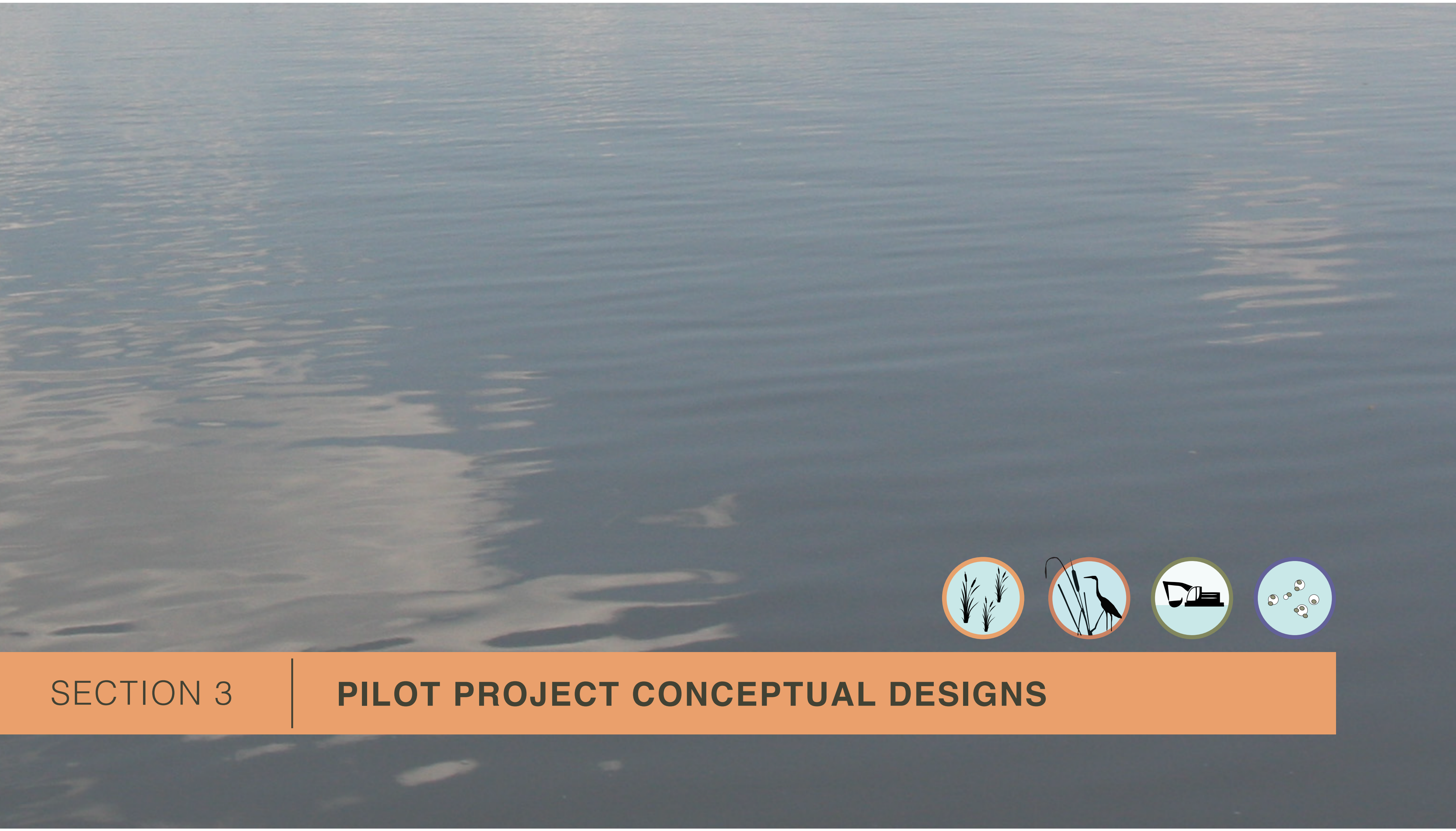


SECTION 3 | PILOT PROJECT CONCEPTUAL DESIGNS

Fig. 3.1 (Above) Numerous low-lying areas and former wetlands in the Wood River Valley are connected through agricultural canals and drainage ditches. Photo: C. Anderson.

Fig. 3.2 (Below) West Canal in the Wood River Valley. Photo: Graham Matthews & Associates.

