



DRAFT TECHNICAL MEMORANDUM

PREPARED FOR: United States Bureau of Reclamation
Klamath Project Office, Klamath Falls

SUBJECT: Water Quality Data Review and Wetland Size Estimate for the
Treatment of Wastewaters from the Klamath Straits Drain

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Executive Summary

Interest in the water quality of the Klamath and Lost River drainages and, in particular, the Klamath Straits Drain has increased due to a perceived reduction in aquatic resource health and viability. This technical memorandum was prepared for the Bureau of Reclamation to provide information about water quality conditions of the Straits Drain and the potential use of wetlands treatment as a water quality improvement option. Analysis of surface water samples collected during the Klamath Straits Drain Water Quality Monitoring Program between 1991 and 1999 found increased concentrations of nitrogen, phosphorus and other constituents. Significant variation in concentrations of total phosphorus (P), ortho-phosphorus (PO₄-P), total kjeldahl nitrogen, ammonia and arsenic were found between monitoring sites (K-1 to K-10). The accumulation of nutrients in drain water could contribute to increased algae populations, which further degrade water quality by decreasing dissolved oxygen and increasing pH, chlorophyll a and temperature.

Previous water studies suggest that phosphorus was responsible for unrestrained algae growth in Upper Klamath Lake. This implies that a reduction in phosphorus concentration could reduce algal populations and improve water quality within the basin. Given this, a reduction in total P concentration in the Straits Drain may have the same effect on the Lost and Klamath River drainages. However, phosphorus is a difficult element to remove from the water column with either traditional wastewater processes (often requiring significant tertiary treatment) or with constructed wetland systems. Wetland systems can be designed to effectively remove P given adequate treatment surface area, appropriate internal removal mechanisms and, if removal and storage processes are optimized, by management techniques.

In the preliminary development of wetland systems, the Kadlec and Knight model is often used to estimate wetland system size requirements. It was estimated from this model that an emergent surface-flow wetland system would require a treatment surface area ranging from 1,633 to 3,115 acres provided the wetland received a daily flow between 70 and 130 cfs. With this estimated treatment surface area, it would be anticipated that the wetland system could achieve a 61% reduction in total P concentration. If a wetland system was considered, it is recommended that a wetland pilot-study be implemented to develop site and water-quality specific parameters prior to design and construction of a full-scale system.

Introduction

Interest in the water quality of the Klamath and Lost River drainages and, in particular, the Klamath Straits Drain (KSD) has increased due to a perceived reduction in aquatic resource health and viability. Past studies found that increased nutrient loads from a variety of sources produced hypereutrophic conditions within the Klamath and Lost River systems¹. It was also reported that elevated nitrogen and phosphorus concentrations together with high biochemical oxygen demand (BOD) and total suspended solids (TSS) were found most of the year in Upper Klamath Lake, Tule Lake and Lower Klamath Lake^{2,3}. This nutrient over-abundance has led to dramatic algae blooms, which further reduce water quality by producing low dissolved oxygen (DO) concentrations, high pH, temperature, chlorophyll a and unionized ammonia levels⁴⁻⁶.

This technical memorandum was prepared at the request of the Bureau of Reclamation (BOR) and presents a summary of historic water quality data collected by the BOR and other agencies of the Klamath and Lost River drainages collected at eight monitoring sites from 1991 to 1999. The monitoring sites included:

- K-1 KSD @ Pumping Plants F & FF, west of railroad tracks
- K-2 KSD Headworks, south of Stateline Highway
- K-3 Pumping Plant D Intake, Tule Lake
- K-4 Anderson Rose Dam on Lost River, upstream of gates
- K-5 Wilson Reservoir @ Crystal Springs Bridge
- K-7 Malone Reservoir @ Recorder Housing upstream of the dam
- K-8 Miller Creek Dam, upstream side of the dam
- K-10 Klamath River, on west bank below the south side of the By-Pass Bridge

From this review, information with respect to the principal constituents of concern, flows and nutrient loads were used to evaluate and develop an estimate of the surface area required for a treatment wetland system designed to improve water-quality from the Straits Drain prior to discharge into the Klamath River.

Methods

The process used to develop information to determine the preliminary size estimate of a treatment wetland system for the Straits Drain included:

1. Review of BOR water quality for the Klamath and Lost Rivers (K-1 to K-10) from May 1991 to November 1999 (excluding some data collected in 1994). In the review of this data, three sampling dates in 1994 (2/23, 6/30 and 9/28) recorded what appeared to be anomalous data values at all monitoring sites. For this reason, this data was not included in the analysis.
2. Review of BOR water flow data for the Klamath and Lost Rivers from January 1987 to June 2000.
3. Review of Oregon Department of Environmental Quality (DEQ), Water Quality Monitoring Section Reports (January 1997).

