Preliminary Feasibility Assessment of Constructed Treatment Wetlands in the Vicinity of the Klamath Hydroelectric Project

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Executive Summary

The objective of this preliminary feasibility assessment was to examine the potential for treatment wetlands to provide improved water quality in the vicinity of PacifiCorp's Klamath Hydroelectric Project (Project). Water quality improvement is a particular focus for PacifiCorp's management of Project reservoirs, which receive large inflowing loads of nutrients and organic matter from upstream sources (notably Upper Klamath Lake), which drive summertime blooms of cyanobacteria (i.e., blue-green algae) in the reservoirs. It is well established that wetlands can act as filters removing particulate material, as sinks accumulating nutrients, or as transformers converting nutrients to different forms, such as gaseous compounds of nitrogen and carbon (Crites et al. 2003, Kadlec and Wallace 2008).

This preliminary feasibility assessment was conducted by a team of wetland scientists and engineers with expertise in constructed wetlands, reservoir limnology, and nutrient and algae control measures. The team conducted a reconnaissance of the Klamath River in the Project vicinity from Iron Gate dam (at River Mile 189.5) upstream to near Link dam at the outlet of Upper Klamath Lake (RM 259). The team identified potential sites and conceptual layouts for locations both upstream and within the Project reservoirs. The upstream sites were considered as "preventative" sites, because upstream sites would be intended for treatment of water quality upstream of the reservoirs (and below UKL) to remove nutrients and algae (i.e., the "cause" component). The "reservoir" sites would be intended for treatment of accumulations of algae biomass within the reservoirs, such as in reservoir coves (i.e., the "effect" component).

A number of candidate sites for upstream "preventative" treatment wetlands were identified, especially in the river upstream of Copco reservoir between about RM 205 to RM 209. Conceptual layouts for constructed treatment wetlands were developed for these sites, along with calculated estimates of potential treatment effectiveness (e.g., nutrient reductions). The sites are characterized by topographic and hydrologic conditions that would be amenable to wetland construction. The sites are generally low-lying and directly adjacent to the river. Several sites are on PacifiCorp property and have the advantage of existing gravity-fed pasture irrigation canals that could be used as the inflow infrastructure for constructed wetlands. The sites generally have soil conditions that are conducive to constructed treatment wetlands, but more thorough site-specific soils investigations would be needed for further wetland design and construction planning. Although these sites offer ready access to flows, a determination of regulatory requirements for diversion and routing of water through potential wetlands would be a critical precursor of further wetland design and planning.

A major constraint identified in this assessment is that the potential sites for constructed wetlands on PacifiCorp-owned lands in the Project area could receive and treat only a minor fraction of the total flow of the Klamath River, and would be unlikely to provide measureable improvements to downstream river or reservoir water quality. Instead, to achieve a demonstrable river nutrient and organic matter load reduction, it would be necessary to develop more and larger wetland sites that would collectively or in the aggregate treat a substantial portion of the river flow. This would by necessity involve constructed treatment wetlands on lands elsewhere above the Project area that are adjacent to the river system. The need to "scale-up" the overall size of constructed wetlands to achieve demonstrable and meaningful water quality benefits points to the need for a basin-wide effort that would require multiple stakeholder participation.

The costs of constructed treatment wetlands vary greatly depending on size and site conditions. If the 300 acres of PacifiCorp-owned sites were developed with treatment wetlands, costs could range from $15 to $45 million for construction, and about $150,000 to $2 million per year for O&M. Additional costs would include any site investigation and engineering design, pre-treatment components (if used), and land costs.

Several candidate sites for "reservoir" treatment wetlands were identified, especially within Copco reservoir (located on the Klamath River from RM 198.6 to RM 203.2). Potential sites were identified and design concepts were developed to evaluate vegetated swale ("bioswale") filtration as a possible treatment of localized accumulations of algae biomass resulting from summertime blooms in the reservoirs.

Site conditions adjacent to reservoir cove areas are amenable to potential construction of vegetated swales (bioswales) for removal and filtering of accumulated algae biomatter. Such swales have well-demonstrated effectiveness for reduction or removal of particulates in water, and offer a possible natural treatment option for reducing algae biomatter. However, a key constraint to the use of this system is how the algae would be efficiently collected from the reservoir and pumped to the swales. In addition, the use of vegetated swales for treatment of algae would need additional pilot-scale or demonstration testing to determine operating conditions and removal efficiencies. Until such determinations are made, the ultimate effectiveness of implementing vegetated swales for reducing algae biomatter remains uncertain.

As with constructed treatment wetlands, the cost of installing and maintaining vegetated swales varies widely with design and site variability. Without assuming the cost of land purchase, the total costs for vegetated swale systems at the two sites identified in this assessment (about 50 acres) would be on the order of $2.5 to $3.8 million for construction, and about $125,000 to $275,000 per year for O&M.

Floating treatment wetlands are an emerging wetland treatment technology that could be used in Copco and Iron Gate reservoirs. Pilot-scale studies have demonstrated the effectiveness of floating treatment wetlands in research elsewhere. However, larger field-scale demonstrations are lacking, and there is currently little or no design basis available for sizing a floating treatment wetland system. Consequently, the effectiveness of implementing a floating treatment wetland system remains uncertain. The estimated cost for this emerging technology would be about $260,000 to $4 million per 20 acres of reservoir area, with O&M costs of $13,000 to $200,000 per year.

Introduction

Objective

The objective of this preliminary wetlands feasibility assessment is to evaluate the potential for constructed treatment wetlands[1] to provide improved water quality in the vicinity of PacifiCorp's Klamath Hydroelectric Project (Project). Water quality improvement is a particular focus for PacifiCorp's management of Project reservoirs, which receive large inflowing loads of nutrients and organic matter from upstream sources, notably Upper Klamath Lake, which drive summertime blooms of cyanobacteria (i.e., blue-green algae) in the reservoirs. It is well established that wetlands can act as filters removing particulate material, as sinks accumulating nutrients, or as transformers converting nutrients to different forms, such as gaseous compounds of nitrogen and carbon (Kadlec and Wallace 2008, Crites et al. 2006).

This preliminary feasibility assessment is an initial determination of the viability of using constructed wetlands to enhance water quality in the vicinity of the Project. The intent is to evaluate the basic efficacy of using constructed wetlands based on site requirements and conditions, so as to assist subsequent decisions to potentially proceed to more detailed study or design. This assessment identifies a variety of possible sites and conceptual approaches for potential treatment wetlands in the vicinity of the Project. Important site conditions and constraints are identified, and approximate costs for constructing potential treatment wetlands are estimated. This preliminary feasibility assessment does not address the scope and magnitude of constructed wetlands that may be necessary in the Klamath River basin to achieve particular levels of water quality improvement, nutrient reduction or particulate removal.

Background

PacifiCorp's Project reservoirs on the Klamath River (i.e., Iron Gate, Copco, and J.C. Boyle reservoirs) are nutrient-enriched (eutrophic) due to large inflow loads of nutrient and organic matter from upstream sources, notably Upper Klamath Lake (UKL). The nutrients that primarily cause eutrophication in lakes and reservoirs are nitrate, ammonia, and various forms of phosphorus (Thornton et al. 1990, Welch 1992, Horne and Goldman 1994, Holdren et al. 2001, Cooke et al. 2005). In general, eutrophic lakes and reservoirs have high algal biomass and low deep water dissolved oxygen during summer, and are typically characterized by summertime blooms of cyanobacteria (Thornton et al. 1990, Welch 1992, Horne and Goldman 1994, Cooke et al. 2005).

The dominant blue-green alga in UKL, and until recently in the Project reservoirs, has been *Aphanizomenon flos-aquae* (APHA), a common bloom-forming species (Phinney 1959, Johnson

[1] The term "constructed treatment wetlands" as used in this document refers to the technology designed to employ ecological processes found in natural wetland ecosystems (e.g., wetland plants, soils, and associated microorganisms) to remove nutrients and particulates from water.

et al. 1985, PacifiCorp 2004a, PacifiCorp 2004b, Wee and Herrick 2005, PacifiCorp 2008a, PacifiCorp 2008b). Since about 2004, the dominant blue-green alga in the Iron Gate and Copco reservoirs has been *Microcystis aeruginosa* (MSAE), which is capable of producing the toxin microcystin (PacifiCorp 2006, PacifiCorp 2008b). The apparent increase in MSAE in Iron Gate and Copco reservoirs in the last few years may be the result of a concomitant increase in the already-high external nutrient loads to the reservoirs from the inflowing Klamath River, particularly nitrogen. Such an increase is indicated in the nutrient loading analyses of Kann and Asarian (2005) and Kann and Asarian (2007), who reported higher loads of nutrients, including nitrogen, collected in 2005 and 2006 than was previously collected in 2002.

Nitrogen in particular is considered as the "limiting" nutrient to algal production in the Project reservoirs, as well as UKL (PacifiCorp 2004a, PacifiCorp 2004b, Kann and Asarian 2005, Moisander 2008), in part suggested by the dominance of APHA, a cyanobacteria species capable of fixing atmospheric nitrogen. However, MSAE does not fix atmospheric nitrogen (it is a non-N-fixing species), and is known to opportunistically dominate during periods of stratification in highly nutrient-enriched systems (eutrophic or hypereutophic), where available nutrients (both phosphorus and nitrogen) are each in high supply and non-limiting (Paerl 1988). In such enriched systems, where phosphorus and nitrogen can be supplied at non-limiting or close to non-limiting rates, very high rates of algae production and biomass accumulation can occur (Paerl 2005). The large loads of nutrients from the Klamath River upstream of the Project reservoirs include substantial quantities of both soluble nitrogen and phosphorus (Kann and Asarian 2005, PacifiCorp 2006, Kann and Asarian 2007).

Normally, the water in rivers and surfaces of lakes is fully oxygenated and the labile organic matter it contains is also fully oxygenated. Typically, lakes and streams have a 5-day biochemical oxygen demand (BOD_5) of 1 to 2 mg/L, which is low compared with raw sewage (80 to 250 mg/L) and confined animals and winery waste (3,000 to 10,000 mg/L). Most sewage treatment plants are allowed to discharge treated water with anywhere from 2 to 30 mg/L, depending on the size and nature of the receiving water (EPA 1996). Unlike most lakes and reservoirs, the BOD_5 of UKL as it flows out of the lake and into the upper Klamath River can be as much as 30 mg/L (Tetra Tech 2004, Doyle and Lynch 2005, Deas and Vaughn 2006), or similar to what is allowed for sewage discharges (EPA 1996).

The BOD in UKL has not been fully characterized, but is probably due to living and decaying cyanobacteria that are abundant in UKL (Wood et al. 2006). Reduction in this BOD level is needed in river waters flowing into the Project reservoirs in order to ensure a well-oxygenated water supply downstream (PacifiCorp 2008a). Thus, removal of soluble and particulate organic matter is desirable in the Klamath River, and forms a key objective of potential constructed treatment wetlands.

Reduction in inflowing nutrients and cyanobacteria cells would further reduce algae production and enhance the water quality in the reservoirs and the Klamath River (PacifiCorp 2006, PacifiCorp 2008a, PacifiCorp 2008b). The current watershed plans with regard to nutrients in UKL are primarily concerned with total maximum daily loads (TMDLs) for total phosphorus (TP) (Boyd et al. 2002). The TMDL plan calls for a 40 percent reduction in external TP loading to UKL as the targeted condition for TMDL implementation, and suggests potential external TP loading reductions can be achieved by near-lake wetland restoration and restoration of upland hydrology and watershed land cover (Boyd et al. 2002). However, algal growth in UKL and the Project reservoirs is mostly N-limited, so TP reductions could have limited success. Thus, reduction of soluble and particulate nutrients, particularly nitrogen, is a primary objective of potential constructed treatment wetlands.

Wetland Treatment Principles

It is well-established that interception and removal of nutrients and particulates (including algae) can be accomplished using constructed wetlands (EPA 2000a, EPA 2000b, ITRC 2003, Kadlec and Wallace 2008). Constructed wetlands consist of shallow (usually less than 1 m deep) ponds or channels, which have been planted with aquatic plants, and which rely upon natural microbial, biological, physical and chemical processes to treat water. The wetland-related mechanisms and processes that are utililized to improve water quality include: (1) settling of suspended particulate matter; (2) filtration and chemical precipitation through contact of the water with the substrate and plant materials; (3) chemical transformation; (4) adsorption and ion exchange on the surfaces of plant materials, substrate, and sediment; and (5) uptake and transformation of nutrients by microorganisms and plants. The most effective treatment wetlands are those that foster these mechanisms and processes.

The design considerations for constructed wetlands systems are varied and site dependent (EPA 2000a, EPA 2000b, ITRC 2003, Kadlec and Wallace 2008). Wetlands are constructed as either surface flow or subsurface flow systems. This feasibility assessment focuses on surface flow systems since the intent is to provide treatment of Klamath River surface waters in the vicinity of the Project. Surface flow systems require more land, but generally are easier to design, construct and maintain. They consist of shallow basins with emergent and submergent wetland plants that tolerate saturated soil and aerobic conditions. Water flows in one end of the basin, moves slowly through, and is released at the other end.

Several factors determine the effectiveness and efficiency of constructed wetlands to retain and remove nutrients and particulates. These factors include hydraulic retention time (HRT)[2], influent nutrient and particulate concentrations, water depth, hydraulic loading rate, alternate dry (aerobic) and wet (anaerobic) conditions, emergent vegetation, water chemistry, and soil type (Kadlec and Wallace 2008, Crites et al. 2006, Chavan et al. 2008). In general, the ability of a wetland to trap or transform nutrients and particulates increases as the water retention time increases. As a result, the hydraulic characteristics and HRT of a constructed wetland is often the most important factor in its effectiveness, and the designs of constructed wetland systems are usually based on HRT (Kadlec and Wallace 2008, Chavan and Dennett 2008). Other important hydrology and hydraulic characteristics in wetland design pertain to inflow rates (including their reliability and extremes), flow movement through the site, hydroperiod, groundwater exchanges (infiltration and exfiltration), and evapotranspiration.

Removal of particulates, including cyanobacteria biomatter, is primarily due to the physical processes of settling, sedimentation, filtration, and interception (EPA 2000a, EPA 2000b,

[2] The hydraulic residence time (HRT) of a treatment wetland is the average time that water remains in the wetland, expressed as mean volume divided by mean outflow rate. If short-circuiting develops, the effective HRT may differ significantly from the calculated HRT.

Kadlec and Wallace 2008). Normally, an HRT of about 2 days is needed to remove approximately 80 to 90 percent of total suspended solids (TSS) typically found in lake and river waters[3]. EPA (2000b) reports that it is common for removal in treatment wetlands of particulate-bound nutrients and particulate organic matter to parallel TSS removal. Crites et al. 2006 report that more buoyant algae biomatter may require 6 to 10 days of HRT in natural treatment systems for removal. The largest wetland designed to remove lake particulates is the 5,000-acre Lake Apopka wetland in Florida. The Lake Apopka system provides gravity flows from the lake to the shallow constructed wetland that result in an HRT of about 7 days in passage through a dense mixed wetland stand, after which flows are pumped back to the lake (Coveney et al. 2002).

