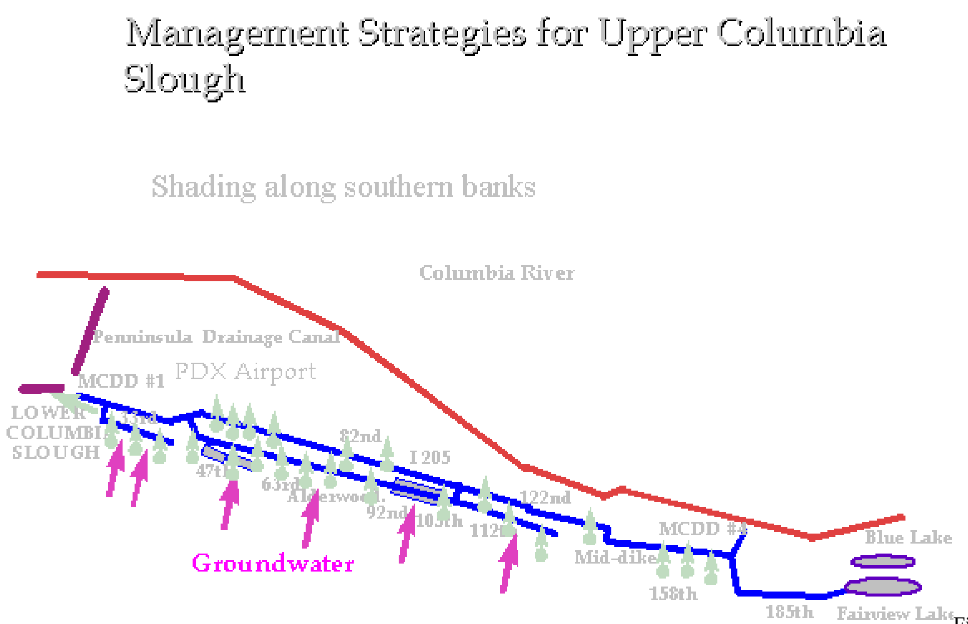

Figure 17. Management strategy for Upper Slough: bank shading.

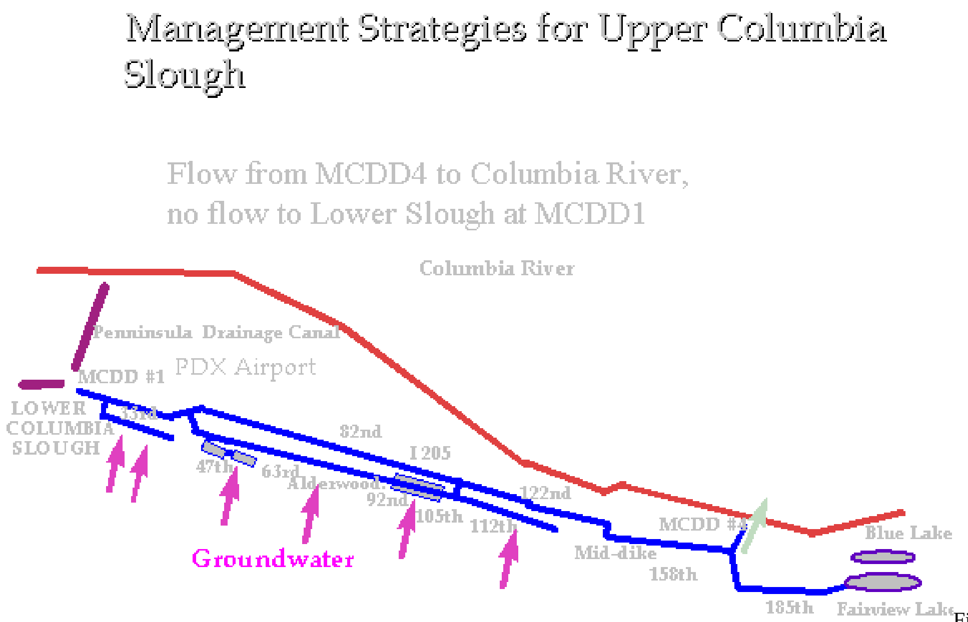

Figure 18. Management strategy for Upper Slough: flow out only at MCDD4.