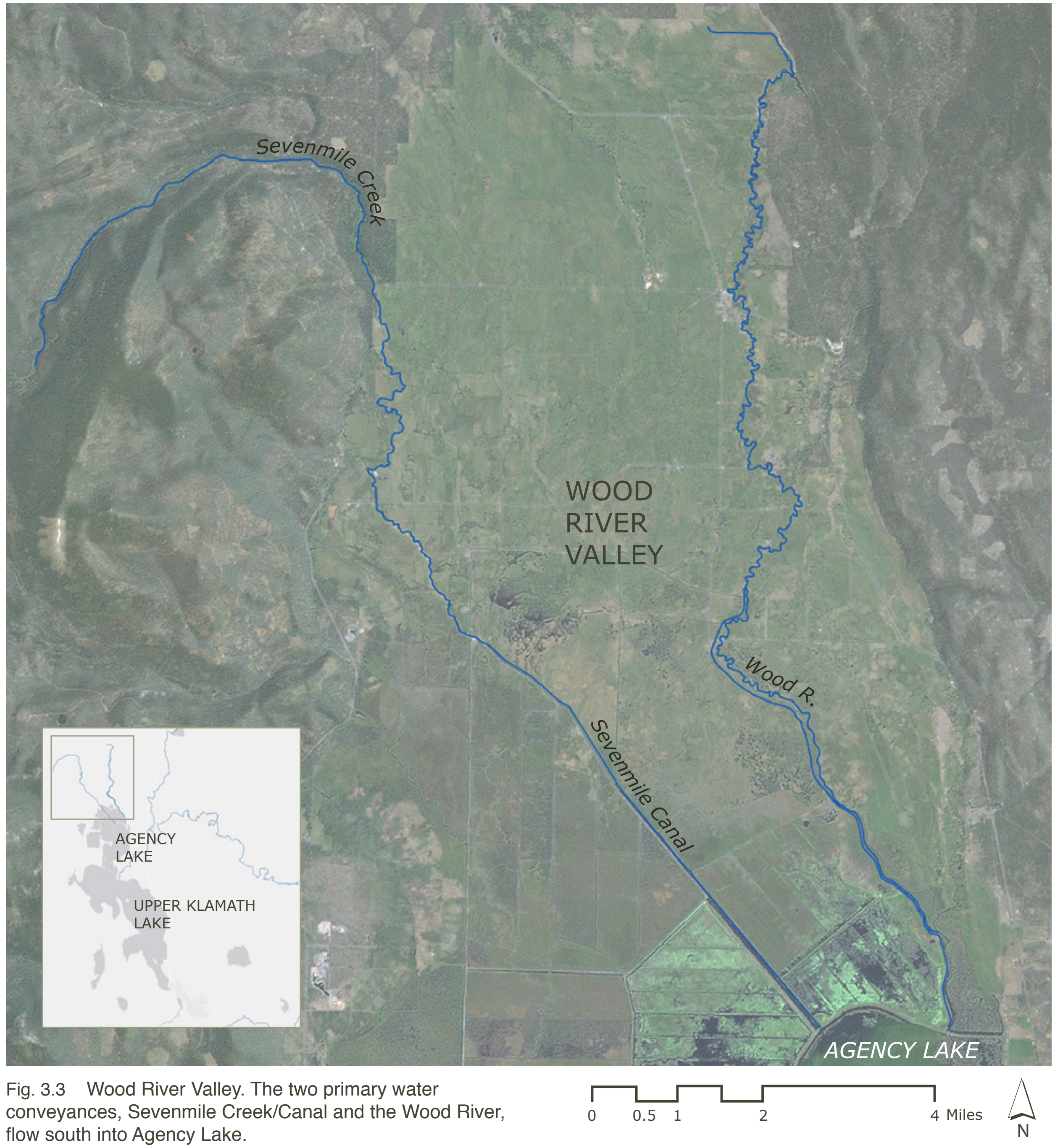


Fig. 3.3 Wood River Valley. The two primary water conveyances, Sevenmile Creek/Canal and the Wood River, flow south into Agency Lake.

WETLAND REHABILITATION

Conceptual designs for wetland rehabilitation in the Upper Klamath Basin are presented as two overarching types with the following general characteristics:

Diffuse source (decentralized) treatment wetlands (DSTWs)

- 1 to 10s of acres
- Wood and Sprague river valleys
- Water quality improvements
- Minimal earthwork, pumping, and infrastructure

Large wetlands

- 10s to 1,000s of acres
- Surrounding Upper Klamath and Agency lakes and along Keno Impoundment
- Water quality improvements
- Sucker habitat

DIFFUSE SOURCE (DECENTRALIZED) TREATMENT WETLANDS

Workshop recommendations related to DSTWs generally prioritized the Wood and Sprague river valleys (Section 2, pages 19-20), which contribute 21% and 23% respectively of the external total phosphorus load to Upper Klamath and Agency lakes.[1] This section presents a conceptual design for large-scale implementation of DSTWs in these watersheds that relies upon a generalized GIS analysis to identify potentially available land area and maximize treatment capacity. No individual parcels were identified for this conceptual-level analysis. This section also provides a conceptual design for two different types of pilot systems for these two watersheds.