The removal of soluble nitrogen may be achieved by plant uptake, nitrification or denitrification, volatilization, and ion exchange, although the latter two are considered to be of minor consequence in most wetland systems (EPA 2000a, EPA 2000b, Kadlec and Wallace 2008). Effective nitrogen removal requires careful wetland system design and management. The removal of soluble nitrogen will require ample HRT (approximately 3 to 7 days) for plant uptake and nitrification/denitrification processes to occur. Wetland plants will take up or assimilate nitrogen as an important part of their metabolism. Inorganic nitrogen forms are reduced by the plant to organic nitrogen compounds used for plant structure. During the growing season, there can be a high rate of uptake of nitrogen by wetland plants. Estimates of net annual nitrogen uptake by emergent wetland plant species vary from 0.5 to 3.3 $gN/m^2/yr$ (Kadlec and Wallace 2008).

Denitrification is a process in which wetland microbes convert nitrate to nitrogen gas (N_2 or N_2O) under anaerobic conditions. Denitrification reactions usually occur in wetland sediments where dissolved oxygen is low and available carbon is high. Nitrification is a process in which wetland microbes convert ammonia to nitrate in the presence of dissolved oxygen. Ammonia will require approximately 10 times the wetland area (or HRT) of that needed to process nitrate since it must be nitrified to nitrate under oxidized conditions. Temperature affects both nitrification and denitrification so that rates can be significantly reduced during the colder months, which can affect design requirements.

The removal of soluble phosphorus is basically achieved by uptake by plants, algae, and bacteria (EPA 2000a, EPA 2000b, Kadlec and Wallace 2008). Uptake occurs during the growth phase of these organisms and release occurs during subsequent senescence and death in the late summer and fall, followed by decomposition. A portion of this phosphorus is lost to the system through accretion processes within the sediments.

In addition to HRT, another important factor that determines the removal rate of nutrients and particulates in wetlands is the influent concentrations or loads of these constituents. For example, several studies have shown that higher influent loads result in higher area-specific nitrogen removal (kilogram per hectare and year) (EPA 2000a, Kadlec and Wallace 2008, Crites et al. 2006). In cases of high influent loads, the addition of pretreatment of the inflow

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[3] Using Stokes' Law to approximate discrete settling velocity, particles ranging from 1 to 10 µm with a specific gravity ranging from 1.01 to 1.10 will settle at a rate of from 0.3 to 4 x 10-4 m/day. Typical hydraulic loads to wetlands are in the range of 0.01 to 0.5 m/day (note that the hydraulic load is equivalent to the mean settling velocity of a particle that will be removed exactly at that loading). Assuming the higher settling velocity of 0.3 m/day and a typical system velocity of 50 m/day and depth of 0.8 m, the larger particles would settle by gravity in approximately 2.7 days, or 133 m along the wetland longitudinal axis.

to the wetland with chemicals (e.g., alum, sulfate) is often considered (EPA 2000a) to augment removal rates.

Although the research literature on constructed treatment wetlands has shown variable success in reducing nutrients (see Kadlec and Wallace 2008), there are relevant examples of regional wetlands that have shown effective nutrient reductions. The New River Wetlands Project near Imperial, California includes two pilot wetlands that were constructed in 2000 in the New and Alamo Rivers (IBWC 2008). These pilot wetlands are being monitored to assess wetland removal of excessive nutrients, including phosphates and nitrates that occur in the rivers from runoff of agricultural fertilizers and municipal wastewater. The two wetlands comprise a total of 29 wet acres and have HRTs of about 7-9 days. Monitoring since construction has shown that both wetlands significantly reduce the amount of nitrogen (i.e. 49-72 percent removal), phosphorous (38-49 percent removal), and total suspended solids (92-94 percent removal) in the water (IBWC 2008).

The Prado Wetlands near Riverside, California include nearly 465 acres of constructed wetlands, consisting of 50 shallow wetland ponds that have been utilized to remove nitrogen in Santa Ana River water since 1992 (OCWD 2008). The wetland system removes approximately 20 tons of nitrate per month, and during summer months reduces nitrate concentration from 10 mg/L to less than 1 mg/L (OCWD 2008). The primary mechanism for the nitrate removal is denitrification. Research indicates that the key to denitrification in the Prado Wetlands are the plant regimes, which determine the quality and quantity of organic matter that provides both a short-term and a long-term organic source for denitrifiers (Ibekwe et al. 2006).

Research on the Prado Wetlands has further assessed the effects of HRT and wetland age on nitrate removal rates (Ibekwe et al. 2006, OCWD 2008). Results determined that longer HRT did lower outflow nitrate concentrations, but varying HRT did not affect removal rates. Nitrate removal rates were seasonally dependent. The ponds are most effective during the warm summer months, due to warm temperature effects on denitrifiers. Nitrate removal rates also increase with wetland age. More mature wetlands provide increased litter which in turn provide additional organic carbon, greater anoxic zones, and improved habitat for the denitrifiers and for the entire microbial community.

Assessment Methods

This preliminary feasibility assessment was conducted by a team of wetland scientists and engineers with expertise in constructed wetlands, reservoir limnology, and nutrient and algae control measures. An extensive reconnaissance survey of the Project vicinity was carried out by the team in April 2008, including the Klamath River in the Project vicinity from Iron Gate dam (at River Mile 189.5) upstream to near Link dam at the outlet of Upper Klamath Lake (RM 259).

During the site reconnaissance, the team identified potential sites for constructed treatment wetlands both upstream and within the Project reservoirs. The upstream sites were considered as "preventative" sites, because upstream sites would be intended for treatment of water quality upstream of the reservoirs (and below UKL) to remove nutrients and algae (i.e., the "cause" component). The "reservoir" sites were intended for treatment of accumulations of algae biomass within the reservoirs, such as in reservoir coves (i.e., the "effect" component).

During the site reconnaissance, the team discussed opportunities and constraints of potential sites, and brainstormed on conceptual layouts of wetlands at these locations. A number of candidate sites for upstream "preventative" treatment wetlands were identified, especially on PacifiCorp-owned lands along the river upstream of Copco reservoir between about River Mile (RM) 205 to RM 209. Some of these sites have existing diversion channels for pasture irrigation that could be readily adapted to feed treatment wetlands.

During the site reconnaissance, the team also identified example sites in Copco and Iron Gate reservoirs for wetlands to treat reservoir accumulations of blue green algae. As explained further is the *Assessment Results* section of this report, the use of wetlands for treatment of algae biomass is uncommon compared to treatment of nutrients and particulates. Therefore, the team's approach to using wetlands for treating accumulations of algae borrows from existing technologies for infiltration-based vegetated swale systems used in stormwater treatment (Wong et al. 2006, Siriwardene et al. 2007, Hatt et al. 2007 and Vymazl 2005).

Following the site reconnaissance, the team prepared example conceptual layouts for constructed treatment wetlands at identified sites. To help characterize the sites, a review of basic information on the characteristics of potential wetlands sites was conducted, including soil and hydrogeologic conditions, and the possible presence of existing wetlands or sensitive flora and fauna. This information was obtained or developed based on data and information available from PacifiCorp Final License Application (FLA) materials (PacifiCorp 2004a, PacifiCorp 2004b, PacifiCorp 2006, PacifiCorp 2008a, PacifiCorp 2008b) and other available information sources (e.g., NRCS soil surveys).

A rough water balance of potential wetland sites was estimated to quantify the water inflows to the constructed wetlands systems from the river and the outflows, including the net losses through evapotranspiration. It was assumed that what is not evapotranspired would be returned to the river (or reservoir) through surface water discharge or indirect discharge through groundwater.

The team developed estimates of potential treatment effectiveness (e.g., nutrient reductions) based on research literature information and first-order treatment calculations based on assumed river water quality and flow conditions, and estimated wetland sizes. The team also derived a rough order-of-magnitude estimate of costs for wetland construction.

Assessment Results

Wetland Treatment Approaches

On the basis of the assessment objectives and the April 2008 site reconnaissance, the team identified two basic approaches to wetland treatment in the vicinity of the Project: (1) a “preventative” treatment wetland approach to remove a portion of the nutrients and algae (i.e., the “cause” component) from the river before entering the reservoirs; and (2) a “reservoir” treatment wetland approach to reduce or remove dense accumulations of algae biomass within the reservoirs, such as in reservoir coves (i.e., the “effect” component).

“Preventative” Approach

Potential treatment wetlands representing the “preventative” approach are envisioned for sites identified by the team upstream of Copco reservoir and downstream of UKL. During the April 2008 site reconnaissance, the team identified several potential sites for such wetlands located along the Klamath River upstream of Copco reservoir (RM 205 to RM 209), and the upper end of J.C. Boyle reservoir and the river reach above it (from about RM 227 to RM 230). Most of these particular sites are owned by PacifiCorp, providing an obvious advantage over non-PacifiCorp-owned sites with regard to potential implementation approvals and costs.

Additional sites for potential treatment wetlands representing the “preventative” approach were identified along Keno reservoir upstream of Keno dam (from about RM 234 to RM 240). These sites are low-lying agricultural lands adjacent to the Klamath River that are not owned by PacifiCorp. These lands are larger and less confined than the PacifiCorp-owned lands in the Project area. As such, these larger tracts, if available, would offer more area to accomplish better treatment performance both quantitatively and qualitatively. Larger wetland areas would be able to accommodate and treat a greater volume of water, and would allow a longer HRT for treatment.

For nutrient reduction and cyanobacteria particulate removal, the team identified potentially important design features for treatment wetlands representing the “preventative” approach, including:

- Surface flow treatment wetlands, in multiple cells and with multiple parallel flow paths.
- Water supplied from the river using existing river diversions for irrigation and existing irrigation canals, new river diversions, with pumping from the river as last resort. Power supply for pumped systems could be by turbines, solar power, and electric supply lines found close to most locations around the sites.
- If necessary to enhance treatment, alum or aluminum polymer addition—drip in, gravity-feed to enhance phosphorus and particulate removal.

- Mulch gabions distributed throughout the wetlands to deliver a steady flow of carbon to enhance microbial denitrification.

The team identified additional design features that could be considered on larger sites in the Keno area, including:

- Shallow periphyton or submerged aquatic vegetation wetlands could be developed similar to the Periphyton Stormwater Treatment Areas (PSTAs)[4] that have been used successfully in the Florida Everglade restoration for significant nutrient removal (Kadlec and Wallace 2008). The advantage of using these systems on larger sites in the Keno area is that there are no canyon walls, so that the sunlight would have a longer period to shine on the periphyton for nutrient uptake, algae filtration, and photo-oxidation of organically-bound nitrogen.

- Soil amendments such as alum, calcium carbonate and dolomite to facilitate the removal of phosphorus by the formation and precipitation of phosphorus salts (e.g., calcium phosphate). The formation of calcium phosphate is associated with the shift in pH to the alkaline range due to increased photosynthetic activity in the daytime. In the shallow periphyton-based wetlands, the photosynthesis occurs within the water column where the plants will take in bicarbonate and expel hydroxide to cause an increase in pH. Within the shallow water column, the increases in pH can facilitate the formation and precipitation of calcium phosphate and calcium carbonate.

- The installation of short, highly-porous mesh barriers (e.g., Vmax³® by North American Green) to provide additional surface area and filtration abilities within the constructed wetland.

The benefit of these additional wetland treatment technologies would be to capture and remove as much of the algae and phosphorus as possible before it gets into the downstream river system. An additional benefit would be oxidation of the organically-bound nitrogen by bacteria and sunlight into forms of nitrogen that are easily removed by the periphyton and other downstream treatment wetlands.

“Reservoir” Approach

The “reservoir” approach consists of the potential removal of cyanobacteria biomatter from reservoir coves into adjacent subsurface flow (SSF) or infiltration-based vegetated swales. The technical design concept behind this approach would include removal of algae bloom material by surface skimming, which is then pumped into adjacent vegetated swales near the coves that contain gravel-filled gabions planted with native grasses. To maintain the plants, a nominal flow of water could be pumped to the gabions throughout the spring and summer. When algae begin to concentrate in the coves of the Project reservoirs, volumes of the surface water containing accumulated algae biomatter would be pumped to the top of these swales, where the algae biosolids would be filtered out by the gravel and plant stems and roots.

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[4] PSTAs are treatment wetland areas based on shallow submersed aquatic vegetation that supports an active periphyton community. PSTA envisions sparse vegetation that forms an anchor and a substrate for periphyton. Emergent vegetation is sparse, if present at all, to avoid shading of the algal mats which occur on the bottom, as floating mats, and as attached growth on submerged plant parts.

This technical design concept is an adaption of the vegetated swale technology that is commonly used in stormwater treatment for the removal of particulate matter based on the approach of gravel-based SSF constructed wetlands. These vegetated swales are often referred to as "bioswales", which can provide good treatment of runoff water through infiltration and filtration (Jurries 2003). For example, Gersberg et al. (1986) showed a consistent 90 percent decrease in suspended solids in gravel-based SSF constructed wetlands where the influent was primary wastewater. The effectiveness of bioswales is generally dependent upon the retention time of the storm water in the bioswale; the longer the retention time, generally, the higher the removal efficiency (Jurries 2003).

In addition to vegetated swales adjacent to the reservoirs, the team discussed the potential of using floating treatment wetlands (also called floating islands, floating wetland islands, and hydroponic nesting islands) directly in the reservoirs. Floating treatment wetlands are an emerging technology that may be applicable to use in the Project reservoirs for nutrient and algae reduction (Headley and Tanner 2006, Nakamura and Mueller 2008, Stewart et al. 2008). Floating treatment wetlands are designed to develop complex aquatic root systems that serve to filter out particulate matter, take up nutrients, and provide habitat and shelter for zooplankton and fish that consume algae. With sufficient coverage, floating treatment wetlands also can provide shade that helps to reduce algae development (Nakamura and Mueller 2008).

Several different techniques have been used for the creation of floating wetlands and commercially available systems are available in the U.S (Headley and Tanner 2006, Stewart et al. 2008). The most common approach to constructing floating wetlands is through the creation of a floating raft or frame supporting a mesh on which plants are grown. Some commercially available systems can be modularized to form floating wetlands of various shapes and sizes.

Potential Treatment Wetlands and Layouts

This section summarizes potential constructed wetlands sites as identified in the Project vicinity during the April 2008 reconnaissance. Included in this discussion are available acreages by site and potential system layouts. More details on specific sites are provided in Appendix A.