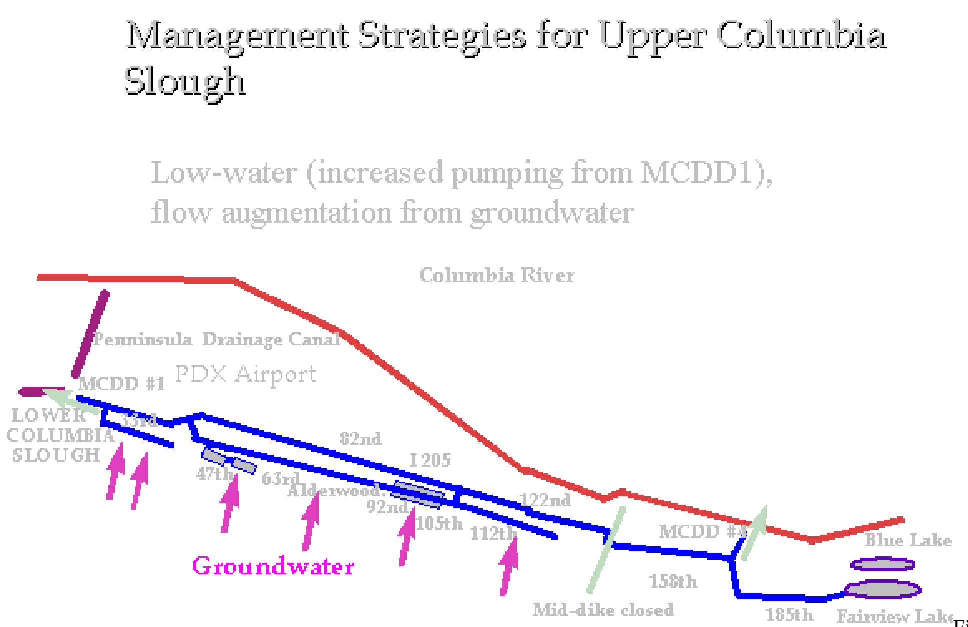

Figure 19. Management strategy for Upper Slough: flow management.

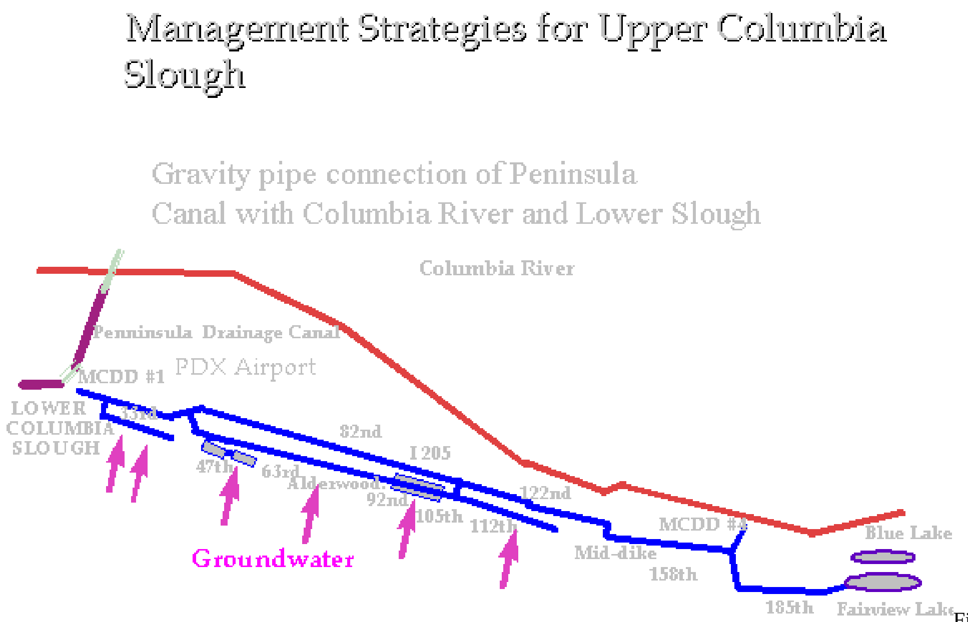

Figure 20. Management strategy for Upper Slough: flow augmentation with gravity connections to Columbia River through Peninsula canal .