OBJECTIVE - To evaluate the potential for large-scale removal of nutrients in the Upper Klamath Lake watershed, in order to decrease external loading of phosphorus and nitrogen to Upper Klamath and Agency lakes and decrease resulting nuisance algal blooms in these waterbodies.

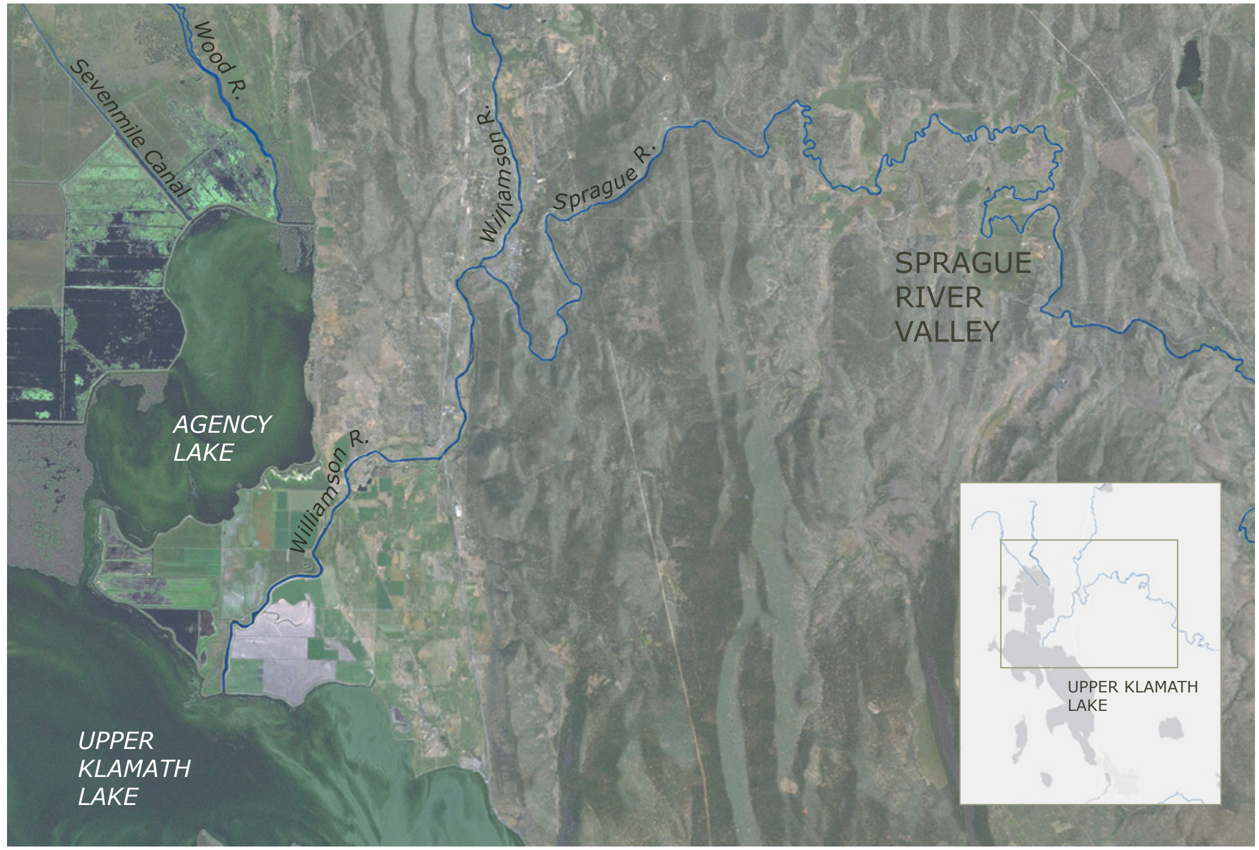


Fig. 3.4 Western portion of the Sprague River Watershed, where the Sprague River joins the Williamson River and empties into Upper Klamath Lake.