Figure 1 shows the locations of 11 sites (Sites 004 through 014) examined during the April 2008 reconnaissance from the upper end of Iron Gate reservoir (Site 004) upstream to the Klamath River near the Oregon-California state line (Site 014 near RM 209). Site 004 is a river site at the entrance to Iron Gate reservoir, and Sites 008 to 014 are river sites upstream of Copco reservoir. These sites offer potential locations for preventative treatment systems using the multiple-cell surface flow wetland approach as previously described. Sites 005 and 006 are adjacent to Copco reservoir at Copco Cove and Beaver Cove, respectively. Large accumulations of algae biomatter along the shoreline in these coves have been observed in recent years. As such, these sites offer potential locations for reservoir treatment systems using the vegetated swale (bioswale) approach as previously described.

Figure 2 shows the locations of 8 sites (Sites 015 through 022) examined during the April 2008 reconnaissance from the lower end of J.C. Boyle reservoir (Site 015) upstream to near the middle of Keno reservoir (Site 019). Sites 015 to 017 are associated with low-lying areas along J.C. Boyle reservoir owned by PacifiCorp. Site 019 is a low-lying area adjacent to Keno reservoir that is similar in character to the J.C. Boyle sites, but not owned by PacifiCorp. Sites 020 and 022 are located on two large plots of low-lying agricultural land near Keno reservoir. These sites are on property not owned by PacifiCorp, but offer examples of the types of sites that could be used for larger-scale surface flow treatment wetlands.

Figure 1. Sites 004 to 014 along the Klamath River with the approximate size (acres) of some sites in the boxes.

Figure 2. Sites 015 to 022 in the Klamath River in the vicinity of J.C. Boyle and Keno reservoirs with the approximate size (acres) of some sites in the boxes.

Preventative Treatment Layout Examples

Figures 3 and 4 show example layouts of constructed surface flow wetlands along the Klamath River just upstream of Copco reservoir (e.g., sites 10 and 11 in Figure 3, and site 13 in Figure 4). These layouts assume the concept of constructed wetlands areas located next to the river that would be configured in a series of wetland cells through which a portion of the river flow would be diverted. This type of wetland provides reductions in nutrients and particulate matter by physical modes such as sinking or sticking to the “biofilm” of bacterial flora on wetlands plants. This type of wetland also allows detention of water sufficient to allow nitrate or phosphate to be metabolized and removed from the water.

The multiple cell configuration of such constructed wetlands provides flexibility for wetland management and function. For example, cells allow for the hydraulics in the wetlands to be adjusted so that flow through the wetland is uniform and provides sufficient HRT. Cells also allow for maintenance flexibility; for example, individual cells can be taken “off line” for maintenance if needed, while the other cells continue to operate. The land depicted in Figures 3 and 4 is owned by PacifiCorp. These particular PacifiCorp-owned sites have the advantage of already-existing gravity fed canals that could be used as the inflow infrastructure for constructed wetlands.

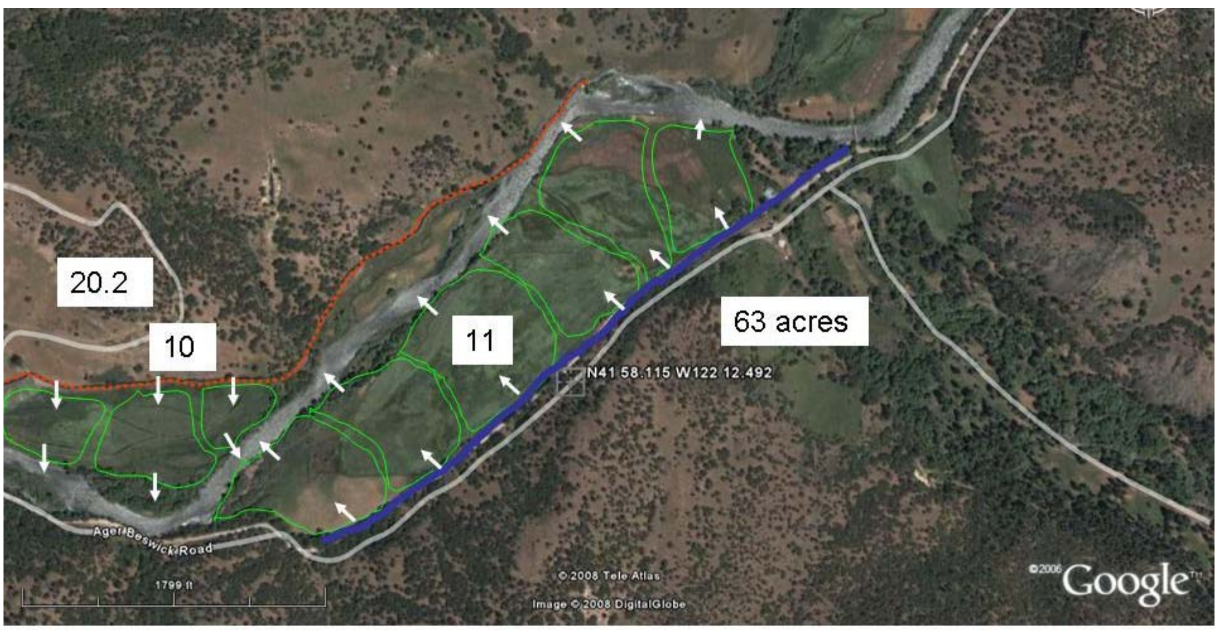


Figure 3. Conceptual layout of surface flow wetlands at Sites 010 and 011 in the Klamath River upstream of Copco reservoir.

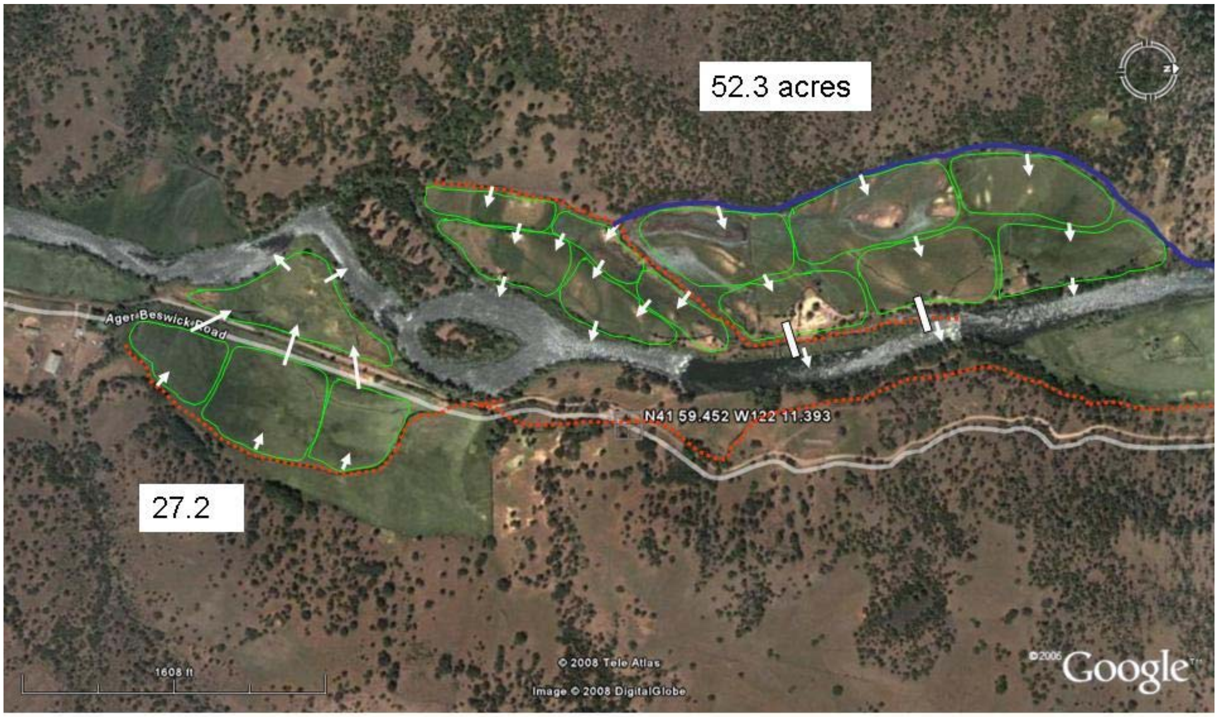


Figure 4. Conceptual layout of surface flow wetlands at Site 013 on the Klamath River upstream of Copco reservoir. As much as possible, this makes use of the pre-existing gravity fed canals (in red) and when necessary, installs new channels (in blue).

Reservoir Treatment Layout Examples

Figure 5 shows examples of reservoir wetlands designed to remove the algae biosolids from accumulations at reservoir cove sites (e.g., sites 005 and 006). As previously described, this concept would use a series of vegetated swales placed adjacent to the reservoir to treat algae biomass “slurry” pumped from the reservoir sites. The treatment occurs by filtration of the slurry through the gravel gabions embedded with native grasses.

Specific sites or layouts for floating treatment wetlands were not identified by the team for this preliminary feasibility assessment. For context, an example of a floating treatment wetlands installed elsewhere is shown in Figure 6. Additional discussion of the potential effectiveness and potential costs of floating treatment wetlands is discussed further in subsequent sections of this report.

Figure 5. Conceptual layouts of reservoir wetlands designed to remove the algae biosolids from reservoir coves by filtration through vegetated swales (top example is from Copco Cove and bottom example from Beaver Cove in Copco reservoir).

Figure 6. Example of a floating wetland deployment from Lake Sinclair in Georgia (designed and installed by Floating Island International, LLC).

Site Conditions of Importance to Effectiveness of Treatment Wetlands

As part of this preliminary feasibility assessment, the team identified three types of site conditions that are particularly important to estimate the potential effectiveness of treatment wetlands. These three types of site conditions include: (1) “baseline” water quality conditions in the river; (2) hydrologic conditions of the river at potential wetland sites; and (3) soil conditions at potential wetland sites. This information was obtained or developed based on data and information available from PacifiCorp FLA materials (PacifiCorp 2004a, PacifiCorp 2004b, PacifiCorp 2006, PacifiCorp 2008a, PacifiCorp 2008b) and other available information sources (e.g., NRCS soil surveys).

Water Quality Constituents and Flow

For purposes of this preliminary wetland feasibility assessment, representative “baseline” conditions for key water quality parameters were defined using available water quality data (PacifiCorp 2004a, PacifiCorp 2004b, PacifiCorp 2006, PacifiCorp 2008a, PacifiCorp 2008b). Assumed baseline water quality values by month are provided in Table 1 for the Klamath River in the Keno area upstream of J.C. Boyle reservoir and in Table 2 for the Klamath River upstream of Copco reservoir. Table 3 provides assumed values in total river flow by month for areas upstream of J.C. Boyle reservoir and Copco reservoir.

These baseline values are assumed to represent the of water quality flowing into the wetlands, and are thus assumed as the “boundary” conditions for water to be treated during wetland through-flow. The values presented in Tables 1, 2, and 3 were used in the team's estimate of the potential effectiveness of treatment wetlands as discussed in subsequent sections of this report. The values presented in Tables 1 and 2 include representative monthly average values for water temperature (˚C), total phosphorus (Total P in mg/L), orthophosphate (PO_4-P in mg/L), total nitrogen (Total N in mg/L), nitrate (NO_3-N in mg/L), ammonia (NH_4-N in mg/L), total organic carbon (TOC in mg/L), and total suspended solids (TSS in mg/L). The values presented in Table 3 include representative monthly average values for river flow (in cfs).

Table 1. Assumed trends by month in selected water quality parameters in the Klamath River in the Keno area upstream of J.C. Boyle Reservoir.

Month	Average Water Temperature (˚C)	Total P (mg/L)	PO_4-P (mg/L)	Total N (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)	TOC (mg/L)	TSS (mg/L)
Jan	2.1	0.150	0.015	2.000	0.500	0.600	8.0	7.0
Feb	2.4	0.150	0.015	2.000	0.500	0.500	8.0	7.0
Mar	6.8	0.150	0.025	1.400	0.400	0.300	8.0	10.0
Apr	10.2	0.150	0.050	0.900	0.300	0.200	7.0	12.0
May	18.1	0.200	0.100	1.000	0.200	0.200	7.0	10.0
Jun	19.6	0.250	0.200	1.600	0.200	0.300	8.0	8.0
Jul	21.9	0.300	0.200	2.100	0.200	0.400	9.0	6.0
Aug	22.1	0.300	0.150	2.600	0.400	0.500	10.0	6.0
Sep	18.0	0.175	0.125	2.600	0.400	0.500	10.0	6.0
Oct	11.8	0.150	0.075	2.400	0.400	0.600	9.0	8.0
Nov	5.0	0.150	0.050	2.400	0.400	0.600	8.0	8.0
Dec	1.1	0.150	0.025	2.200	0.500	0.400	8.0	9.0

Table 2. Assumed trends by month in selected water quality parameters in the Klamath River above Copco reservoir.

Month	Average Water Temperature (˚C)	Total P	PO_4-P (mg/L)	Total N	NO_3-N (mg/L)	NH_4-N (mg/L)	TOC	TSS
Jan	2.8	0.150	0.015	1.800	0.500	0.500	8.0	7.0
Feb	3.5	0.150	0.015	1.800	0.500	0.400	8.0	7.0
Mar	7.9	0.150	0.025	1.300	0.400	0.300	8.0	10.0
Apr	9.9	0.150	0.050	0.800	0.300	0.100	7.0	12.0
May	17.2	0.175	0.100	0.800	0.300	0.050	7.0	10.0
Jun	18.6	0.250	0.200	1.200	0.400	0.050	8.0	8.0
Jul	20.9	0.250	0.200	1.500	0.600	0.050	9.0	6.0
Aug	21.2	0.200	0.150	1.800	0.800	0.050	9.0	6.0
Sep	17.2	0.175	0.125	1.800	1.000	0.050	9.0	6.0
Oct	11.8	0.150	0.075	1.800	0.900	0.050	8.0	8.0
Nov	5.4	0.150	0.050	2.000	0.700	0.100	8.0	8.0
Dec	2.1	0.150	0.025	2.000	0.600	0.300	8.0	9.0

Table 3. Assumed flow in the Klamath River Flow upstream of J.C. Boyle reservoir and Copco reservoir.

Month	Flow in Keno Area (cfs)	Flow Above Copco (cfs)
January	1,510	1,790
February	1,520	1,820
March	1,720	2,040
April	1,920	2,240
May	1,720	2,020
June	1,170	1,440
July	650	920
August	600	860
September	700	940
October	830	1,080
November	830	1,070
December	920	1,170

Soil Characteristics

Site Soil Conditions

Soil conditions are important to the construction and operation of treatment wetlands. Parameters of particular interest include permeability, flooding hazards, depth to water, presence of larger rock fragments, and soil piping potential[5]. The Natural Resource Conservation Service (NRCS) web-based soils data were used to define site conditions for candidate sites identified during the reconnaissance of the Project vicinity.