4. Review of published memos, reports and publications from U.S. Geological Service, DEQ, U.S. Fish and Wildlife Service, University of Washington and other organizations.
5. Review of California North Coast Regional Water Quality Control Board (NCRWQCB) Water Quality Monitoring Data (Self-Extracting Archive KLM96979.exe 1996-1997).
6. Statistical analyses including Kruskal-Wallis and Mood Median tests, One-way analysis of variance (ANOVA), Tukey's Multiple Comparison procedures and General Linear Model (GLM) calculations on water quality and flow data to determine average constituent concentrations, flow rates and to investigate constituent concentration differences between sampling locations and dates.
7. Calculations to determine the preliminary treatment wetland size estimate required for the improvement of KSD water quality.

Table 1 identifies information sources that were reviewed to assess historic water quality data of the Klamath Basin and the KSD, to determine constituents of concern, flows and the treatment wetland size estimate.

Table 1. Information sources used in the review of water quality and flow data.		
<i>Agency</i>	<i>Location</i>	<i>Data Type</i>
U.S. Bureau of Reclamation	Klamath Falls, Oregon	Water Quality, Flow ^a
California North Coast Regional Water Quality Control Board (NCRWQCB)	Santa Rosa, California.	Water Quality ^a
Department of Environmental Quality	Portland, Oregon	Water Quality ^{a,b}
US Geological Survey	Sacramento, California	Water Quality ^b
US Fish and Wildlife Service	Portland, Oregon	Water Quality ^b

^a Unpublished data.

^b From published reports.

Results and Discussion

Water Quality Parameters. Water quality of the KSD is inherently linked to water quality of the Upper Klamath Basin including Upper Klamath Lake and its watersheds and the Lost River drainage (Tule Lake and Lower Klamath Lake)⁷⁻¹⁰. Sources of nutrients, elements and other contaminants may come from fertilizer application, wastewater treatment facility discharge, outdated septic systems, run-off from animal husbandry, urban stormwater, natural sources and

concentrated wildlife populations¹. The federal Clean Water Act Section 303(d) requires that each state lists water bodies within its boundaries for which standard point source controls are not stringent enough to maintain water quality. The Klamath and Lost Rivers have been listed in Oregon and California¹¹.

Table 2 provides a summary of water quality parameters and constituents listed under Oregon's 1998 Section 303(d) for the Klamath and Lost Rivers.

Table 2. Summary of water quality parameters and constituents listed under Oregon's 1998 Section 303(d) water-quality limited water bodies for the Klamath and Lost Rivers.			
<i>Water Quality Parameter</i>	<i>Water Body</i>	<i>Boundaries</i>	<i>Criteria</i>
Dissolved Oxygen	Klamath and Lost Rivers	Keno Dam to Link River, California Border to California Border	DO < 6.5 mg/L (Cool-water aquatic resources; DO < 5.5 mg/L (Warm-water aquatic resources)
Chlorophyll a	Klamath and Lost Rivers	Keno Dam to Link River, California Border to California Border	Summer chlorophyll a standard (15 µg/l)
pH	Klamath River	Keno Dam to Link River	Summer pH maximum standard (6.5 – 9.0)
Temperature	Klamath and Lost Rivers	Keno Dam to Link River, Keno Dam to California Border, California Border to California Border	Rearing 64 F (17.8 C); Protection of Resident Fish and Aquatic Life
Toxics	Klamath River	Keno Dam to Link River	Unionized-ammonia (criteria are pH and temperature dependent)
Fecal coliform	Lost River	California Border to California Border	Summer fecal coliform standard (no single sample shall exceed 406 <i>E. coli</i> per 100 ml)

An extensive list of water quality standards including other constituents, metals and organic compounds with their accompanying concentration criteria have been developed by the DEQ¹¹. At the present time, concentration criteria have not been developed for nutrients, including some nitrogen compounds (total kjeldahl nitrogen [TKN], nitrates), phosphorus (total P and PO₄) and other compounds for waters of the Klamath Basin. The DEQ is in the process of developing new Total Maximum Daily Load (TMDL) guidelines for the Klamath Basin to possibly include concentration criteria for excessive nutrient concentrations and other compounds. (For information on the status of additional TMDL guidelines, see TMDL memo dated 6/28/00.)¹²

Elements of Concern. To develop the wetland system design, it is necessary to establish which element of concern or regulated parameter will determine the wetland area necessary for the reduction of that pollutant to the required level. Preliminary sizing models have been developed for several parameters including TSS, BOD, total phosphorus (P), total nitrogen, organic nitrogen, fecal coliform and some metals¹³. Typically, wetland systems are not specifically designed to improve water quality parameters such as DO, temperature, alkalinity, redox, electrical conductivity (EC) and Chlorophyll a, but these parameters are normally improved as a result of reducing the concentration of other constituents¹³⁻¹⁵.