1 Walker et al. 2012

Watershed Characteristics

Wood River

The Wood River Valley is located on the northern end of Upper Klamath and Agency lakes, with a relatively small area of approximately 32,260 acres. Ranging in size from less than one to 7,100 acres, parcels in the Wood River Valley are primarily located in low-lying areas and former wetlands and are connected through numerous agricultural canals and drainage

DSTWs AND SPRAGUE RIVER RESTORATION

Numerous stream restoration projects have been conducted in the Sprague River Basin since the early- to mid-1990s, including fencing, wetland creation, floodplain reconnection, levee breaching, meander bend cutoff plugging, riparian planting, channel realignment, fish screens, spring reconnection, and wetland connection. A recent effort was undertaken to evaluate the performance of completed stream restoration projects in the basin, identify key lessons learned, and guide future project prioritization, planning, and design.[2] Based on this evaluation, several project types have the potential to contribute to basin wide restoration goals for the Sprague River. Of these, riparian expansion, floodplain reconnection, and floodplain modification project types hold the most promise for accommodation of DSTWs located along creeks and rivers because they involve actions such as levee removal/notching and wetland excavation that could support typical DSTW design features (see Figures 3.7 and 3.8).

In the Sprague River Basin, floodplain reconnection and modification projects are desirable because they possess a high magnitude and certainty of benefits and a low level of effort and/or number implemented in the basin,[2] consistent with characteristic features of DSTWs.

It is critical that DSTW design and implementation occur within existing Sprague River riparian and floodplain conceptual models, such that these systems do not interfere with the anticipated benefits of a properly functioning riparian corridor. For example, existing riparian conceptual models in the basin are based on seasonal inundation of wetlands during high flows, which, for DSTWs, would focus water treatment from December to May and would be a primary hydrologic design component.

DSTWs located outside of the riparian corridor and floodplain would not necessarily be subject to the same design considerations as those located within the riparian corridor. These DSTWs could potentially treat water during the low-flow period (June to October) when nutrient inputs can also be high.

Regardless, design and implementation of DSTWs in the Sprague River Basin would benefit from recommendations common to all of the stream restoration project types considered, including the use of basin-specific conceptual models, the development of tailored monitoring metrics and assessment approaches, and adaptive management.[2] Additionally, a targeted study to quantify the water quality benefits of a properly functioning riparian corridor in the Sprague River Basin would help identify to what degree additional treatment by DSTWs is needed to meet water quality goals.

2 NewFields River Basin Services and Kondolf 2012

ditches (Figures 3.1 and 3.2). These characteristics make the Wood River Valley an ideal location for DSTWs. The Wood River and the Sevenmile Creek[3] are the two primary water conveyances in the Wood River Valley (Figure 3.3). Preliminary GIS analysis indicates that roughly 16,000 acres of parcels in the Wood River Valley are bounded or crossed by one or both of these conveyances and approximately 42 miles of land is directly adjacent to the conveyances.

3 The creek becomes the Sevenmile Canal as it moves toward Agency Lake.

Fig. 3.5 A recent wetland restoration, Anderson Ranch, Sprague River Valley. Photo: River Design Group.

Sprague River

The larger Sprague River Valley is approximately 52,000 acres located on the north eastern side of Upper Klamath Lake (Figure 3.4). The Sprague River flows through constrained reaches and small river valleys on its path to the lake. In the small valleys, the river is sinuous, containing multiple bends and oxbows.[4] Here, given the “flashy” seasonal hydrology of the Sprague River, the river has opportunities to overflow its banks and sustain seasonal wetlands and wet meadows, sequestering natural phosphorus transported downstream with sediments during snow melt periods. Parcel sizes in the Sprague River Valley range in size from less than one acre to 20,000 acres. There are fewer canals and agricultural ditches bounding or crossing parcels in the Sprague River Valley as compared to the Wood River Valley. However, the total acreage of river-front, valley land along the Sprague River is still relatively large, at roughly 15,100 acres.[5]