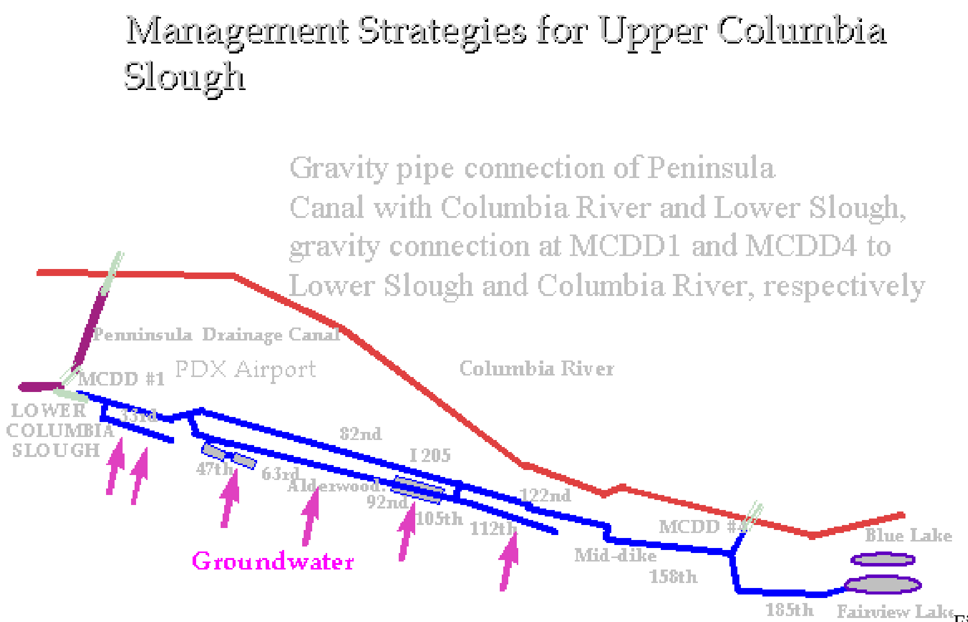

Figure 21. Management strategy for Upper Slough: flow augmentation with gravity connections to Columbia River through Peninsula canal and MCDD4.

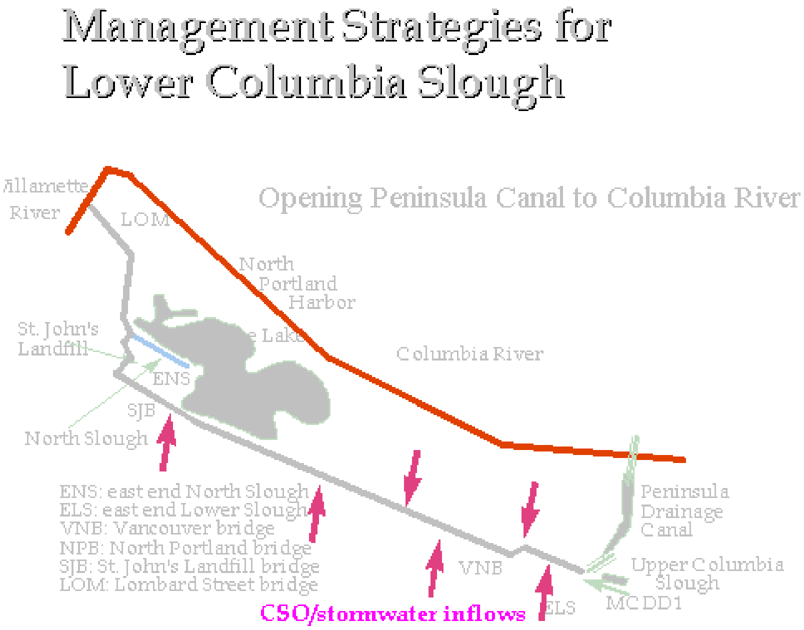

Figure 22. Management strategy for Lower Slough: opening Peninsula Canal.