Major soil map units and their major characteristics for each of the main candidate sites for treatment wetlands facilities are summarized in Appendix B. There is no single, integrated soil suitability criterion for treatment wetlands. Site-specific soils investigations would be required before further wetland design development and construction.

The NRCS provides soil suitability rankings for closely related engineering features such as embankments, dikes, berms, and levees. These recommendations tend to be very conservative, and even soils considered by NRCS to have "very limited" potential for these uses may still be suitable for that use with appropriate design. Many soils limitations can be overcome, but at increased costs.

Soils at potential wetlands sites (identified during the April 2008 reconnaissance) range from nearly level, deep, fine-textured soils to very steep soils consisting mainly of lava rock fragments to very sandy, gravelly, or stony materials. It is generally more feasible to construct treatment wetlands on gently sloping topography, and therefore steeper areas should be avoided. Construction of wetlands on soils that are very shallow over bedrock may not be feasible due to the inability to make needed cuts. Construction of wetlands on coarse textured materials may be feasible if sufficient hydraulic loading is applied until infiltration rates decline as sediments and organic materials accumulate. Where berm construction issues are limiting with site soils, other engineering approaches such as liners and imported materials can be considered.

The majority of the sites identified along the river upstream of Copco reservoir appear to have soil conditions that will allow construction of treatment wetlands, but costs may vary considerably by site, and site-specific soils investigations would be required before further wetland design development and construction.

Soil Infiltration Rates

The available data on long-term infiltration rates for treatment wetlands suggests that a value of 0.48 inch per day (0.04 foot/day) is a reasonable preliminary estimate to assume for determining the site water balance. This is approximately the same average value that has been observed for a detailed U.S. Geological Survey (USGS) study of a large treatment wetland in a floodplain area of Missouri (Richards 2002) and for a range of treatment wetland sites in southern California (CH2M HILL, unpublished).

It should be noted that a wide range of values were observed in the California data, from essentially zero to 8 inches/day. It should also be noted that team member Dr. Alex Horne

[5] Soil piping is a particular form of soil erosion that occurs below the soil surface. Turbulent flow removes soil starting from the mouth of the seep flow and subsoil erosion advances upgradient. It is associated with levee and berm failure, as well as sink hole formation, and could be important to the extent that constructed wetlands include berms.

has observed significant reductions in infiltration on wetland sites due to deposition of detritus in only a few months. A similar, but slightly lower value of 0.42 inch/day was reported for the Jackson Bottom Experimental Wetlands (JBEW) in Hillsboro, Oregon, after making adjustments for lateral seepage (SRI/Shapiro 1995).

The Potential Need for Soil Amendments at Treatment Wetland Sites

Several recent publications describe the amending of wetland soils to improve water quality. Since most of the land under consideration as potential wetland treatment sites has been used for agriculture, there is the possibility of release of nutrients once it is converted to a wetland. The addition of alum to similar soils in Ireland (i.e., agricultural land converted to treatment wetlands) was successful in binding the labile phosphorus and preventing it from entering the water column. Other papers describe the successful application of finely ground calcium carbonate (calcite) or calcium-magnesium carbonate (dolomite) that facilitated the formation and precipitation of calcium and magnesium phosphate.

Since the soils in this region are of volcanic origin, there is relatively little native calcium in the soil. Mineral addition to the wetland soils along the river and in the agricultural zone just south of UKL could contribute to the removal and sequestering of phosphorus (Babatunde et al. 2008, Kaasik et al. 2008, Prochaska and Zouboulis 2006, Song et al. 2006, Kwon et al. 2004, Ann et al. 1999).

Potential Effectiveness of Treatment Wetlands

Preventative Treatment Wetlands Effectiveness

The team made an initial estimate of potential effectiveness of potential treatment wetlands at sites identified during the April 2008 reconnaissance. As an initial estimate of potential effectiveness of these treatment wetland sites, the available sizes of the sites (in acres) were calculated, and from these sizes the corresponding flows were calculated that could be accommodated assuming a minimum 2-day HRT at a water depth of 2 feet. Based on the experience of the team, a 2-day HRT and a water depth of no more than 2 feet is the minimum needed to provide some level of treatment. In fact, as discussed further below, longer HRTs may be required for more complete treatment of nutrients, which is a primary focus of water quality concerns in the basin. Table 4 provides a summary of the calculated available area at each site, and the estimated flow capacity that could be accommodated assuming a minimal 2-day HRT at a water depth of 2 feet.

Table 4. Potential constructed treatment wetland sites on PacifiCorp-owned lands, potential available acreage, and initial estimate of flow capacity.

		Initial Estimate of Flow Capacity	
Site	**Acres**	**cfs**	**mgd**
004c	11	5.7	3.7
004b	8	4.1	2.7
008	28	14.3	9.2
009	17	8.6	5.6
010	20	10.2	6.6
011	63	31.8	20.5
012	45	22.9	14.8
013 (a)	27	13.7	8.9
013 (b)	52	26.4	17.0
015	26	13.0	8.4
Total Acres Owned by PacifiCorp	297		
Total Wetland [a]	254	150.7	97.4

[a] Assumes 15 percent reduction for berms, roads, and setbacks. Surface flow treatment wetland systems require berms, roads, and setbacks in some areas that reduce the total area available for treatment. A typical rule of thumb is about 15 percent of the total available acreage is consumed by these features.

On the basis of flow capacity alone, a major constraint associated with constructed treatment wetlands on PacifiCorp-owned lands in the Project area was indicated. That is, constructed treatment wetlands individually could receive and treat only a minor fraction of the total flow of the Klamath River. As such, to achieve a goal of river nutrient load reduction, it would be necessary to develop many wetland sites in series that would collectively or in the aggregate treat a substantial portion of the river flow. The team adopted the phrase “a string of pearls” to capture this aggregate concept.

However, even if wetlands were constructed on all the PacifiCorp-owned sites listed in Table 4, the total portion of river flow potentially treated would be on the order of about 150 cfs, which equates to about 6 to 17 percent of the overall river flow (depending on monthly flow level as listed in Table 3). In light of this potential constraint, the team examined lands in the Keno reservoir area upstream of the Project area to identify other example sites that might offer significantly larger sites for potential constructed treatment wetlands. As previously described, the team identified Sites 020 and 022 as examples of the types of sites that could be used for larger-scale surface flow treatment wetlands.

Sites 020 and 022 are located on two large plots of low-lying agricultural land off of Keno reservoir as shown in Figure 2. The sizes and estimated flow capacities of these sites are listed in Table 5, and detailed figures and photographs of these sites are provided in Appendix A. The values in Table 5 suggest that larger sites (as represented in Sites 020 and 022) would substantially increase the total portion of river flow that could be treated. For illustrative purposes, the addition of the two example sites to the PacifiCorp-owned sites listed in Table 4 could provide a combined theoretical flow capacity of about 800 cfs. This flow level equates to about 42 to 100 percent of the overall river flow (depending on monthly flow level as listed in Table 3).

Table 5. Example constructed treatment wetland sites near Keno reservoir, estimated available acreage, and preliminary flow capacity.

Site	Acres	Preliminary Flow Capacity	
		cfs	mgd
020	660	332.8	215.1
022	624	314.8	203.5
Total Wetland Area of These Sites	1,284	647.6	418.6
Total Wetland Area of PacifiCorp Sites[a]	254	150.7	97.4
Total Wetland Area From All Sites	1,538	798.3	516.0

[a] From Table 4.

As an additional estimate of potential effectiveness of the treatment wetland sites, the team also performed a simple first-order treatment wetland analysis model developed by CH2M HILL. The wetland analysis model provides estimates of the reduction in nutrient load based on assumed wetland sizes and flow, water quality, and soil conditions as previously described in the "Site Conditions" section of this report. The analysis model was run for an assumed period covering April through October to bracket the "growing season" when natural wetland processes would be most functional and effective. The analysis assumed only the occurrence of natural wetland treatment processes; that is, the analysis did not assume any chemical additions or other potential enhancements.

For the combined 254 acres of constructed treatment wetland sites on PacifiCorp-owned land (as listed in Table 4), the analysis model results indicate that, over the April through October period, about 33 percent of the water would be infiltrated, and the percent reduction in mass (or load) would be 99 percent for NH_4-N, 72 percent for TSS, 29 percent for TP, and 28 percent for NO_3-N (Table 6). By comparison, the average percent reduction by concentration would be 98 percent for NH_4-N and 59 percent for TSS. However, the model indicates that the average percent reduction by concentration would effectively be zero percent for NO_3-N and TP.

Table 6. Summary of results of analysis modeling for combined 254 acres of constructed treatment wetland sites on PacifiCorp-owned land. Analysis assumes 2 Day HRT in the model.

Time Period	Category	TSS	NH_4-N	NO_3-N	TP
April-Oct	Average % reduction by mass (load)	72%	99%	28%	29%
April-Oct	Average % reduction by concentration	59%	72%	0%	0%

These model results were further used to evaluate the net effect of the 254 acres of treatment wetlands on river water quality. A 2-day HRT in the treatment wetlands and associated infiltration resulted in slight reductions in river concentrations for TSS and NH_4-N, but no improvement in river concentrations for NO_3-N and TP. A 7-day HRT, with associated smaller flow diverted to the wetlands, decreased the river concentration of TSS less compared to that achieved with a 2-day HRT in the wetlands while only slightly reducing the NO_3-N and TP concentration in the river. This information is presented in Appendix C, Table D-1.

The first-order model results indicate that even with reasonable and expected reduction in nutrients and TSS within the wetlands, measureable changes in downstream river or reservoir water quality are unlikely given the small proportion of river flows that could be treated by constructed wetlands at these sites. The potential addition of design enhancements and adjunct technologies, such as alum addition or wetland banding, could increase treatment performance, but the additional effect on downriver concentration might still be modest given the small proportion of river flows that could be treated by constructed wetlands at these sites. Further evaluation of the applicability and effectiveness of design enhancements and adjunct technologies at these sites should be conducted if the analysis and design of constructed treatment wetlands in the Project area are pursued further.

For example, there are variations of banded surface flow treatment wetland whose basic design has been used in the past for solids removal. The variations include wetlands with and without mulch gabions as shown in Figure 7. The mulch gabions provide a source of additional carbon to enhance water treatment effectiveness. The variations also include amending the inflow to the wetlands with an alum or aluminum polymer drip system to facilitate phosphorus precipitation and removal. The variations also include use of soil amendments (e.g., calcite or dolomite) to increase phosphorus removal as shown in Figure 8. Figure 8 shows the installation of the plastic mesh material to increase the total surface area and to provide a filtration step within the wetland to remove algae particles.

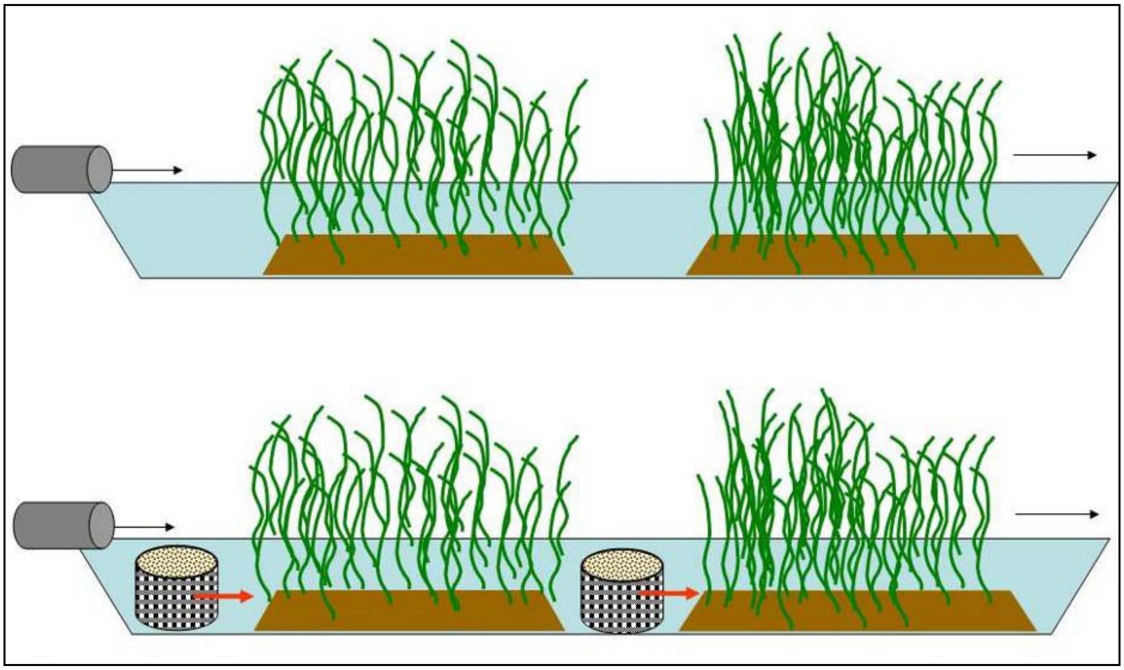
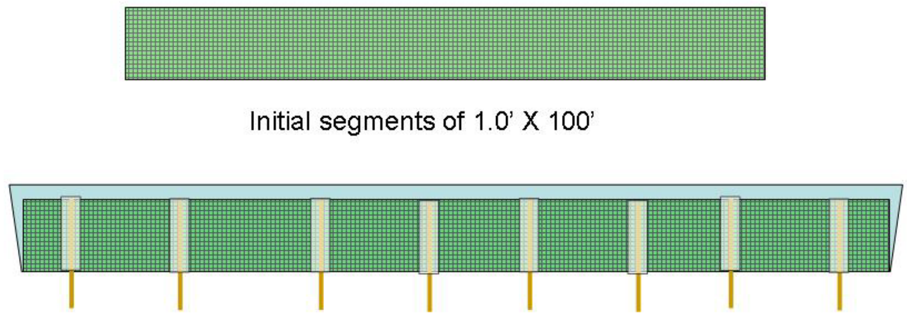
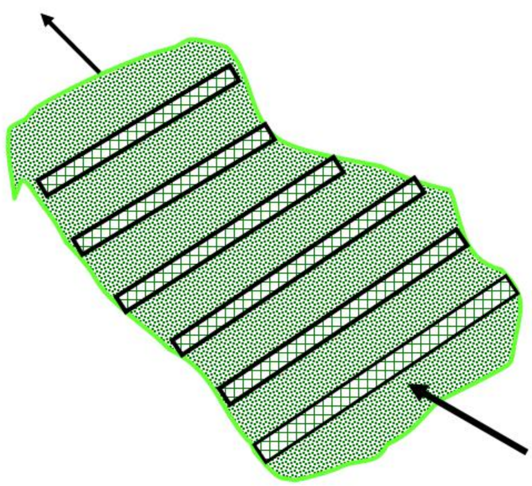


Figure 7. Conceptual depiction of the banded surface flow with and without the submerged mulch gabions.