4 Rasmussen 2012
5 This value is estimated using a 1,000 foot buffer on either side of the river.

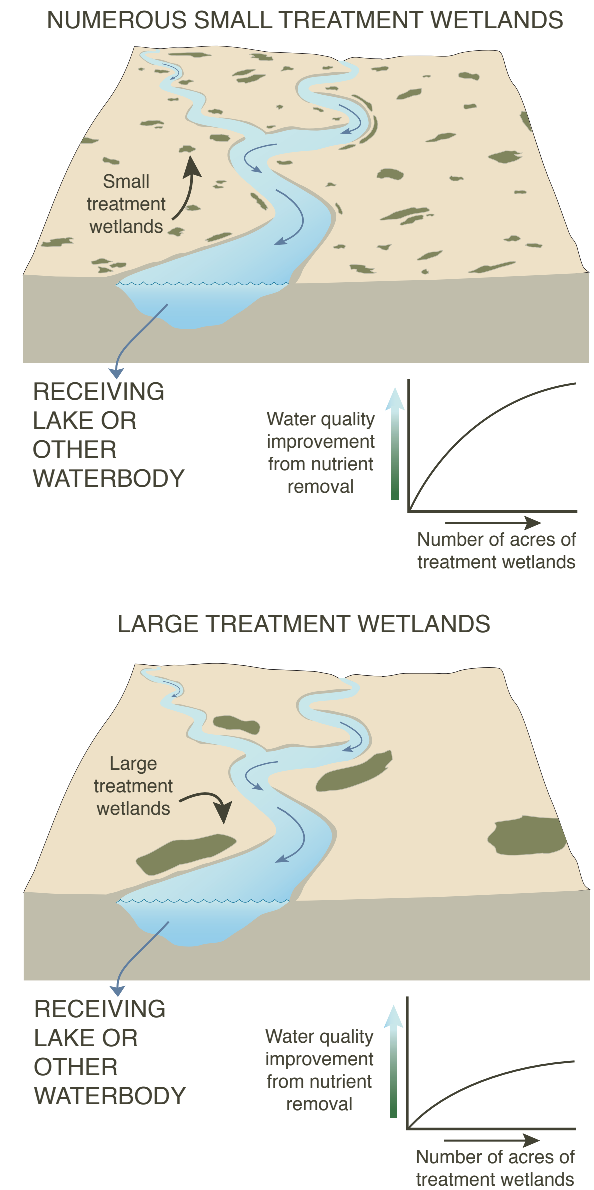


Fig. 3.6 Numerous small, distributed wetlands can have greater treatment potential than a few larger wetlands in the same watershed. Although generalized for illustration purposes in this figure, rates of removal for nitrogen and phosphorus would be different based on the specific removal mechanisms for each.

In the Sprague River Valley, recent projects have restored wetlands on private agricultural lands by removing levees to allow winter/spring time flooding of lands adjacent to the river banks (see text box on page 42).[6]

Pilot Project Conceptual Design

DSTWs are a network of relatively small pockets of wetlands distributed throughout the watershed (Section 2, page 18). In order to accomplish large-scale water quality improvement goals at the scale of the watershed, a sufficient cumulative acreage is required. For nitrogen removal, this is typically 1-2% of the total watershed area, but varies depending on treatment needs and local conditions.[7] Phosphorus removal can require relatively more area.[8] Theoretical consideration of typical wetland hydraulics and treatment potential suggests that for the same total area of wetlands, many smaller wetlands scattered throughout a watershed may be more efficient than a few larger wetlands in the same watershed (Figure 3.6).

Through the TMDL process, ODEQ has established an external loading target for total phosphorus in Upper Klamath and Agency lakes that would require a 40% reduction from current levels (Section 1, page 10). Available GIS information for the Upper Klamath Basin was used to consider the type, general location, and size of DSTWs in the Wood and Sprague river valleys that would contribute to a meaningful reduction in external phosphorus loading to the lake. No individual parcels were identified for this conceptual-level analysis.

6 K. Gorman (Oregon Division of Water Rights), personal communication, 2013.
7 Mitsch and Day 2006, Mitsch et al. 2011
8 Richardson et al. 2011

Types of Diffuse Source (Decentralized) Treatment Wetlands

Two different types of DSTWs were considered for implementation in the Wood and Sprague River valleys; *flow-through wetlands* and *terminal wetlands*. These are described in general terms below.