Table 3 provides a summary of water quality parameters and constituents that were included in this review.

Table 3. Summary of water quality parameters and other constituents included in this review¹.				
<i>Parameter</i>	<i>Nutrients (mg/L)</i>	<i>Minerals (mg/L)</i>	<i>Elements (µg/L, mg/L)</i>	<i>Heavy Metals (µg/L, mg/L)</i>
DO (mg/L)	TKN	Sodium (Na)	Arsenic (As)	Cadmium (Cd)
pH	Ammonia (NH ₃ -N)	Potassium (K)	Boron (B)	Copper (Cu)
EC (µS/cm)	Nitrate (NO ₃ -N)	Calcium (Ca)	Iron (Fe)	Mercury (Hg)
Temperature (°C)	Total P	Magnesium (Mg)	Manganese (Mn)	Lead (Pb)
TDS (mg/L)	Ortho-phosphorus (PO ₄ -P)	Carbonate (CO ₃)	Selenium (Se)	Zinc (Zn)
Alkalinity (mg/L)		Bicarbonate (HCO ₃)		
Redox (mV)		Chlorine (Cl)		
Turbidity (Avg)		Sulfate (SO ₄)		

¹An extensive list of herbicide, fungicide and insecticide compounds was also reviewed. Compounds that were detected in surface waters were often below the µg/L range.

In the review of the water quality data, it was found that several of the monitoring sites recorded elevated concentrations for nitrogen, phosphorus and other constituents between 1991 and 1999. The highest total P concentration of 0.41 mg/L was found at KSD @ Stateline Highway while ortho-P concentration was highest at Anderson Rose Dam on the Lost River (See Figures 1 & 2).

The highest TKN and NH₃-N concentrations were found at Miller Creek Dam and KSD @ Pumping Plants F & FF, respectively. An arsenic concentration of 19.5 µg/L was highest at KSD @ Stateline Highway, which is well below the drinking water standard concentration of 0.05 mg/L.

Figures 1 & 2 illustrate the mean total P and PO₄-P concentrations at each sampling location and year (1991-1999).

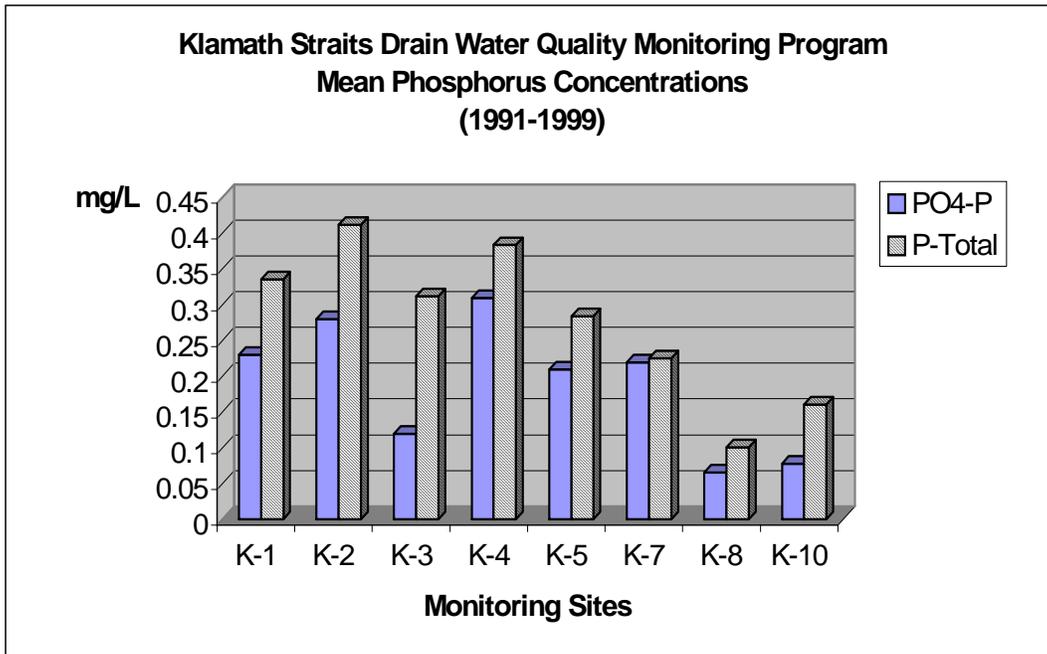


Figure 1. Mean total P and PO₄-P concentrations at Monitoring Sites K-1 to K-10.