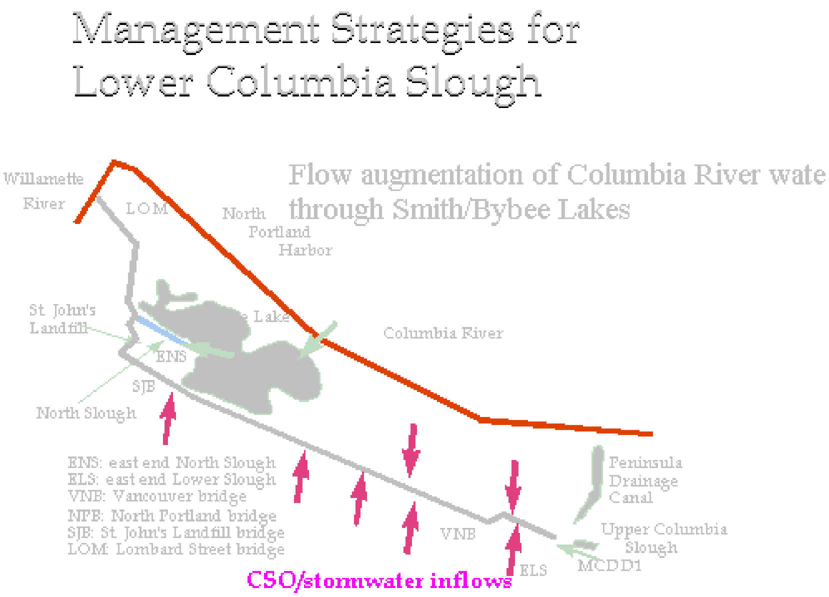

Figure 23. Management strategy for Lower Slough: flow augmentation Smith/Bybee Lakes.

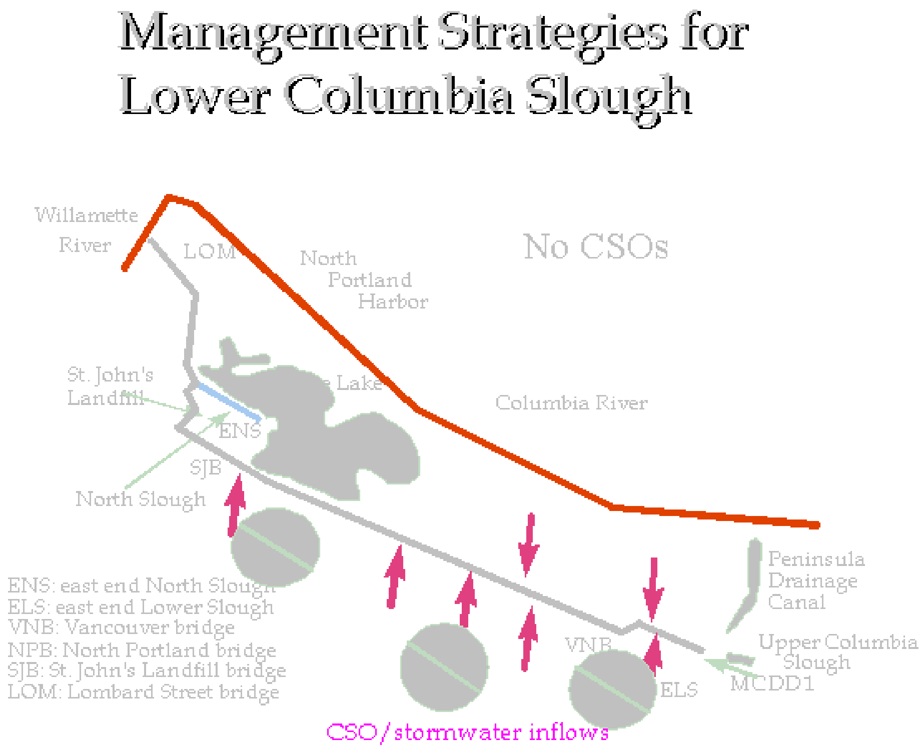

Figure 24. Management strategy for Lower Slough: no CSOs.

What have been the conclusions of these earlier studies ?

The following general conclusions were made (specific details, such as information as to how great an improvement or how small the improvement was, are itemized in technical reports shown in the References section):