- The wetland would be designed to have an operating depth of 1' max.
- To construct the filters start out with Vmax[3] cut to 1.5' height x 100' length
- Pound 3' rebar rods into the ground every 30' and place a 1.5' segment of 1.25" PVC over the rebar
- Attach the Vmax3 sheets to the PVC tubes with plastic zip-ties or coated wire



- The total surface area of the wetland is increased by the addition of the mesh walls
- The biofilms formed on the vertical mesh help to remove algae
- Since the soil in this area is of volcanic origin, it could be improved by the addition of ground up limestone to provide calcium ions and alum to facilitate the removal of phosphate from the water

Figure 8. Conceptual depiction of the periphyton-based wetland.

Reservoir Treatment Wetlands Effectiveness

Vegetated Swale System

During the April 2008 reconnaissance, the team identified Sites 005 and 006 as examples of sites for reservoir treatment wetlands using the vegetated swale (bioswale) approach as previously described. Sites 005 and 006 are adjacent to Copco reservoir at Copco Cove and Beaver Cove, respectively. In recent years, large accumulations of algae biomatter have occurred during summer along the shoreline in the coves near these sites. The locations of these sites are shown in Figure 1. Detailed figures and photographs of these sites are provided in Appendix A.

To our knowledge, the idea of a vegetated swale (bioswale) filter built on a hillside to remove algae has not been described in the current scientific or engineering literature. However, there is a substantial body of evidence of vegetated swale systems that are highly effective in the removal of solids in both stormwater and wastewater treatment applications (e.g., Gersberg et al. 1986, EPA 1999, EPA 2000a, EPA 2000b, Jurries 2003). Vegetated swale systems with a gravel-dominated base are preferred due their ability to treat a broad range of total suspended solids (TSS). A sand or soil-based swale system more easily clogs with settled particulates.

Based on values from stormwater and wastewater research, the team estimates that the proposed vegetated swale system (with a gravel-dominated base) could potentially remove 80 percent of the algae biomatter introduced to the system. This is based partially on physical filtration and by attachment to the microbial film that forms on the gravel and grass roots. The aerobic conditions within the swale will accelerate the decay of the algae. Since this approach to dealing with algae biomatter is new, it would be prudent to develop a demonstration-scale filter to determine the best operating conditions with regards to flow, residence time, and other swale features to optimize solids removal.

The goal of the reactive treatment systems is to remove the algae in the coves with the least number of intermediate steps. The use of slurry or dewatering devices is an option, but it introduces a further level of complexity and additional energy demands. The range of TSS in the surface water should be 20-200 mg/L throughout the summer. No special types of pumps are required with this low level of solids. The main requirement will be that the water is consistently pumped to the top of the swale that could be as much as 30-50 feet above the level of the reservoir. The algae could be collected at one or more collection points in the coves. Moveable radial intake pipes could be used to evenly remove the slurry of accumulated algae at the collection points. These intake pipes could be designed to exclude small fish and other aquatic animals so that only the algae would enter the system.

Floating Treatment Wetlands

As previously described, specific sites or layouts for floating treatment wetlands were not identified by the team during the April 2008 reconnaissance. However, during the reconnaissance, the team discussed floating treatment wetlands as a potential wetland treatment technology for use in Copco and Iron Gate reservoirs.

Headley and Tanner (2006) report that pilot-scale floating wetlands studied in Hungary (termed Artificial Floating Meadows) removed 85 percent of the total nitrogen content and

40 percent of total phosphorus. This pilot experiment was conducted using water from the Danube River with a retention time in the artificial floating meadow of two weeks. Stewart et al. (2008) report that pilot-scale floating islands studied in testing tanks indicated a combined ammonium and nitrate removal of about 60 percent after two weeks.

In monitoring associated with deployment of experimental cattail and bulrush platforms in Lake Mead (Nevada), Boutwell (2002) at times found a zone of lower nutrient concentration immediately under the platforms. This lowering of nutrients was seen as a gradient with the highest concentration occurring upstream of the platforms and decreasing as the water flowed under the platforms toward the downstream end of the platforms. The reductions observed in this zone were on the order of 10 to 50 percent. The zone of reduced nutrient concentrations was detected to a depth of about 5 feet (1.5 m) below the platforms.

In a review of floating wetlands (termed artificial floating islands or AFIs) in Asia, Nakamura and Mueller (2008) report that "to provide significant improvement in water clarity and reduce algal blooms, it is generally necessary for AFIs to cover 10 to 30% of the water surface" of reservoirs or lakes. A regression curve presented in Nakamura and Mueller (2008) showing the relationship of surface area to the percentage decline in chlorophyll-a indicates that 10 to 30 percent cover equates to about a 50 to 80 percent decrease in chlorophyll-a.

Headley and Tanner (2006) indicate that there is currently little or no design basis available for sizing a floating treatment wetland system. Consequently, the size of a floating treatment wetland required to achieve particular treatment goals can not be determined with any certainty. Headley and Tanner (2006) conclude that substantial additional research is needed in order to identify the key treatment processes and expected treatment performance of floating treatment wetlands for water quality improvement. This would then enable the surface area of floating treatment wetlands required to achieve a given effluent concentration to be estimated for design purposes.

Approximate Costs of Constructed Wetlands

The team derived a rough order-of-magnitude estimate of costs for wetland construction based on our experience and research literature information. The estimated total cost (assuming no land purchase or lease costs) of construction was developed for the constructed treatment wetlands, based on comparably-sized treatment wetlands in the western United States.

Preventative Treatment Wetlands

The cost of establishing a constructed wetland varies greatly depending on size and site conditions. The size of the system will depend on the water quality goals and local climatic conditions. In general, larger constructed wetlands involve higher construction, installation, and maintenance costs. The cost of the constructed wetland is proportional to the number and sizes of treatment cells required. Site-specific factors, such as slopes, hydrologic and hydraulic conditions, soil quality, or plant species required, can also influence the cost of wetland restoration.

In our experience, the costs of wetland construction, including earthwork, planting, and control structures, generally range from $50,000 to $150,000 per acre, depending on site access and amount of earthwork required. EPA (2000a) cites construction costs of surface flow wetlands ranging from $14,000 to $96,000 per acre (in 1997 dollars). Kadlec (1995) cites construction costs from 18 North American surface flow wetlands ranging up to $120,000 per acre, with a mean of about $40,500 per acre (in 1994 dollars). Reed et al. (1995) cited a range of about $40,000 to $100,000 per acre for construction costs of surface flow wetlands (in 1994 dollars). Kadlec and Wallace (2008) gave a median value of $98,000 per hectare ($39,700 per acre) based on the capital costs of 84 wetlands. Kadlec and Wallace (2008) also present a general capital cost formula for surface flow treatment wetlands: $C = 194\ A^{0.690}$, where C is cost in thousands of dollars and A is area in acres. This formula was developed from a regression (with an R2 value of 0.79) based on empirical data of costs over a wide range of wetland sizes (e.g., about 1 to 1,000 acres).

Additional costs would include any site investigation and engineering design, pre-treatment components (if used), and land costs. An appropriate rule-of-thumb for engineering design services is 15 percent of capital costs. The annual cost of routine maintenance has been estimated ranging from about 1 to 5 percent of the construction cost. EPA (2000a) cites operation and maintenance (O&M) costs for constructed wetlands ranging from about $800 to $1,600 per acre (in 1997 dollars). Kadlec (1995) cites O&M costs for constructed wetlands of generally less than $1,000 per acre per year (in 1994 dollars). Kadlec and Wallace (2008) gave a median O&M value of $2,000 per hectare ($800 per acre) for surface flow treatment wetlands.

For context, if the full approximately 300 acres identified in this study owned by PacifiCorp were developed as preventative treatment wetlands, costs could range from $15 to $45 million for construction, and about $150,000 to $2 million per year for O&M.

Vegetated Swale System

As with constructed treatment wetlands, the cost of installing and maintaining vegetated swales varies widely with design and site variability. For example, Weiss et al. (2005) report that costs of vegetated swales may range from about $9 to $50 per linear foot (depending on swale depth and bottom width), whereas ODOT (2005) reports that a typical 200-ft length of swale with a bottom width of 8 ft and a depth of 3 ft costs about $65,000, or $325 per linear foot. These ODOT (2005) dimensional assumptions result in an area equal to 0.24 acres, which scales up to approximately $268,000 per acre. The same dimensional assumptions scale up to approximately $7,500 to $42,000 per acre using the linear-foot cost reported by Weiss et al. (2005).

The estimated cost for vegetated swale construction could range from $50,000 to $ 75,000 per acre with the cost of construction materials, site access, and potential earth-moving being the major determinants. As with constructed treatment wetlands, additional costs would include land costs and any site investigation and engineering design (i.e., at about 15 percent of capital costs).

EPA (1999) indicates that annual O&M costs for swales range from between five and seven percent of the construction cost. ODOT (2005) suggests that annual maintenance of a 0.24-acre vegetated swale (such as described above) costs approximately $320 to $500 per year.

ODOT (2005) also indicates that their swales require additional rehabilitation about every 10 years. ODOT (2005) concludes that nine years of annual maintenance combined with rehabilitation costs every ten years result in total O&M costs of about $100,000 per acre per decade.

PacifiCorp owns some of the land adjacent to Copco Cove, but not at Beaver Cove. The combined area identified by the team as possible reservoir treatment wetland sites using the vegetated swale systems (Sites 005 and 006) is about 50 acres. Without assuming the cost of land purchase, the total costs for vegetated swale systems at these sites would be on the order of $2.5 to $3.8 million for construction, and about $125,000 to $275,000 per year for O&M.

Floating Treatment Wetlands

Our team has limited direct experience with floating treatment wetlands. We found no details on cost reported in the literature. Some cost information is available from manufacturers. Pricing appears quite variable according to the project needs, thickness of the island, materials used, and additional services offered by the installer. At the lower end, Aqua BioFilter™ reports that floating wetland installations have ranged from $30 to $120 per m2 (about $3 to $11 per ft2). At the higher end, Canadian Pond Products offers a 15-sq ft island that costs about $700 (about $46 per ft2).

For context, assuming that 10 percent of the surface of a 20-acre cove in Copco reservoir would be installed with floating islands, approximately 2 acres (or 87,120 sq ft) of floating islands would be needed. This coverage equates to an installed cost of about $260,000 to $4 million. O&M costs are not reported but would be about $13,000 to $200,000 per year at an assumed five percent of the installation cost.

Important Design and Performance Considerations

During the course of this assessment, the team identified several design and performance elements that are important to consider if future constructed treatment wetlands are pursued in the Project vicinity.

Provide Ample HRT and Avoid Short-Circuiting of Flow

Wetlands can be effective at removing many pollutants but natural wetlands are generally inefficient for the loads imparted by anthropogenic pollution. The primary reason for the inefficiencies of natural wetlands is hydraulic. In a natural wetland the water flows through a channel of least hydraulic resistance so that most of the water passes quickly through the system with little time for pollutant removal. In contrast, water in the outer fringes of the wetland may linger for weeks and is over-treated. Constructed wetlands are made more efficient than natural wetland by the modification of the hydraulics so that flow through the wetland is uniform (or plug flow for pulsed contaminants) rather than in a channel that short circuits the water as is normal in natural wetlands.

It takes time for removal of either particulate matter by physical modes such as sinking, flocculation with natural flocculants, or sticking to the biofilm on wetlands plants. The removal of particles, including blue-green algal, is a primarily physical process. Normally about 2 days HRT are needed for removal of approximately 80 to 90 percent of the typical suspended particles found in lakes and rivers. The removal of soluble nutrients such as nitrate will require additional HRT (~3-7 days) and will be a bacterially mediated process, and is slower in winter than the late spring-autumn period. Ammonia removal could require substantially more HRT than that needed to process nitrate since it must be nitrified to nitrate under oxidized conditions. Also, the cyanobacteria found in the outflow of UKL and in the Klamath River are buoyant, so when they arrive at the constructed wetland sedimentation will naturally take longer. The design of the wetland will need to take this buoyancy into account.

Design Goal and Emphasis: Nutrient Reduction

The ability of constructed treatment wetlands to reduce nutrients from Klamath River water will be a primary factor is pursuing the implementation of this technology. The evaluation of different wetland designs, including the potential for pre-treatment techniques (e.g., alum addition), will be an important task for establishing nutrient removal potential and requirements for wetland design and operation.

As stated above, it takes ample HRT for soluble nutrients such as nitrate or ammonia to be metabolized and removed from the water. Removal of soluble phosphate and small colloidal TP could be inefficient in the wetland, but can be increased by alum addition at the inflow (although the high TOC in UKL water may negate this option).

The evaluation of wetland designs should select an important nutrient form such as nitrate for which detailed removal coefficients are known. For example, for a cattail wetland in a California-Oregon climate, the removal of nitrate can be approximated as a zero order process with a rate of 500 mg NO_3-N/m^2/d for most of the warmer months of the year (temperature > 15.5^{o}C). Given that a constructed treatment wetland will have a water depth of 2 feet for optimum performance, the concentration of the nitrate-N in the Klamath River will be 0.5-1.5 mg/L for most of the time, and the volume of water and land area that will match the mass denitrification rate can be estimated.

Healthy Microbial Biofilm is Essential

It is important to recognize that the microbial community, especially the bacteria, is the dynamo of the constructed wetlands. Physical and chemical removal processes are much faster, often thousands of times faster, when biologically mediated via bacteria. In a wetland the active microbial community is the biofilm which forms on submerged plants stems and dead leaf litter. It contains primarily bacteria, attached algae, protozoans, rotifers, nematodes, and small insect larvae such as chironomid midges. The composition and health of the biofilm is thus an important concern of the designer of treatment wetlands.

Dense Stands of Plants Are Needed

For maximum pollutant treatment, dense stands of emergent or submerged plants are needed. This is because the sustainable power that runs a wetland is the sun acting via photosynthesis in higher plants. However, growing plants are not the driving factor; most pollution treatment occurs only when the plants die and sink to the bottom and provide surfaces for bacteria growth and decay to provide bacteria with organic carbon energy. Plant stems do support a biofilm that will assist with particle removal but could be replaced by plastic sticks if it were not for the carbon the dead plants provide. Open water will decrease performance and should be limited to that needed for hydraulic mixing and/or wildlife habitat.

Thus the optimum design is a long thin (at least 3:1 ratio and 10:1 is better) wetland with a ratio of dense plants to open water of 10:1 or 20:1 is ideal. However, wetlands are flexible in shape and so long as the water is guided through the plants stems and not allowed to take the path of least resistance around them.