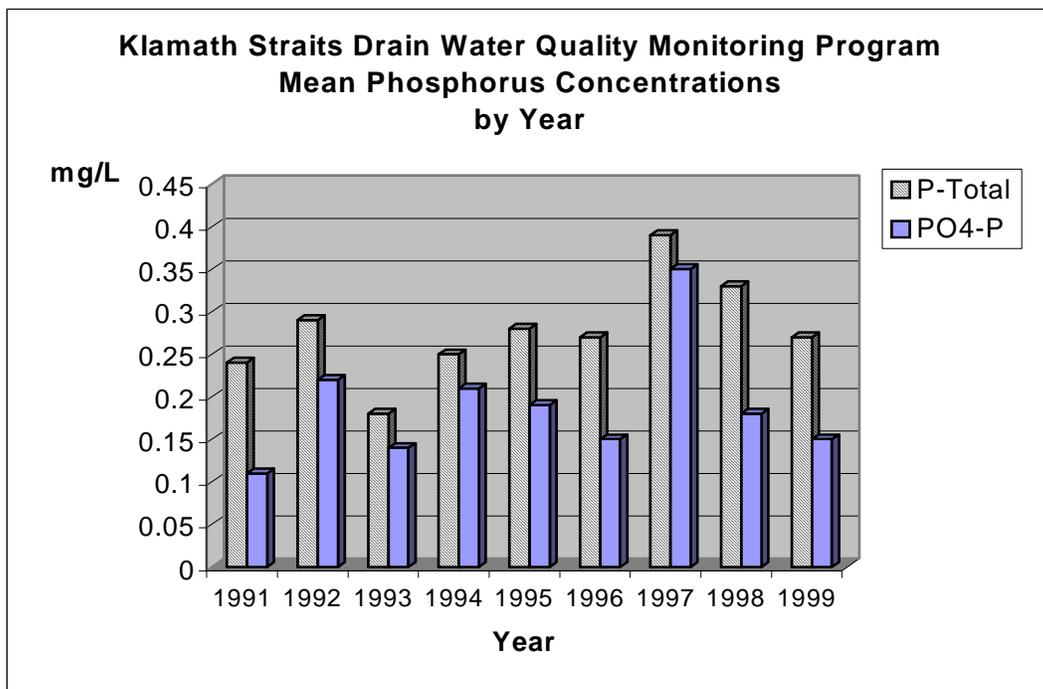


Figure 2. Mean total P and PO₄-P concentrations between 1991 and 1999.

Table 4 provides a comparison of water quality parameter ranges for the KSD at Pumping Plants F & FF, (K-1), the Miller Creek Dam, Lost River (K-8) and Klamath River (K-10) from 1991 to 1999. This table also provides the water quality standards for each parameter.

Table 4. Comparison of water quality parameters for KSD Pumping Plant F and FF and Miller Creek Dam, Lost River and Klamath River from 1991 to 1999.			
<i>Monitoring Site</i>	<i>Parameter</i>	<i>Range</i>	<i>Standards</i>
Miller Creek Dam, Lost River (K-8)	DO (mg/L)	8 to 12	>6.5mg/L
	pH	7.2 to 8.8	6.5-9.0
	EC (µS/cm)	53 to 230	Not a listed criteria
	Temperature (°C)	NA ¹	64°F
Klamath River (K-10)	DO (mg/L)	1 to 16	>6.5mg/L
	pH	6.0 to 10.3	6.5-9.0
	EC (µS/cm)	75 to 186	Not a listed criteria
	Temperature (°C)	NA	64°F
Pumping Plants F & FF (K-1)	DO (mg/L)	3 to 12	>6.5mg/L
	pH	6.8 to 8.6	6.5-9.0
	EC (µS/cm)	270 to 910	Not a listed criteria
	Temperature (°C)	5 to 26	64°F

¹Not Available

Significant variation ($P \leq 0.05$) in total P, PO₄-P, TKN, NH₃-N and arsenic (As) concentrations were found between sampling locations.

Table 5 provides a statistical summary of mean constituent concentrations by sampling location.

Table 5. Statistical summary of mean constituent concentrations by sampling location (1991-1999). Means sharing the same letter were not significantly different ($P \leq 0.05$).					
<i>Monitoring Site</i>	<i>Tot-P mg/L</i>	<i>PO₄-P mg/L</i>	<i>TKN mg/L</i>	<i>NH₃-N mg/L</i>	<i>As µg/L</i>
KSD @ Pumping Plants F & FF (K-1)	0.34a	0.23a	0.8a	0.47a	14.8a
KSD @ Stateline Highway (K-2)	0.41a	0.28a	1.0a	0.35a	19.5b
Pumping Plant D Intake, Tule Lake (K-3)	0.31a	0.19a	1.7b	0.42a	12.0a
Anderson Rose Dam on Lost River (K-4)	0.38a	0.31a	0.9a	0.24a	6.7c
Wilson Reservoir @ Crystal Springs Bridge (K-5)	0.29a	0.21a	0.8a	0.14b	2.7c
Malone Reservoir @ Recorder Housing (K-7)	0.23a	0.22a	1.0a	0.04b	1.9c
Miller Creek Dam (K-8)	0.10b	0.07b	1.8b	0.05b	1.3c
Klamath River @ So. Side By-Pass Bridge (K-10)	0.16b	0.08b	1.1a	0.46a	4.6c