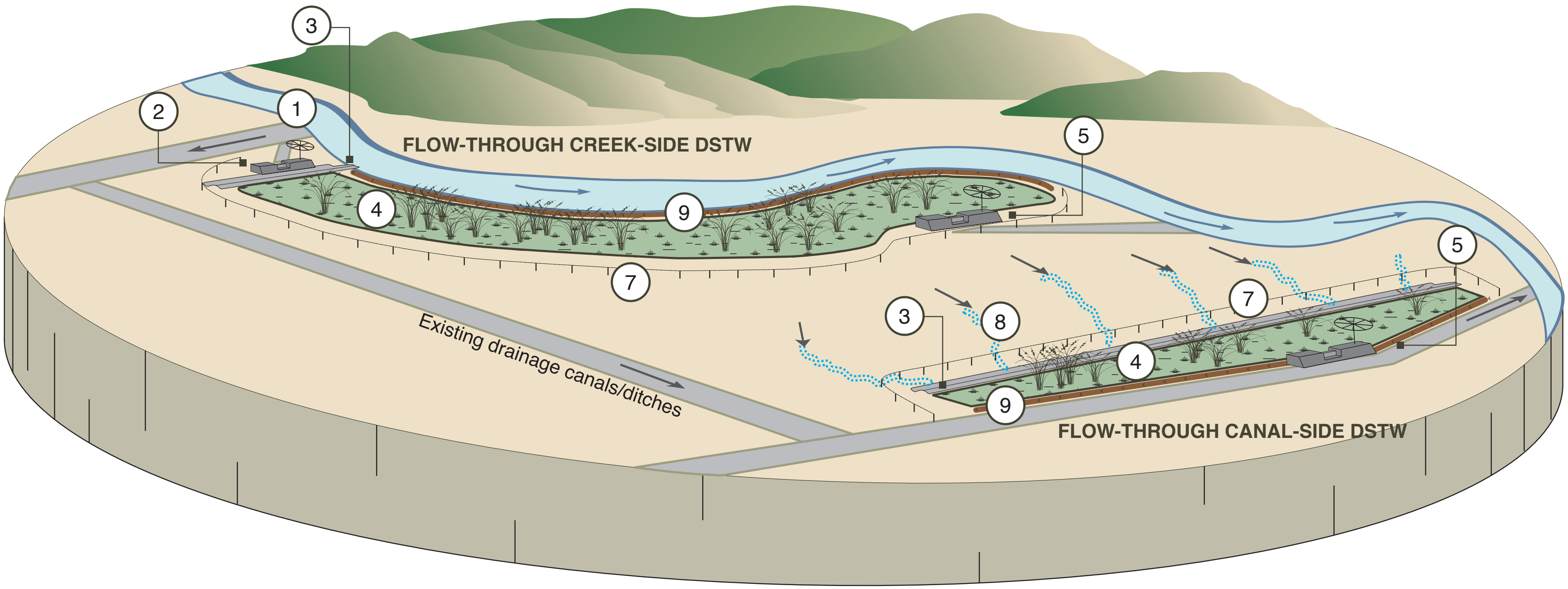
Flow-through DSTWs

Flow-through DSTWs rely on continuous flow for water treatment. By installing overflow weirs in appropriate locations, flow from rivers, creeks, canals, and fields can be diverted into adjacent low-lying areas, treated, and returned to a waterway. As with larger treatment wetlands, the required wetland area is linked to the amount of time water spends in the wetland. This is called *hydraulic residence time* (HRT) and is typically on the order of 2–5 days for these wetlands in order to reduce water losses (evapotranspiration) while still maintaining treatment and wildlife habitat values. The required area for individual flow-through DSTWs is determined using the relationship between wetland area, inlet flow, hydraulic residence time, and average water depth.

Flow-through DSTWs have a designated outflow and can be located along waterways and in naturally low-lying depressions in pastures and agricultural fields.

Nutrient reduction potential in flow-through wetlands is typically estimated using performance models reported in the scientific literature, where the potential to reduce sediment-associated pollutants such as total suspended solids, total phosphorus, and pathogens is based on particle settling time, and reduction for biochemical oxidation and nitrogen reduction processes is based on reaction time. One such model is called the "P-k-C* model" and is a model of

Fig. 3.7 Concept designs for flow-through creek-side and flow-through canal-side DSTWs.



1. **EXISTING POINT OF DIVERSION** - Water is diverted from the creek by way of existing drainage canals/ditches adjacent to or near the proposed site.
2. **OVERFLOW WEIR AND DIVERSION BOX** - Water flows over the weir and into the diversion box to control inflow. The diversion box can be shut off completely if necessary.
3. **DISTRIBUTION TRENCH** - Constructed at the head of the wetland, the distribution trench ensures the water is 4 feet deep and at right angles to the direction of flow.
4. **VEGETATION** - DSTW is planted with primary species such as cattail (*Typha spp.*), bulrush (*Scirpus spp.*), bur-reed (*Sparganium eurycarpum)*, and spike rush (*Eleocharis spp.*) for water treatment; secondary species such as pond lilies (*Nuphar lutea* ssp. *polysepala*) for food and habitat.
5. **ADJUSTABLE DISCHARGE WEIR** - Maintains water levels in the vegetated area at 2 feet or less for a system with a designated discharge.
6. **LEVEL CONTROL STRUCTURE** - Maintains water levels in the vegetated area at 2 feet or less for a terminal system.
7. **EXCLUSION FENCING** - Keeps grazing animals out of the wetlands.
8. **VEGETATED SWALE** - Diverts run-off from higher elevations on the parcel.
9. **EARTHEN BERMS** - Generally to be avoided, since the site is likely to be wet and difficult to work with using typical earth moving equipment. If required, berms should have two feet of freeboard and should be higher at the discharge end of the wetlands.