For general pollutant removal for the Klamath River, a mixture of mostly cattails with a small amount of bulrush would be best. Cattail wetland releases more labile carbon than a bulrush wetland, so would be best for nitrate removal by denitrification. A bulrush wetland with its ample non-labile carbon (= high lignin content) will best absorb organic pesticides and ionic metals. Cattails and bulrush, once established do well in temperate climates and can be regulated by mechanical means if needed. Use of other plants is possible but maintaining stands of water grasses or duckweed has proven impossible in large wetlands. Submerged plants can also be used but again, maintenance over several years with winter die-back and the possibility of new species taking over is a problem in the temperate zone.

Other Important Considerations

- Where possible the wetland should be graded to be level and sloped down to allow flows against the resistance of the plants. The costs of grading are offset by the much better performance (lower hydraulic short-circuiting) and lack of perched fish-free water (prevents mosquitoes).
- Lining of the wetlands will not be needed. Any water that seeps through the bottom of the wetland will soon return to the river and most pollutants will be treated as the water seeps slowly down. Even in sandy soils (as at Prado wetland, Orange County Water District, California) percolation is slow (<10%) once the wetland is established. The alga and bacterial muco-polysaccarides soon clog the bottom of wetlands making them effectively self-sealing.
- A freeboard of 2 feet (making 4 feet in all) would be appropriate and would allow the holding of especially algae-rich water for treatment.
- Access berms are useful but take up good treatment land so should be kept to the minimum. Normally berms are needed to keep disease vectors down. It is not expected that there will be mosquito problems in the Klamath wetlands since ammonia is expected to be less than 2 mg/L and dissolved oxygen conditions of the wetlands surface waters favorable for fish are anticipated.
- A deep (6 feet) open pond at the upstream end would allow removal of sediment (including particulate TP) easily by mechanized equipment.
- Small cross trenches (4-6 feet deep to prevent cattail invasion) should be placed at intervals to allow mixing but should be kept to a minimum.

Conclusions

The objective of this preliminary feasibility assessment was to determine the potential for treatment wetlands to provide improved water quality in the vicinity of PacifiCorp's Klamath Hydroelectric Project (Project). Water quality improvement is a particular focus for PacifiCorp's management of Project reservoirs, which receive large inflowing loads of nutrients and organic matter from upstream sources (notably Upper Klamath Lake), which drive summertime blooms of cyanobacteria in the reservoirs. The intent was to evaluate the basic efficacy of using constructed wetlands based on site requirements and conditions, so as to assist subsequent decisions to potentially proceed to more detailed study or design.

On the basis of this assessment, two basic approaches to wetland treatment are identified: (1) a preventative treatment wetland approach to remove a portion of the nutrients and algae (i.e., the "cause" component) from the river before entering the reservoirs; and (2) a reservoir treatment wetland approach to reduce or remove dense accumulations of algae biomass within the reservoirs, such as in reservoir coves (i.e., the "effect" component).

Nineteen potential wetland sites were examined during the April 2008 site reconnaissance in the vicinity of the Project from Iron Gate reservoir to the middle of Keno reservoir. The sites include locations for potential constructed surface flow treatment wetlands along the Klamath River, and vegetated swales adjacent to the reservoirs to treat algae biomatter. Floating wetlands in the reservoirs were discussed during the reconnaissance but no specific sites are identified.

The sites are characterized by topographic, hydrologic, and soils conditions that would be amenable to wetland construction. The sites identified for potential constructed wetlands are generally low-lying and directly adjacent to the river. Several sites are on PacifiCorp property and have the advantage of existing gravity-fed pasture irrigation canals that could be used as the inflow infrastructure for constructed wetlands. The sites generally have soil conditions that are conducive to constructed treatment wetlands, but more thorough site-specific soils investigations would be needed for further wetland design and construction planning. Although these sites offer ready access to flows, a determination of regulatory requirements for diversion and routing of water through potential wetlands would be a critical precursor of further wetland design and planning.

A major constraint identified in this assessment is that the available potential sites for constructed wetlands on PacifiCorp-owned lands in the Project area could receive and treat only a minor fraction of the total flow of the Klamath River, and would be unlikely to provide measureable improvements to downstream river or reservoir water quality. Instead, to achieve a demonstrable river nutrient and organic matter load reduction, it would be necessary to develop more and larger wetland sites that would collectively or in the aggregate treat a substantial portion of the river flow. This would by necessity involve constructed treatment wetlands on lands elsewhere above the Project area that are adjacent to the river system. The need to "scale-up" the overall size of constructed wetlands to achieve demonstrable and meaningful water quality benefits points to the need for a basin-wide effort that would require multiple stakeholder participation.

The costs of constructed treatment wetlands vary greatly depending on size and site conditions. If the 300 acres of PacifiCorp-owned sites were developed with treatment wetlands, costs could range from $15 to $45 million for construction, and about $150,000 to $2 million per year for O&M. Additional costs would include any site investigation and engineering design, pre-treatment components (if used), and land costs.

Site conditions adjacent to reservoir cove areas are amenable to potential construction of vegetated swales (bioswales) for removal and filtering of accumulated algae biomatter. Such swales have well-demonstrated effectiveness for reduction or removal of particulates in water, and offer a possible natural treatment option for reducing algae biomatter. However, a key constraint to the use of this system is how the algae would be efficiently collected from the reservoir and pumped to the swales. In addition, the use of vegetated swales for treatment of algae would need additional pilot-scale or demonstration testing to determine operating conditions and removal efficiencies. Until such determinations are made, the ultimate effectiveness of implementing vegetated swales for reducing algae biomatter remains uncertain.

As with constructed treatment wetlands, the cost of installing and maintaining vegetated swales varies widely with design and site variability. Without assuming the cost of land purchase, the total costs for vegetated swale systems at the two sites identified in this assessment (about 50 acres) would be on the order of $2.5 to $3.8 million for construction, and about $125,000 to $275,000 per year for O&M.

Floating treatment wetlands are an emerging wetland treatment technology that could be used in Copco and Iron Gate reservoirs. Pilot-scale studies have demonstrated the effectiveness of floating treatment wetlands in research elsewhere. However, larger field-scale demonstrations are lacking, and there is currently little or no design basis available for sizing a floating treatment wetland system. Consequently, the effectiveness of implementing a floating treatment wetland system remains uncertain. This uncertainty in effectiveness, also comes with substantial costs (a single-cove reservoir deployment can cost anywhere from about $260,000 to $4 million, with O&M costs of $13,000 to $200,000 per year). At this time, it is not known how many cove deployments would be necessary to make demonstrable and meaningful improvements in water quality.

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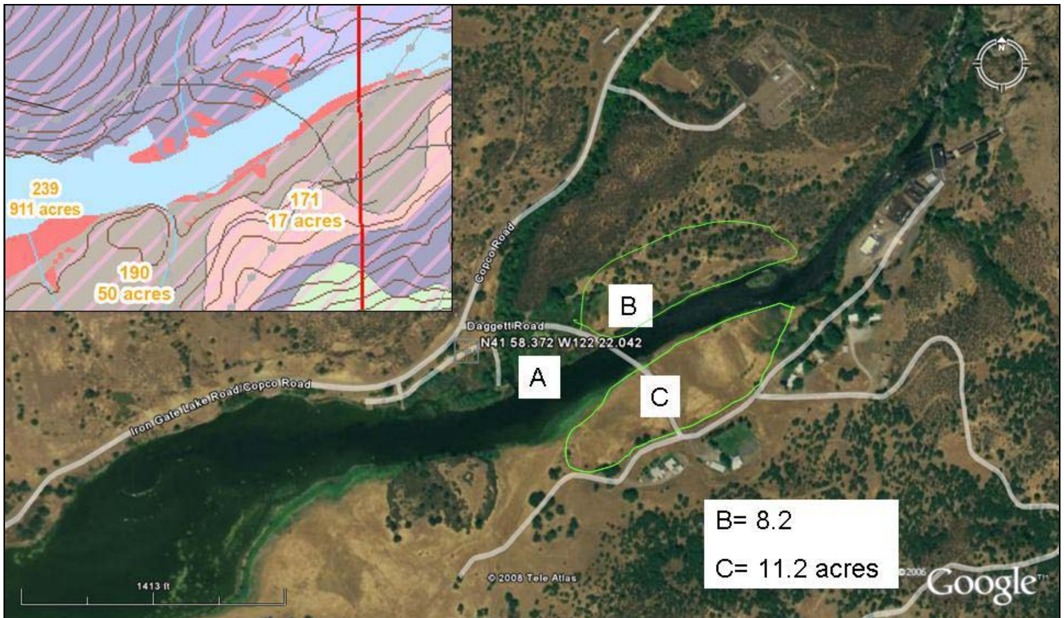
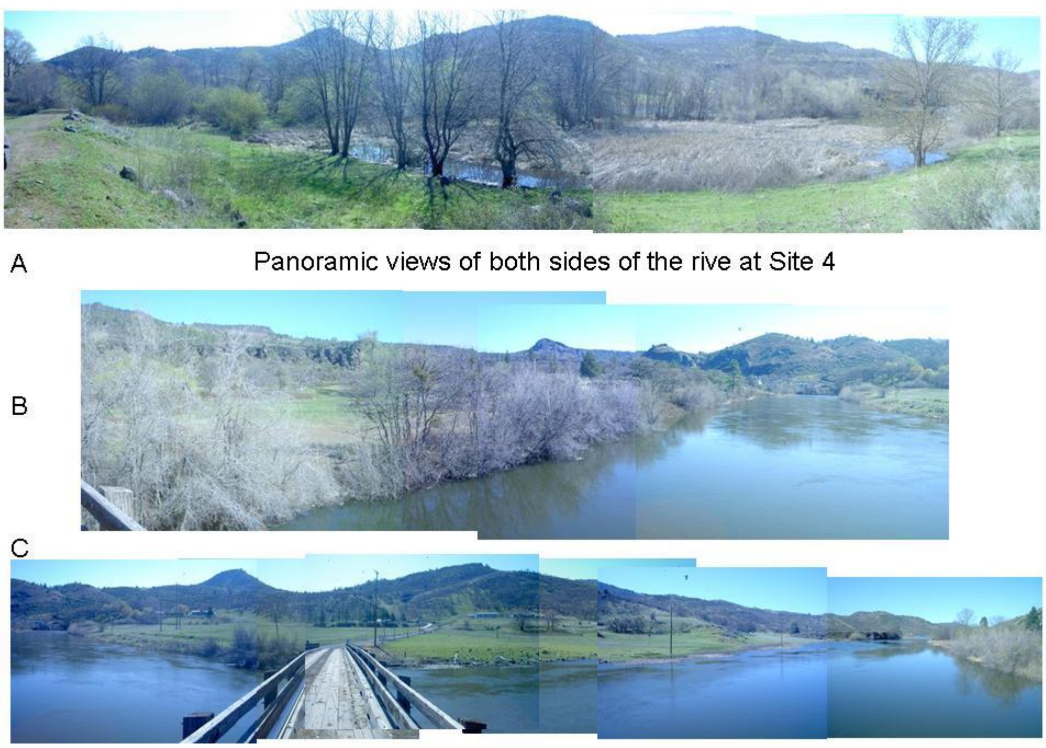
APPENDIX A

Descriptions of Potential Treatment Sites Investigated



Site 4: First stop on the tour. Potential wetland sites on the north and south banks