Targeting Phosphorus for Water Quality Improvement. It was apparent that the accumulation of nutrients, principally nitrogen and phosphorus, in the KSD may have indirectly contributed to variations in other water quality parameters (via algae growth, etc.) including DO, EC, temperature and pH (See Table 4). Due to the nitrogen fixing capabilities of algae that are responsible for dramatic variations in water quality in the Upper Klamath Lake, it has been reported that total P may be the limiting nutrient required for algal growth^{2,3}. This implies that a reduction in total P concentration in waters of the Klamath Basin could reduce seasonal algae blooms and thus improve overall water quality. Given this assumption, a reduction in total P concentration in the Klamath and Lost River systems including the KSD may have a similar effect. Consequently, it is suggested that total P is the element of greatest concern in the KSD and should be targeted for removal. However, total P is one of the more difficult nutrients to remove from the water column with either conventional wastewater treatment or with the use of constructed treatment wetlands¹⁶⁻¹⁷.

Typically in wetland systems, total suspended solids and biochemical oxygen demand require the smallest treatment areas for effective removal. In contrast, total nitrogen (ammonia, nitrate and organic nitrogen), total P and some trace elements often require large wetland areas for adequate treatment¹³. Compared with the other constituents of concern in the Straits Drain, it appears that treatment of total P would require the largest wetland surface area¹³⁻¹⁵.

Comparison of Phosphorus Removal by Conventional Wastewater and Wetlands Treatment. Constructed wetlands can be used as a low-cost, natural technology for the treatment for rural, urban and industrial wastewaters. Many conventional wastewater treatment technologies require intensive inputs; however, this technology uses natural energies to accomplish this treatment. Wetland plants absorb nutrients and metals into root and shoot tissues where they are stored and detoxified. A variety of plant species are effective depending on water quality conditions.

The use of constructed wetlands is one of these land-intensive, natural technologies. When concentrated wastewaters are discharged into wetlands, many of the residual pollutants remaining in the effluent become a resource for the wetland biota, which can transform these raw materials into biomass, new sediments, or harmless atmospheric gases. These transformations result in the cleansing of wastewater. For this reason, the use of constructed wetlands for wastewater treatment should be viewed as a beneficial reuse of water. Constructed wetland treatment systems, if designed and operated in a way that does not degrade natural wetland functions, result in an important environmental reuse of wastewaters when compared to the direct discharge of untreated effluents into streams, rivers and estuaries¹⁸.

In conventional wastewater treatment, the removal of phosphorus compounds (HPO_4^{2-}) from wastewater to prevent or reduce eutrophication is typically accomplished by advanced tertiary treatment, which often requires the chemical precipitation of phosphorus with one of three compounds, ferric chloride, alum or lime. The precipitation reaction for ferric chloride is shown below¹⁹:



One should note that ferric chloride and alum reduce the pH while lime increases it. The effective range of pH for alum and ferric chloride is between 5.5 and 7.0. If there is not enough naturally occurring alkalinity to buffer the system to this range, then lime must be added to counteract the formation of H^+ . The precipitation of phosphorus also requires a reaction basin and a settling tank to remove the generated precipitate or sludge.

For example, to determine the theoretical amount of ferric chloride required for phosphorus removal at Pumping Plants F& FF, the following equation can be used¹⁹. With a mean ortho-P concentration of 0.28 mg/L at Pumping Plants F & FF, the amount of ferric chloride that would be required on a daily basis is equal to $0.28 \times (162.21/30.97) = 1.47$ mg/L. With a mean daily flow rate of 133 cubic feet per second (cfs) (325,200 m³/day), the theoretical amount of ferric chloride that would be required to treat the phosphorus is equal to 1,052 lbs (478 kg). Because of side reactions, solubility product limitations and day to day variations, the actual amount of chemical to be added must be determined by jar tests. One can expect that the actual chemical dose will be 1.5 to 3.0 times the theoretically calculated amount.

Given the results of this calculation, it is estimated that the daily ferric chloride dose that would be required to reduce the ortho-P concentration at Pumping Plants F & FF would range between 1,578 lbs (717 kg) and 3,156 lbs (1,434 kg). This amount of ferric chloride may make the use of conventional treatment processes less than desirable for the treatment of phosphorus in the KSD.