- shading in the Upper Slough lowers water temperatures in the summer (the groundwater does not warm up as much as under current conditions), but this temperature improvement is not enough to meet temperature regimes for cold water fish
- removal of CSOs significantly improves water quality in the Lower Slough by removing most coliform bacteria water quality violations
- opening up the Lower Slough to the Columbia River through the Peninsula Drainage Canal allowed CSOs (such as the major 13th Street CSO) to discharge quickly out of the Slough and into the Columbia River
- removing the barge in North Slough does little to improve water quality conditions in North Slough, but opening up Smith and Bybee Lake improved water quality significantly (when the lakes were opened back up to the Slough, removal of the barge was important in allowing increased circulation)
- flow augmentation of Columbia River water at MCDD4 in the Upper Slough did not improve the eutrophication problems in the Upper Slough - they made the Southern arms worse than they are at present
- flow augmentation of Columbia River water at MCDD4 required extensive new pipes or increased pipe sizes to pass the flows necessary to make any appreciable impact on water quality in the Northern arm of the Upper Slough
- flow augmentation with groundwater in conjunction with low water levels in the Upper Slough improved water quality in the Upper Slough but sent high nutrient concentrations into the Lower Slough making the algae problem slightly worse
- reduction of nutrients from groundwater solved the eutrophication problems in the Upper and Lower Sloughs (if the source of nutrients in groundwater were from unsewered areas of East Multnomah County, this source may exist for another decade or two)
- significant reduction of airport deicing chemicals from the Portland International Airport was necessary to prevent violation of dissolved oxygen water quality standards in the winter

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7. Have Our Management Strategies for the Slough Been Working ?

In 1993 the City of Portland in cooperation with MCDD1 and PSU began a flow augmentation strategy using groundwater. The idea was to reduce the detention time in the Upper Slough so that algae would not have time to grow. In addition, a larger culvert was added at Prison Pond at 112th to reduce water levels further. The lower the water levels in the system, the shorter the detention time in the Slough. During this period, the mid-dike levee was closed to provide irrigation water to those on the East side of the mid-dike.

Figure 25 shows a comparison of chlorophyll a concentrations in the Upper and Lower Slough between 1992 and 1995. Algae concentrations decreased starting in 1993 and were less than 15 g/l in 1995. Figure 26 also shows the dissolved phosphorus in the Upper Slough for 1995. This figure shows that the Northern arm of the Upper Slough was below 0.02 mg/l as P.

What is responsible for this reduction in algae growth ? The lower water levels in the Upper Slough reduced suspended algae concentrations by reducing the detention time of the water in the Upper Slough. This has caused a gradual build up of rooted aquatic plants, macrophytes in the Upper Slough since light now was able to penetrate to the bottom of the channel. The macrophytes take nutrients generally from the sediment. But other plants use the macrophytes as a substrate or a base on which they live. These other plants are probably taking up nutrients from the water column. This increase in macrophyte growth has then lead to a significant reduction in dissolved orthophoshorus, resulting in a significant lowering of chlorophyll a levels in 1995.