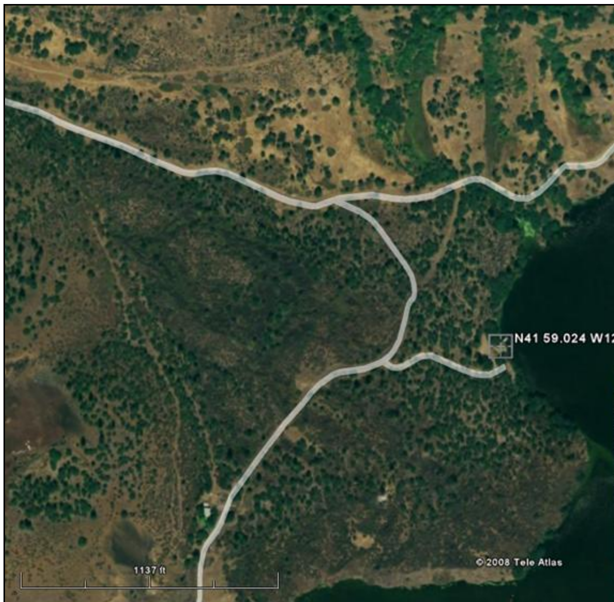


A

Panoramic views of both sides of the rive at Site 4

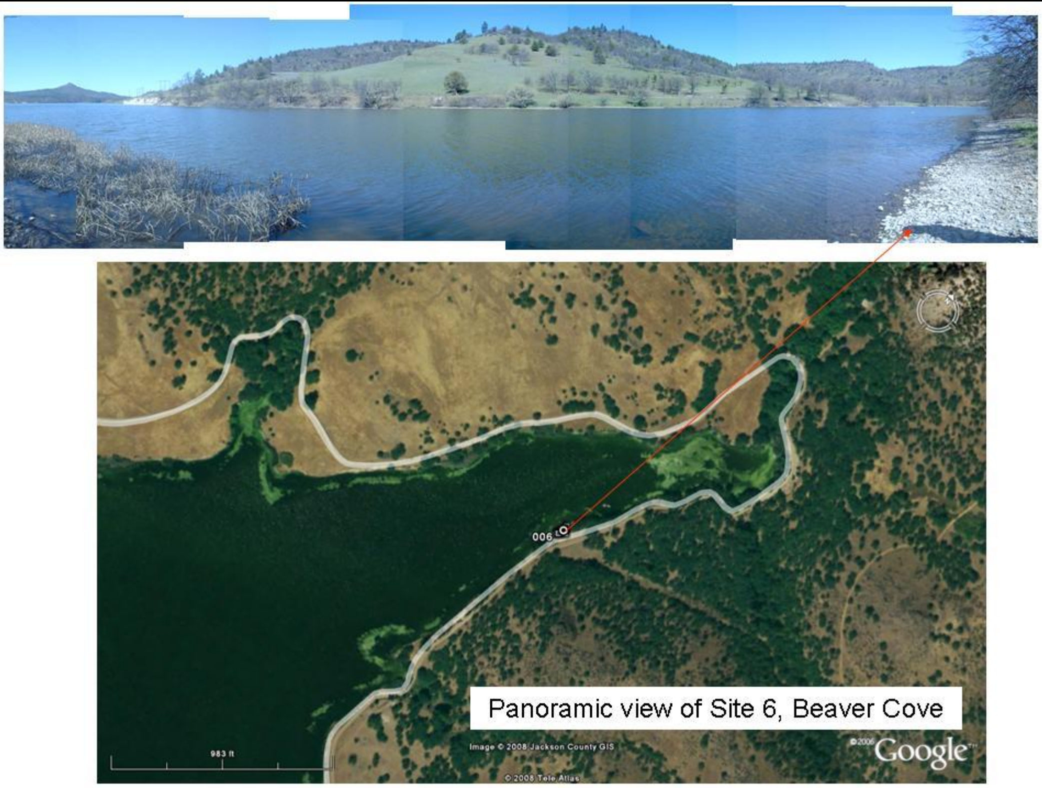
B

C

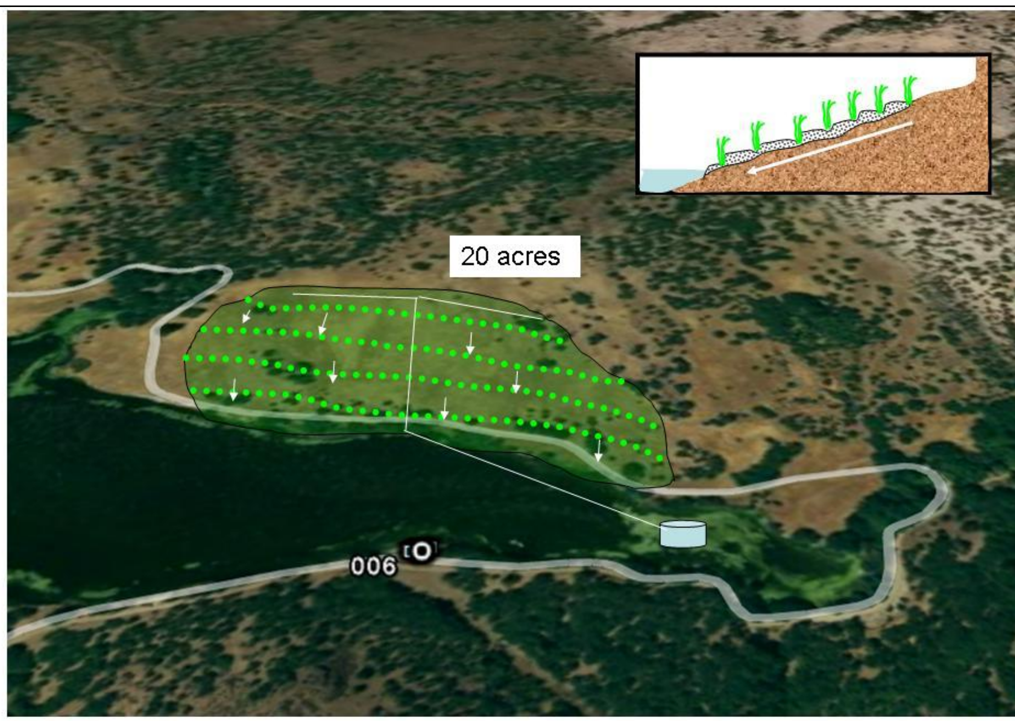


Site 5: Copco Cove – site of major algae blooms

North and south edges of Copco Cove



Panoramic view of Site 6, Beaver Cove



Tiered gravel-based grassy swales designed for the removal of algae solids from Beaver Cove

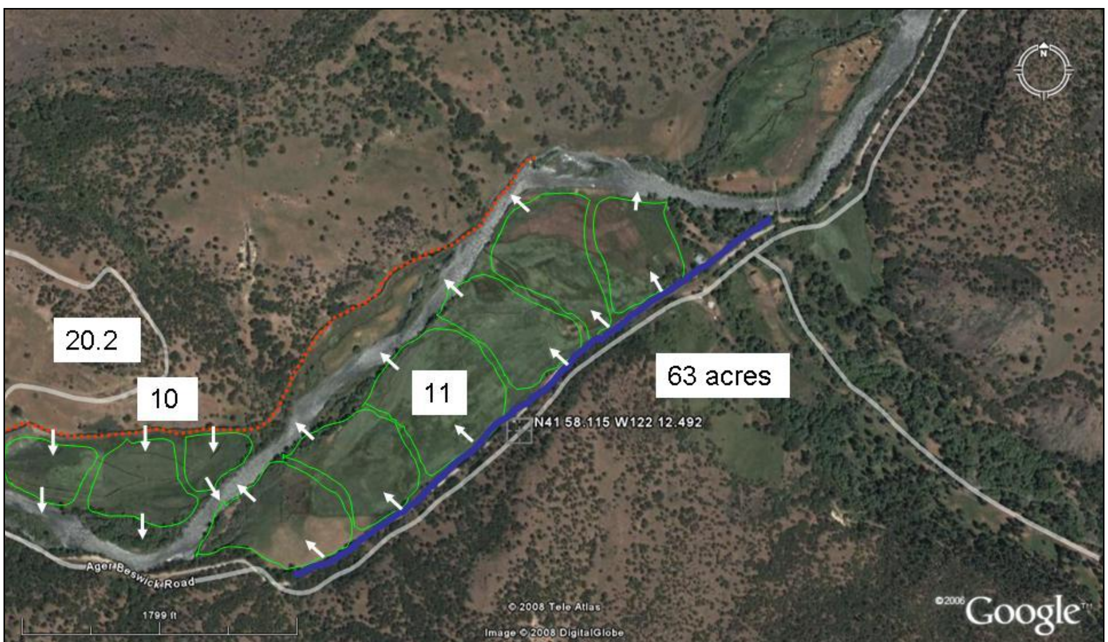
Site 8: First large area for potential wetland development

-pre-existing gravity-fed canal that can provide water for the wetland

* -the field shown in the panoramic view in the next slide

Site 9

Panoramic views of sites 10 and 11

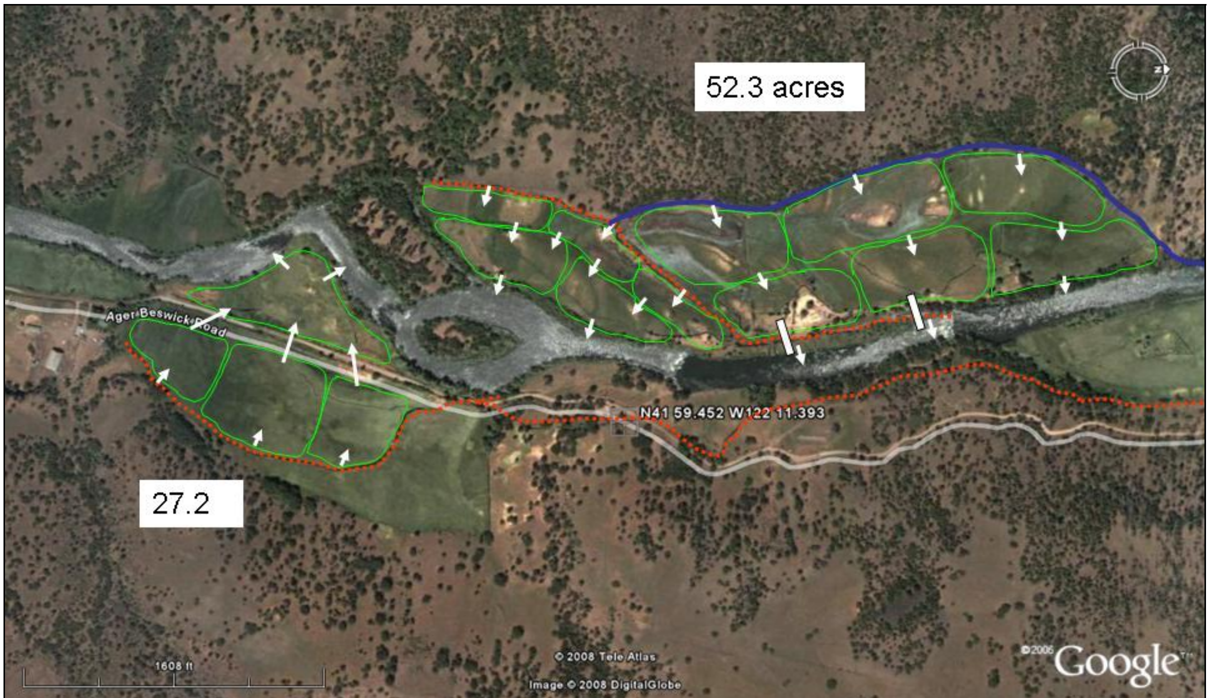


Sites 10 and 11

- Pre-existing gravity-fed canal that can provide water for the wetland

- Need to construct a gravity-fed canal

Panoramic view of Site 13 looking due west

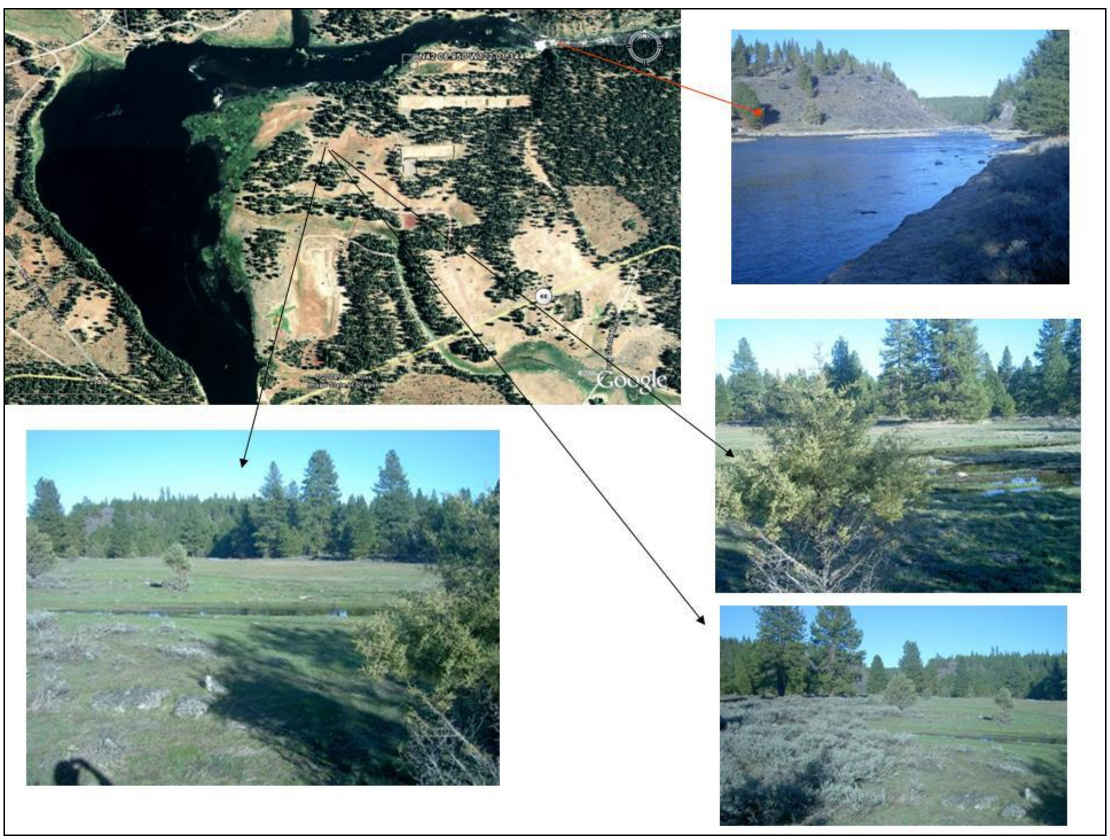


Site 13

- Pre-existing gravity-fed canal that can provide water for the wetland

- Need to construct a gravity-fed canal

Sites 15,16 and 17 in the recreational park



Site 20 at the beginning of the agricultural zone just below Upper Klamath Lake

Panoramic view of Site 20 looking north east, showing the irrigation ditch on the right

All of the sites in the agricultural zone

This property would have to be purchased by PacifiCorp and could be developed as periphyton-based wetlands

Panoramic view of site 22 in the middle of the agricultural zone. Note the built in canals that could be used to deliver water to future wetlands

APPENDIX B

Soil Properties of Sites

Table B-1. Summary of Major Soil Characteristics at Potential Treatment Wetland Sites

Site	Predominant Soil Map Unit	Slope (%)	Soil Depth (in)	Depth to Water Table (in)	Permeability Most Limiting Layer (in/hr)	Flooding	Ponding	Textural Profile (surface/subsoil layers)	Suitability for Berms	Drainage class	Comments
4B	173/176										
4C	190 (Medford clay loam)	2-5	>80	>80	0.2-0.57	None	None	Clay loam/silty clay to clay loam/clay	Shrink-swell	Mod. Well drained	
5N	174 (Lassen-Rock outcrop-Kuck Complex)	2-50	0-40	>80	0-0.2	None	None	Very stony clay or clay loam/bedrock	Cobbles and bedrock	Well drained	Algae land application concept would not be feasible unless applied at very low rates. Construction of grassy swales not feasible.
5S	176 (Lava flows-Xerorthents Complex)	0-50	0-40							Excessively drained	Algae land application concept would not be feasible unless applied at very low rates. Construction of grassy swales not feasible.
6	172 (Lassen-Kuck complex)	15-50	20-40	>80	0.06-0.2	None	None	Clay and clay loam over bedrock	Shrink-swell	Well drained	
8	160 (Jenny clay)	2-15	>80	>80	0.06-0.2	None	None	Clay/silty clay/stratified loam to clay	Shrink-swell	Well drained	

Table B-1. Summary of Major Soil Characteristics at Potential Treatment Wetland Sites

Site	Predominant Soil Map Unit	Slope (%)	Soil Depth (in)	Depth to Water Table (in)	Permeability Most Limiting Layer (in/hr)	Flooding	Ponding	Textural Profile (surface/subsoil layers)	Suitability for Berms	Drainage class	Comments
9	190 (Medford clay loam)	2-5	>80	>80	0.2-0.57	None	None	Clay loam/silty clay to clay loam/clay	Shrink-swell	Mod. Well drained	
10	104 (Atter very gravelly sandy loam	0-5	>80	>80	6-20	Rare	None	Very gravelly sandy loam/stratified very cobbly sand	Seepage and fragments >3”	Somewhat excessively drained	May require soil amendments or very high flow rates to maintain wetland hydrology until detrital layer established
11	190 (Medford clay loam) (small area 160)	2-5	>80	>80	0.2-0.57	None	None	Clay loam/silty clay to clay loam/clay	Shrink-swell	Mod. Well drained	
12	160										Also areas of 161 and 104 soil map units
15, 17	13C (Bly-Royst complex) – Bly component	1-12	>80	>80	0.2-0.57	None	None	Loam/clay loam	Somewhat limited - piping	Well drained	

Table B-1. Summary of Major Soil Characteristics at Potential Treatment Wetland Sites

Site	Predominant Soil Map Unit	Slope (%)	Soil Depth (in)	Depth to Water Table (in)	Permeability Most Limiting Layer (in/hr)	Flooding	Ponding	Textural Profile (surface/subsoil layers)	Suitability for Berms	Drainage class	Comments
15, 17	Royst component	1-12	20-40	>80	0.06-0.2	None	None	Gravelly loam/very cobbly clay loam/weathered bedrock/unweathered bedrock	Somewhat limited - piping	Well drained	Royst component is typically 25% of the map unit. Significant cuts would not be feasible due to bedrock.