Phosphorus Removal in Wetlands. Wetland systems remove P through adsorption to soils, organic and biological materials. The plant-algae-microflora communities provide short-term P storage while the major long-term P sink is the soil and plant litter. Both pH and redox potential control the mobility of P in this environment. Precipitation of P as insoluble Ca-P is the dominant transformation at pH values greater than 7.0. Emergent wetland plants also uptake P from the sediments. When plants die-back during the fall and winter, some of the P is released to the surface water by way of the plant shoot material. The short-term net effect of rooted emergent vegetation is to transfer some P from the sediment to the water column, while root and residual decomposition products result in long-term P storage via peat development. Permanent storage of P in wetlands is estimated at 1.0 g/m²/year²⁰. Each year plants and periphyton dieback and release 35 to 75% of the P back to the water column and litter compartment. The only way to maintain adequate P uptake from the water column is to balance input levels to uptake rates. Long-term storage of P for emergent wetlands is keyed to the short-term capacity and the collective turnover rates for each process.

Some studies²⁰ found that efficiency of any wetland to store P on a long-term basis is determined by the peat or sediment accretion rate times the net increase of P stored by these processes each year. To retain as much P as possible, the input rates should be limited to the long-term storage capacity, which is controlled by peat/sediment accretion. In typical North American freshwater wetlands accretion rates average from 1 to 2 mm/year.

In general, it appears that wetlands receiving low levels of P can remove P effectively over the long term. Submerged aquatic plants are capable of taking up large amounts of P and some are capable of producing allelopathic polyphenols that inhibit algae growth and development^{21,22}. Recent studies of plant uptake capacity of P shows that phytoplankton are more efficient than

macrophytes at removing P from the water column. Calculations show that in low P environments, almost twice as much P added to the water was taken up by *Cladophora*, epiphytic on *Potamogeton pectinatus* L. (sago pondweed) than by *Potamogeton* itself, although the biomass of the latter was some 30 times greater²⁰. It has been suggested that submerged macrophytes, such as sago pondweed with high P-accumulation potential and high waterfowl utility, be cultivated in wetland systems as a waterfowl food resource. In this way, wetland plants like sago pondweed with seasonally high-accumulated P concentrations could be naturally harvested by migrating waterfowl and shorebirds. This would result in a potential net decrease of available P in the wetland system.

Table 6 provides a general comparison of treatment effectiveness of conventional wastewater processes versus wetland systems for constituents included in this review.

Table 6. General comparison of treatment effectiveness of conventional wastewater processes versus wetland systems (● = effective, ◐ = somewhat effective, ○ = less effective).				
<i>Water Quality Components</i>	Primary & Secondary	Tertiary	Wetlands	Comments on Wetland System Effectiveness:
Parameters: DO, pH, EC, Temp., Turbidity	○	◐	◐	Somewhat effective dependent on system design, plant type and density, water depth and retention time.
Constituents: BOD ₅ , TSS, Total and Fecal Coliform	●	●	●	Wetland treatment highly effective in removing these constituents.
Nutrients: TKN, NH ₃ -N, NO ₃ -N, Total P, PO ₄ -P	○	◐	●	Highly effective in reducing nutrient concentrations with appropriate treatment surface area and design.
Minerals: Na, K, Ca, Mg, CO ₃ , HCO ₃ , Cl, SO ₄	○	◐	◐	Little effect on mineral concentrations. Some reduction of sulfate.
Elements: As, Fe, Mn, Se	○	◐	●	Elements removed by precipitation, sedimentation and biological uptake with appropriate treatment surface area and design. Selenium is volatilized by microbes and plants.
Heavy Metals: Cd, Cu, Hg, Pb, Zn	○	◐	●	Heavy metals removed by precipitation, sedimentation and biological uptake with appropriate treatment surface area and design.

Klamath Straits Drain Flows and Nutrient Loads. The mean annual flow rate of KSD at Pumping Plants F & FF between January 1987 and June 2000 was 132.12 cfs. Flow rates at this location were highly variable, ranging from 0 cfs to nearly 600 cfs, depending on seasonal water demands. See Figure 4 for an illustration of the variation in combined flows at Pumping Plants F

& FF. At Stateline Highway and Pumping Plants E & EE, mean annual flow rates were 71.19 and 207.71 cfs, respectively.

Typically, wetland systems are designed to accommodate a constant flow volume so wetland units remain flooded. With the highly variable flows found at Pumping Plants F & FF, it would be necessary to impound or to manage flows so that the wetland system received a constant flow.