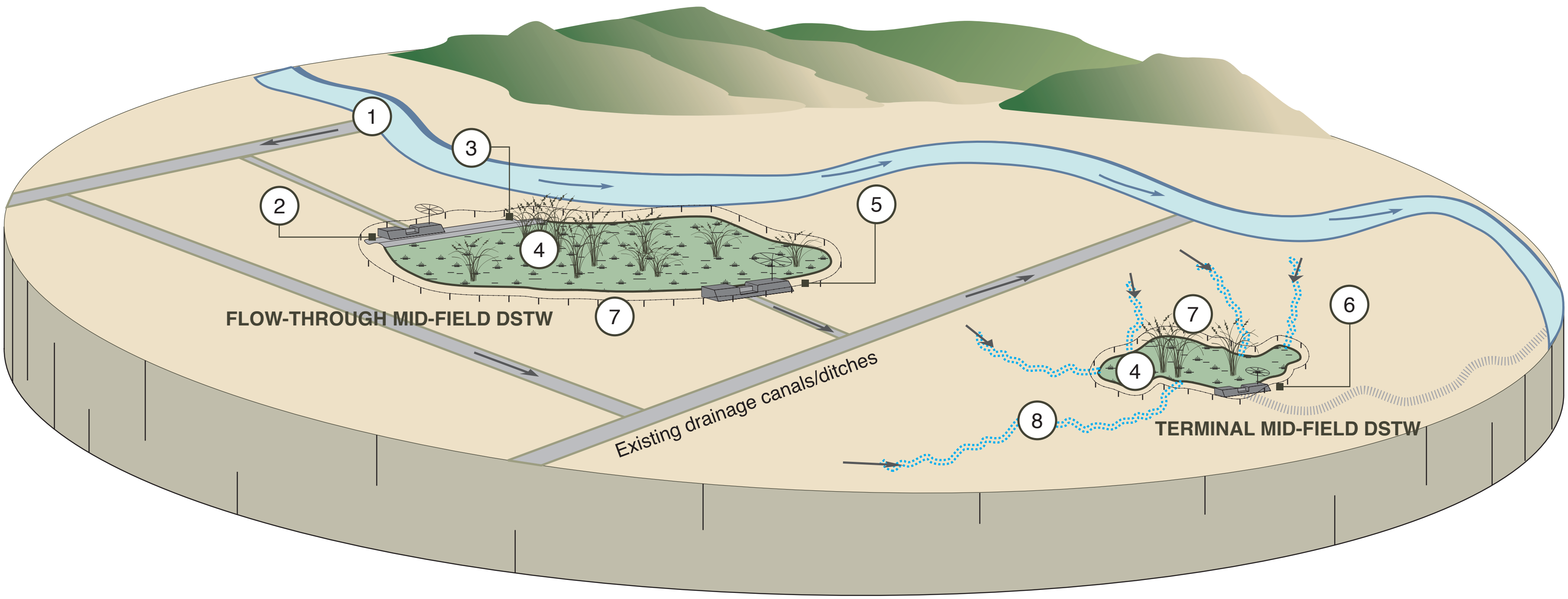


Fig. 3.8 Concept designs for flow-through mid-field and terminal mid-field DSTWs.

central tendency for nitrogen and phosphorus outlet concentrations for treatment wetlands.[9] Estimates of wetland evapotranspiration and groundwater seepage for typical flow-through wetlands are also available in the scientific literature.

Terminal DSTWs

Terminal DSTWs are located in naturally low-lying depressions in pastures and agricultural fields and do not have a designated outflow. These wetlands are designed to mimic the natural variability in water depth and areal extent of wetlands dependent on runoff. For this type of application, DSTWs can be conceived of as vegetated detention basins, designed on the basis of estimated runoff. The required wetland area is determined using annual rainfall, parcel area, a runoff coefficient, and annual evapotranspiration. The resulting wetland area tends to be on the order of 1 to 2% of the parcel area.[10]

Nutrient reduction potential in terminal wetlands is typically estimated using performance models developed for a "batch" system, or a system lacking a designated outflow.[11]

9 Kadlec and Wallace 2009

10 Michael Ogden (NSI/Biosystems), personal communication, 2013.

11 Kadlec and Wallace 2009

General Location of Diffuse Source (Decentralized)Treatment Wetlands

In the Wood River and Sprague River valleys, flow-through DSTWs would be located in the following two general locations:

Creek/Canal-side Sites

DSTWs located along the primary water conveyances would be flow-through systems sized to maximize waterway frontage and elevation difference between system inlet and outlet. Where possible, the wetland cells would be relatively long and narrow, supporting gravity flow through the wetlands and minimizing the need for pumping. Direct diversion from the creek or canal into this type of DSTW may not be feasible