Soil information not obtained for Sites 20 and 22.

APPENDIX C

Wetlands Modeling Analysis Results

Table D-1. Effect of Treatment Wetlands on River Load and Concentrations

HRT	Form	Scenario	Total River Avg Flow, May-Sep	Inflow To Wetland	River Flow Minus Flow Into Wetland	Outflow From Wetland	Avg River Conc Before Wetland	River Load Minus Flow To Wetland	Wetland Load To River	Outflow Conc Of Wetland	Conc In River D/S Of Wetland With Mixing	Load In River Down-stream Of Wetland
			MGD	MGD	MGD	MGD	mg/L	lbs/day	lbs/day	mg/L	mg/L	lbs/day
2 day	TSS	with wetlands	800	83.0	717.0	48.1	7.200	43018.3	1271	3.170	6.946	44289.3
2 day	TSS	w/o wetlands	800	0.0	800.0	0.0	7.200	47998.1	0	0.000	7.200	47998.1
2 day	NH4-N	with wetlands	800	83.0	717.0	48.1	0.050	298.7	0	0.000	0.047	298.7
2 day	NH4-N	w/o wetlands	800	0.0	800.0	0.0	0.050	333.3	0	0.000	0.050	333.3
2 day	NO3-N	with wetlands	800	83.0	717.0	48.1	0.702	4193.2	284	0.708	0.702	4477.2
2 day	NO3-N	w/o wetlands	800	0.0	800.0	0.0	0.702	4678.6	0	0.000	0.702	4678.6
2 day	TP	with wetlands	800	83.0	717.0	48.1	0.230	1374.2	93	0.232	0.230	1467.2
2 day	TP	w/o wetlands	800	0.0	800.0	0.0	0.230	1533.3	0	0.000	0.230	1533.3
7 day	TSS	with wetlands	800	23.8	776.2	0.2	7.200	46569.0	0	0.000	7.198	46569.0
7 day	TSS	w/o wetlands	800	0.0	800.0	0.0	7.200	47998.1	0	0.000	7.200	47998.1
7 day	NO3-N	with wetlands	800	23.8	776.2	0.2	0.702	4539.3	0	0.000	0.702	4539.3
7 day	NO3-N	w/o wetlands	800	0.0	800.0	0.0	0.702	4678.6	0	0.000	0.702	4678.6
7 day	TP	with wetlands	800	23.8	776.2	0.2	0.230	1487.6	0	0.000	0.230	1487.6
7 day	TP	w/o wetlands	800	0.0	800.0	0.0	0.230	1533.3	0	0.000	0.230	1533.3

Table D-2. Wetlands Model Analysis – Scenario: April to October Period at HRT of 2 Days.

Surface Flow Monthly Treatment Wetland Design Model w/ Water Balance (Wastewater Parameters)

User inputs indicated by white boxes.
Pop-up notes indicated by red triangles.

Project Name	Paficorp-Klamath River Valley
Project Number	ET= 0.8x(30 yr avg pan evap)

Flow Rate Converter

	Value	Units
Flow (Enter monthly flowrate below under "General and Hydrologic Input Data"; use this cell simply for converstion between units)	83	mgd
Converted Flow	314,155	m^3/d

General and Hydrologic Input Data

Wetland Hydrology

Month	Days in Month	Air Temp (°C)	Precip (m/mo)	Inflow (m3/d)	ET (m/mo)	Infiltration (m/mo)	Outflow (m3/d)	
January	31		2.30		0.40			
February	28		1.59		0.61			
March	31		1.57		1.49			
April	30		0.94	314155	2.30	0.370	255083	
May	31		1.07	314155	3.54	0.370	219969	
June	30		0.66	314155	4.21	0.370	179806	
July	31		0.28	314155	5.49	0.370	129020	
August	31		0.32	314155	4.55	0.370	161722	
September	30		0.62	314155	2.77	0.370	228023	
October	31		1.38	314155	1.25	0.370	306217	
November	30		2.28		0.48			
December	31		2.69		0.35			% infiltration:
Average			1.309264	314155	2.29	0.37	211406	33%

Table D-2 (continued). Wetlands Model Analysis – Scenario: April to October Period at HRT of 2 Days.

Water Quality Input Data

	Month	BOD5	TSS	Organic N	NH_4-N	$NO_{2/3}$-N	TN	TP	FC
	January								
	February								
	March								
	April		12		0.1	0.3	0.8	0.15	
	May		10		0.1	0.3	0.8	0.18	
	June		8		0.1	0.4	1.2	0.25	
	July		6		0.1	0.6	1.5	0.25	
	August		6		0.1	0.8	1.8	0.20	
	September		6		0.1	1.0	1.8	0.18	
	October		8		0.1	0.9	1.8	0.15	
	November								
	December								
	Annual Average		8.0		0.1	0.6	1.4	0.19	
Target Effluent Conc., mg/L	C_e =				0.1	0.5			
Max Month/Annual Factor		1.7	1.9	1.8	2.5	1	1.6	1.8	3.0
Design Target Conc., mg/L	C_d =				0.0	0.5			
Wetland Background Limit, mg/L	C* =	=3.5+0.053 *Ci	=(5.1+0.16 *Ci)*Θ^(T-20)	1.5	0	0	1.5	0.02	300
Areal Rate Constant, 20°C, m/y	k_{20} =	34	200	17	18	35	22	12	75
Temperature Factor	θ =	1.00	1.065	1.05	1.04	1.09	1.05	1.00	1.00

Table D-2 (continued). Wetlands Model Analysis – Scenario: April to October Period at HRT of 2 Days.

Wetland Size and Output Predictions

Wetland Area

254	ac
102.83	ha
1028340	m2

Effluent Concentrations

Month	BOD5	TSS	Organic N	NH_4-N	$NO_{2/3}$-N	TN	TP	FC
January								
February								
March								
April		4.3		0.0	0.3	0.9	0.14	
May		3.8		0.0	0.3	0.9	0.17	
June		3.3		0.0	0.4	1.5	0.27	
July		2.9		0.0	0.8	2.1	0.31	
August		2.9		0.0	1.0	2.3	0.23	
September		2.8		0.0	1.0	1.9	0.17	
October		3.2		0.0	0.8	1.6	0.13	
November								
December								
Annual Average		*3.3*		0.001	*0.7*	*1.6*	*0.203*	

	BOD5	TSS	Organic N	NH_4-N	$NO_{2/3}$-N	TN	TP	FC
	1	1	1	1	1	1	1	1
Avg Percent Reduction (by concentration)		59%		98%	-7%	-16%	-5%	
Average Mass Loading (lb/day)		5538		40	425	959	133	
Average Mass Loading (kg/ha/d)		24.4		0.2	1.9	4.2	0.6	
Average Mass Out (lb/day)		1543		1	305	748	94	
Average Mass Out (kg/ha/d)		6.8		0.0	1.3	3.3	0.4	
Percent Reduction (by mass)		72%		99%	28%	22%	29%	

Hydraulic Properties Based on Area and Flow

						Override
Percent Open Water	20%	Transition Side Slopes (H:V) - (4:1)	4			
Marsh Zone Depth (m)	0.6	Berm Side Slopes (H:V) - (2:1)	2	# of Deep Zones	9	
Deep Zone Depth (m)	2	Approx Aspect Ratio (L:W) - (5:1)	5	Deep Zone Bot Length	50	
Volume (m3)	631104					

Table D-2 (continued). Wetlands Model Analysis – Scenario: April to October Period at HRT of 2 Days.

Nitrogen Species Calculations

Nitrogen Models
per K&K Eqns 13-28. 13-29, 13-39:
Adapted for Monthly TIS model
Organic Nitrogen (ON)

$$C_{ON_{OUT}} = C^*_{ON} + (C_{ON_{IN}} - C^*_{ON})\left[1 + \frac{k_{ON}A}{NQ}\right]^{-N}$$

Ammonia Nitrogen (AN)

$$C_{AN_{OUT}} = C^*_{AN} + (C_{AN_{IN}} - C^*_{AN})\left[1 + \frac{k_{AN}A}{NQ}\right]^{-N} + \left(\frac{k_{ON}}{k_{AN} - k_{ON}}\right)(C_{ON_{IN}} - C^*_{ON})\left(\left[1 + \frac{k_{ON}A}{NQ}\right]^{-N} - \left[1 + \frac{k_{AN}A}{NQ}\right]^{-N}\right)$$

Nitrate Nitrogen (NN)

$$C_{NN_{OUT}} = C_{NN_{IN}}\left[1 + \frac{k_{NN}A}{NQ}\right]^{-N} + \Psi\left[\begin{aligned} &\left(\frac{k_{AN}}{k_{NN} - k_{AN}}\right)C_{AN_{IN}}\left(\left[1 + \frac{k_{AN}A}{NQ}\right]^{-N} - \left[1 + \frac{k_{NN}A}{NQ}\right]^{-N}\right) \\ &+ \left(\frac{k_{ON}}{k_{AN} - k_{ON}}\right)\left(\frac{k_{AN}}{k_{NN} - k_{ON}}\right)(C_{ON_{IN}} - C^*_{ON})\left(\left[1 + \frac{k_{ON}A}{NQ}\right]^{-N} - \left[1 + \frac{k_{NN}A}{NQ}\right]^{-N}\right) \\ &- \left(\frac{k_{ON}}{k_{AN} - k_{ON}}\right)\left(\frac{k_{AN}}{k_{NN} - k_{AN}}\right)(C_{ON_{IN}} - C^*_{ON})\left(\left[1 + \frac{k_{AN}A}{NQ}\right]^{-N} - \left[1 + \frac{k_{NN}A}{NQ}\right]^{-N}\right) \end{aligned}\right]$$

where Ψ = fraction of ammonium nitrified, assumed to be 100% = 100%

Table D-3. Wetlands Model Analysis – Scenario: May to September Period at HRT of 7 Days.

Surface Flow Monthly Treatment Wetland Design Model w/ Water Balance (Wastewater Parameters)

User inputs indicated by white boxes.
Pop-up notes indicated by red triangles.

Project Name	Paficorp-Klamath River Valley (WQ above Copco)
Project Number	ET= 0.8x(30 yr avg pan evap)

Flow Rate Converter

	Value	Units
Flow (Enter monthly flowrate below under "General and Hydrologic Input Data"; use this cell simply for converstion between units)	23.81978	mgd
Converted Flow	90,158	m^3/d

General and Hydrologic Input Data

Wetland Hydrology

Month	Days in Month	Air Temp (°C)	Precip (m/mo)	Inflow (m3/d)	ET (m/mo)	Infiltration (m/mo)	Outflow (m3/d)	
January	31		2.30		0.40			
February	28		1.59		0.61			
March	31		1.57		1.49			
April	30		0.94		2.30			
May	31		1.07	90158	3.54	0.370	0	
June	30		0.66	90158	4.21	0.370	0	
July	31		0.28	90158	5.49	0.370	0	
August	31		0.32	90158	4.55	0.370	0	
September	30		0.62	90158	2.77	0.370	4026	
October	31		1.38		1.25			
November	30		2.28		0.48			
December	31		2.69		0.35			% infiltration:
Average			1.309264	90157.88	2.29	0.37	805	99%

Table D-3 (continued). Wetlands Model Analysis – Scenario: May to September Period at HRT of 7 Days.

Water Quality Input Data

Month	**BOD5**	**TSS**	**Organic N**	**NH_4-N**	**$NO_{2/3}$-N**	**TN**	**TP**	**FC**
January								
February								
March								
April								
May		10		0.1	0.3	0.8	0.18	
June		8		0.1	0.4	1.2	0.25	
July		6		0.1	0.6	1.5	0.25	
August		6		0.1	0.8	1.8	0.20	
September		6		0.1	1.0	1.8	0.18	
October								
November								
December								
Annual Average		7.2		0.1	0.6	1.4	0.21	

		BOD5	TSS	Organic N	NH_4-N	$NO_{2/3}$-N	TN	TP	FC
Target Effluent Conc., mg/L	C_e =				0.1	0.5			
Max Month/Annual Factor		1.7	1.9	1.8	2.5	1	1.6	1.8	3.0
Design Target Conc., mg/L	C_d =				0.0	0.5			
Wetland Background Limit, mg/L	C* =	=3.5+0.053*Ci	=(5.1+0.16*Ci)*Θ^(T-20)	1.5	0	0	1.5	0.02	300
Areal Rate Constant, 20°C, m/y	k_{20} =	34	200	17	18	35	22	12	75
Temperature Factor	θ =	1.00	1.065	1.05	1.04	1.09	1.05	1.00	1.00

Table D-3 (continued). Wetlands Model Analysis – Scenario: May to September Period at HRT of 7 Days.

Wetland Size and Output Predictions

Wetland Area

254	ac
102.83	ha
1028340	m2

Effluent Concentrations

Month	BOD5	TSS	Organic N	NH_4-N	$NO_{2/3}$-N	TN	TP	FC
January								
February								
March								
April								
May		2.1		0.0	0.2	1.5	0.15	
June		2.0		1.9	-1.5	0.3	0.02	
July		2.0		0.1	2.5	4.8	0.49	
August		1.9		0.2	0.7	1.3	0.16	
September		1.9		0.0	1.1	2.6	0.16	
October								
November								
December								
Annual Average		*2.0*		0.000	*0.6*	*2.1*	*0.197*	

	BOD5	TSS	Organic N	NH_4-N	$NO_{2/3}$-N	TN	TP	FC
	1	1	1	1	1	1	1	1
Avg Percent Reduction (by concentration)		73%		100%	6%	-50%	6%	
Average Mass Loading (lb/day)		1430		10	123	282	42	
Average Mass Loading (kg/ha/d)		6.3		0.0	0.5	1.2	0.2	
Average Mass Out (lb/day)		3		0	1	4	0	
Average Mass Out (kg/ha/d)		0.0		0.0	0.0	0.0	0.0	
Percent Reduction (by mass)		100%		100%	99%	99%	99%	

Hydraulic Properties Based on Area and Flow

						Override
Percent Open Water	20%	Transition Side Slopes (H:V) - (4:1)	4			
Marsh Zone Depth (m)	0.6	Berm Side Slopes (H:V) - (2:1)	2	# of Deep Zones	9	
Deep Zone Depth (m)	2	Approx Aspect Ratio (L:W) - (5:1)	5	Deep Zone Bot Length	50	
Volume (m3)	631104					

Hydraulic Loading Rate, q	HLR =	8.8	cm/d
Nominal Hydraulic Residence Time,	HRT =	7.0	days