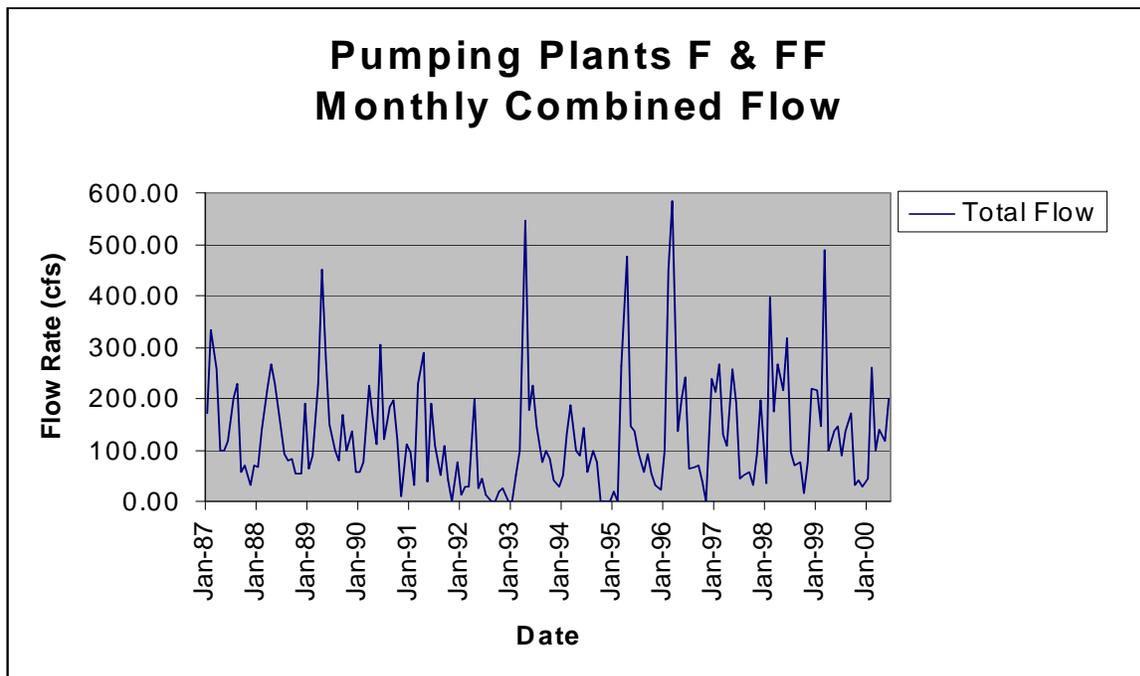


Figure 3. Combined monthly flows at Pumping Plants F & FF between 1987 and 2000.

With a mean annual flow of approximately 133 cfs at Pumping Plants F & FF, a rough estimate of annual nutrient loads entering into the Klamath River via the KSD were calculated from mean constituent concentrations. Table 7 indicates the mean constituent concentrations and the estimated annual constituent loads at the KSD Pumping Plants F and FF from 1991 through 1999.

Table 7.
Mean constituent concentrations (mg/L or µ/L) and estimated annual constituent loads (MT/year) at the KSD Pumping Plants F and FF (1991-1999).

Tot-P		PO ₄ -P		TKN		NH ₃ -N		As	
mg/L	MT/year	mg/L	MT/year	mg/L	MT/year	mg/L	MT/year	µg/L	MT/year
0.34	40.4	0.23	27.4	0.8	95.1	0.47	55.9	14.8	1.8

Preliminary Treatment Wetland Size Estimate. Constructed treatment wetlands may be designed to effectively remove P if their internal removal mechanisms are understood and if these removal and storage processes are optimized by management techniques²⁰. In general, treatment wetlands have been found to remove 0.17-0.73 g/m²/year of total P or 9 to 80% of the

available phosphorus²³. Phosphorus removal by treatment wetlands often requires the largest treatment area when compared to other constituents to provide effective removal and long-term storage.

Kadlec and Knight Model. A common approach for the development of treatment wetland size estimates is the use of a model formulated by Kadlec and Knight¹³. Kadlec and Knight have collected information (North American Wetland Database) from natural and constructed wetland systems used in the treatment of a variety of wastewaters. From this data, they have developed parameters for use in a first order areal model of the removal effectiveness in wetland systems. An estimate of the necessary wetland treatment area can be calculated for several constituents including total P, biochemical oxygen demand, total suspended solids, total nitrogen, organic nitrogen and fecal coliform. This model requires values for the following model parameters:

Q = Design flow, m³/day

C_i = Influent concentration, mg/L

C_e = Target effluent concentration, mg/L

C* = Wetland background concentration, mg/L

k = Areal rate constant, m/yr (developed from regression model on existing wetlands in the North American Wetland database)

A = Required wetland treatment area, ha

Model: $A = (0.0365 \cdot Q/k) \cdot \ln(C_i - C^*/C_e - C^*)$. To carry out this calculation, mean values of total P concentrations were used:

Design Input flow (Q): To estimate appropriate design flow, mean daily flow rates from Pumping Plant F & FF and Stateline Highway were used in order to develop a range of possible flow values found along the KSD. Values of 71.19 cfs and 132.12 cfs were determined from daily flow data collected at Stateline Highway and Pumping Plant F & FF between January 1987 and June 2000. This calculation was determined with the values of 70 and 133 cfs (171,158 and 325,200 m³/day).