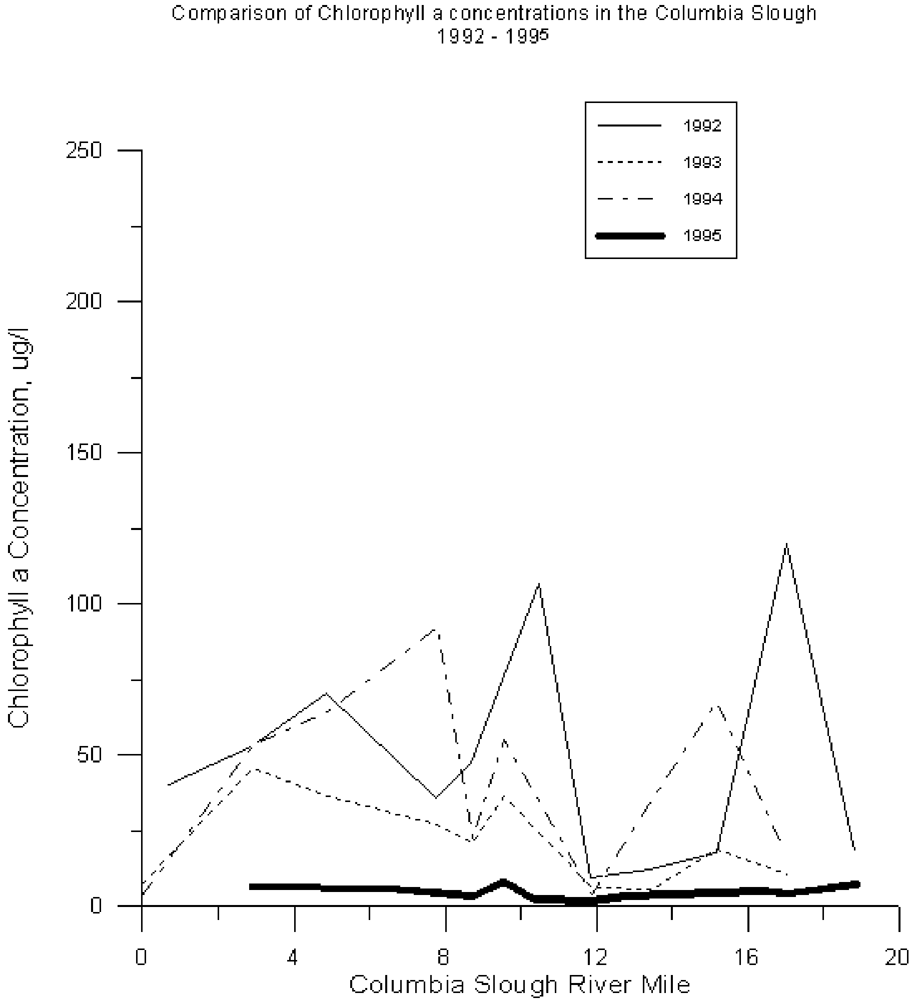

Figure 25. Summer average chlorophyll a in the Columbia Slough between 1992 and 1995.

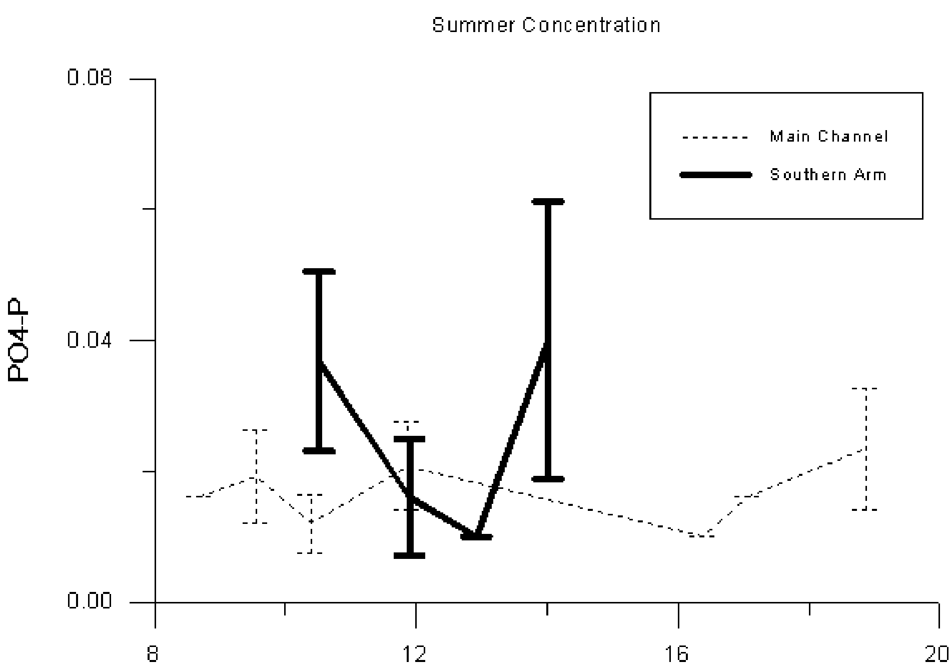

Figure 26. Summer average PO_4-P in the Upper Slough in 1995.

To illustrate the changes in average pH (pH provides an indication of algal growth in the Slough for comparable weather and nutrient conditions) over the years, Figure 26 shows the decrease in pH by about 1 pH unit (a factor of 10 decrease) from 1992 to 1995.

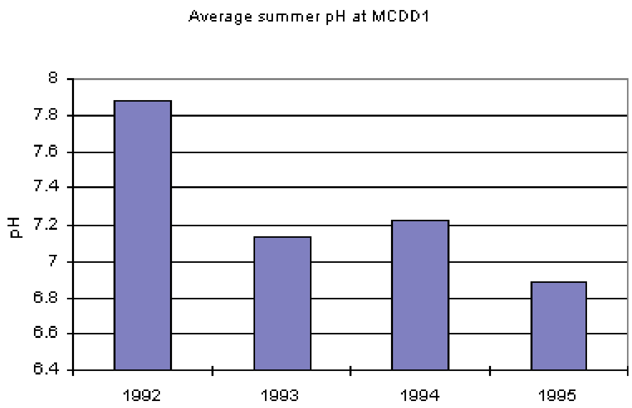

Figure 27. Average pHpH during summer periods at MCDD1MCDD1 in the Upper Slough from 1992 through 1995.