Influent concentration (C_i): In this analysis, the highest mean total P concentration measured at Stateline Highway was determined from data collected between May 1991 and November 1999. In order to provide a conservative wetland size estimate, the highest value of 0.41 mg/L of total P was used in the analysis.

Target effluent concentration (C_e): It was reported that a concentration of 0.08 mg/L total P should be the target concentration aimed for in a comprehensive eutrophication control plan for Upper Klamath Lake^{2,3}. This value could be considered as the target effluent concentration given the fact that the water quality of the KSD is highly influenced by the water quality of the Klamath River and Upper Klamath Lake. A value obtained from TMDL guidelines for the KSD would have also been utilized, but at this writing, the DEQ has changed their focus concerning the draft TMDL document for the KSD and was unable to provide a target effluent goal for total P¹².

Another alternative was to develop the target effluent concentration from the calculated mean total P concentrations from monitoring sites upstream of the discharge point. It was assumed

that the water quality of upstream monitoring sites would be superior to the quality of water at the KSD discharge point, Pumping Plants F & FF. Consequently, mean total P concentrations were determined from data collected at monitoring sites upstream from the KSD. The lowest mean total P concentration of 0.10 mg/L was found at Miller Creek Dam (K-8) within the Lost River drainage. A concentration of 0.16 mg/L was found at Klamath River (K-10) upstream of the KSD and 0.22 mg/L total P was found at Malone Reservoir (K-7) within the Lost River drainage. For this analysis, we used the value of 0.16 mg/L total P, which was found at Sampling Station K-10 along the Klamath River upstream of the KSD.

It should be noted at the present time, that phosphorus is not a regulated parameter (TMDL or Section 303(d)) within the Klamath Basin, so this target effluent concentration was used solely for the purpose of developing the preliminary wetland system size. This value was not determined for the establishment of any new concentration criteria for total P within the Klamath or Lost River drainages.

Wetland background concentration (C^):* It has been reported that the Klamath Basin has a naturally high P load with background values ranging from 0.049 mg/L on the Sprague River to 0.08 mg/L on the Williamson River and 0.063 mg/L for the entire watershed^{16,17}. The latter value of 0.063 mg/L was used in this analysis.

Areal rate constant (k): The preliminary sizing model requires an estimate of the first order P removal rate constant (k). Kadlec and Knight suggest a value of 12 meters/year (m/y) for emergent surface-flow wetlands¹³. This value is based on data from 20 emergent marshes (14 were wetlands treating municipal wastewater and 6 were wetlands treating other wastewater). From other research, it was suggested that a rate constant developed from the six wetlands treating non-municipal wastewater would be more representative of wastewaters within the Klamath Basin. It was determined the rate constant could range from 6.3 to 14.7 m/yr. In this analysis, the standard 12 m/yr was used.

Required wetland area (A): The wetland surface area required for the treatment of total P in KSD water can be estimated with values incorporated into the Kadlec and Knight Model. From this calculation, it was determined that an emergent surface-flow wetland system would require an approximate treatment area ranging between 1,633 to 3,114 acres depending on daily flow rate (70 to 133 cfs). Given this treatment surface area, it is estimated that the wetland system would have a total area including roads, dikes and levees ranging between 2,041 and 3,893 acres.

Conclusion

With an estimated wetland treatment area ranging between 1,633 and 3,114 acres, according to the Kadlec and Knight Model, the wetland could achieve a 61% reduction in total P concentration (0.41 to 0.16 mg/L) and a 90% reduction in total nitrogen including $\text{NH}_3\text{-N}$. Given this percent reduction in total P, an estimated 16 to 30 MT/year, could be removed from the Straits Drain depending on drainage flows. This reduction in total P concentration would substantially reduce many of the negative impacts to water quality in the KSD. However, to maintain a constant flow rate, water storage strategies would be required to manage higher flow periods.

The model used by Kadlec and Knight was based on information collected from over 100 wetland systems located throughout North America. However, there has been no real assessment of how successful their model is for predicting the treatment success of a given constituent. If a wetland system were to be considered, it would be recommended that a treatment wetland pilot-study be established to develop site and water quality specific parameters. The pilot-study could be used to better estimate treatment potential of a full-scale wetland system to improve the water quality of the Straits Drain.

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