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8. Future Approaches to Managing Water Quality in The Slough

The Slough system model is being refined further by improving the following algorithms and input data:

- use of hourly meteorological data rather than daily averaged
- improvement in the model geometry by coordinating the spatial scale of the model with aerial photographs
- improvement in the algorithm that calculates flow between branches through culverts in the Upper Slough and between the Upper Slough and Lower Slough
- adding multiple algal species to the model
- adding macrophyte growth to the model
- joining the separate model components (i.e., Smith and Bybee Lake, Peninsula Drainage Canal, Lower Slough, and Upper Slough) together in a more global model incorporating the entire system
- use of improved water quality, hydrodynamic, and meteorological data for the Slough system in summer and winter periods of 1995 and 1996

In addition to these improvements noted above, PSU is simulating some new scenarios for water quality and aquatic health improvement in the Columbia Slough system. These scenarios are focused on long-term management of the Slough system when the need for irrigation water from the Upper Slough diminishes. These additional modeling scenarios (some of which are illustrated in Figures 15-23) include the following items:

- opening up Peninsula Drainage Canal to the Columbia River and east end of the Lower Columbia Slough by gated culverts (this would allow water from the east end of the Lower Columbia Slough to exit through the Peninsula Drainage Canal, including inflows from the Upper Slough)
- opening up Peninsula Drainage Canal to the Columbia River and east end of the Lower Columbia Slough by gated culverts and allowing the discharge from MCDD1 to be gravity flow only (pumping would only occur during emergencies) allowing the Upper Slough to respond to full tidal forcing (this would allow water levels in the Upper Slough to mimic the water levels in the Columbia River system)
- opening up Peninsula Drainage Canal to the Columbia River and east end of the Lower Columbia Slough by gated culverts, allowing the discharge from MCDD1 to be gravity flow only (pumping would only occur during emergencies) allowing the Upper Slough to respond to full tidal forcing (this would allow water levels in the Upper Slough to mimic the water levels in the Columbia River system), and allowing the discharge at MCDD4 to be a gated gravity pipe where the east end of the Upper Slough can respond to Columbia River tidal forcing
- allowing the discharge from MCDD1 to be gravity flow only (pumping would only occur during emergencies) allowing the Upper Slough to respond to full tidal forcing (this would allow water levels in the Upper Slough to mimic the water levels at the east end of the Lower Columbia Slough) and allowing the discharge at MCDD4 to be a gated gravity pipe where the east end of the Upper Slough can respond to Columbia River tidal forcing

These scenarios are intended to evaluate the effects of re-opening up the Slough system to the Columbia River. Historically, the Upper Slough was kept separate to provide water for irrigation in the summer and for flood control. With the diminishing use of the irrigation water, these simulations will assess the utility of allowing the Upper Slough to respond to tidal fluctuations in the Columbia River (either through the Peninsula Drainage Canal or Lower Slough). Gated pipes were thought to be necessary for these simulations to continue the flood protection value of the systems.

The re-connection of these systems to the Columbia River should have both water quality and habitat restoration value for the Columbia Slough. The computer simulations will help water managers to assess which alternatives are the most valuable and how those alternatives can be designed and implemented.

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10. Glossary of Terms

Algae: small plant that is transported by the water and that settles.

CSOs: combined sewer overflows; these are combined storm and sanitary sewers built decades ago; hence rainwater and raw sewage are combined and treated at the Columbia Blvd. treatment plant by the City, but during periods of high-rain, often only as little as a 0.1 inch in an hour, the treatment plant becomes overloaded and combined sewers discharge into the Columbia Slough. The largest is located at NE 13th St.

Macrophyte: rooted aquatic plant

MCDD1: Multnomah County Drainage District 1; a drainage district with headquarters at the wets end of the Upper Slough. Staff currently manage the Upper Slough, the culverts connecting Fairview Lake to the Upper Slough, and some of the Peninsula Pump Station Districts along the Lower Slough.

MCDD4: Multnomah County Drainage District pump station 4 located at Marine Drive near the Columbia River. This pump station sends water from the Upper Slough to the Columbia River.

Storm water discharges: rainwater from the streets, parking lots, roof drains, etc. are collected and routed to the Columbia Slough through pipes.

Zooplankton: small animal which eats algae, bacteria, and other solid organic matter.

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11. Index