TABLE 3.1 - CONCEPTUAL DESIGN ELEMENTS FOR DSTWS

DESIGN ELEMENT	FLOW-THROUGH CREEK/ CANAL-SIDE AND MID-FIELD	TERMINAL MID-FIELD
Water treatment period	Diversion season	Year round
Habitat period	Year round	
DSTW inflow and outflow rates	0.5-2 cfs	0.01-0.5 cfs (no designated outflow)
Hydraulic residence time	2 - 5 days	> 5 days
Width	Variable	
Length	As needed to meet minimum 10:1 length:width aspect ratio	Variable
Water depth	2 - 2.5 feet	
Consumptive use due to evapotranspiration[12]	2-3 feet per acre per year (April-October)	
Nitrogen removal rate[13]	35 m/yr (April-October) 15 m/yr (November-March)	
Phosphorus removal rate[13]	20 m/yr (April-October) 10 m/yr (November-March)	

12 Typical wetland evapotranspiration losses in the Upper Klamath Basin: 1.7 feet per acre for May - October (Bidlake 2002); 2.6 to 2.9 feet per acre annually (emergent vegetation and seasonal wetland) (Risley and Gannett 2006); 2.2 to 2.3 feet per acre for May-September (Stannard et al. 2013).

13 Rates are generalized from Kadlec and Wallace (2009). Wetland performance models are sensitive to k values and site-specific rates should be developed during pilot studies.

due to water availability challenges. Instead, irrigation water could be collected on-site through existing small agricultural drains and treated prior to tailwater/ effluent discharge from the DSTWs. Common design elements, including target width, length, and water depth for wetland cells are presented in Figure 3.7 and Table 3.1; however, wetland cell orientation along the creek/canal would be dependent on local topography and the pre-existing point of diversion for a given site.

Mid-field Sites

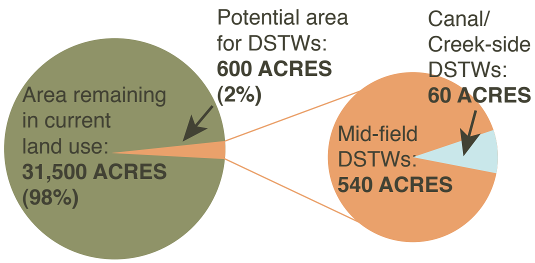
DSTWs located in natural low-lying areas in existing pastures or fields that support the hydrology, vegetation, and soils characteristic of wetlands would be either flow-through or terminal systems, depending on site characteristics (see Figure 3.8). The dimensions of each DSTW would be variable and based on local conditions to minimize the need for earthmoving, pumping, and exclusion fencing. The mid-field, flow-through DSTWs would be designed for a target hydraulic residence time, so cell dimensions would, where possible, achieve the target width, length and depth values presented in Table 3.1.

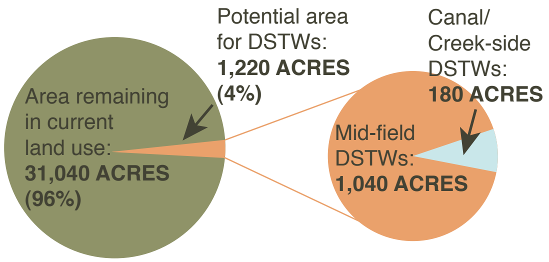
Potential Area and Treatment Capacity for DSTWs

A generalized GIS analysis of the Wood River Valley indicates that DSTWs sized at 10 acres or less using design elements presented in Figures 3.7 and 3.8, could theoretically represent a maximum potential cumulative area of 600 acres (Figure 3.9). This analysis assumes that for any given parcel, a theoretical maximum of 5% of the existing land use would be converted to a DSTW, regardless of the parcel size. While not an established regulatory threshold, the 5% assumption represents a "small amount", which, in the case of an actual project would minimize the requirement to transfer an existing water right for irrigation or agricultural use to a wetland use (see text box on page 48). For the creek/canal-side DSTWs, approximately 60 acres in the Wood River Valley are theoretically available for this purpose, not including lands that recently have been or may soon be enrolled in programs such as the NRCS Wetland Reserve Program (WRP). The majority of DSTW acreage (540 acres) would be mid-field systems scattered throughout the valley (Figure 3.9). Typical DSTW size would be 5-6 acres. For the valley as a whole, 31,500 acres or 98% of the existing land use would remain the same.

To project annual nutrient removal for an individual DSTW, the removal rates for April-October and November- March (Table 3.1) can be used. Summing the estimates across 600 acres suggests that a roughly 5-20% cumulative annual reduction of phosphorus and a roughly 5-15% cumulative annual reduction of nitrogen would be possible for the valley, depending on the relative amounts of flow-through and terminal DSTWs (Figure 3.11). The corresponding cumulative flow reduction from the adjacent waterways would be just over 3%, based on estimated evapotranspiration losses (calculations are shown in Appendix B).

Including wetlands greater than 10 acres in size, but still maintaining a theoretical land use conversion for individual parcels of no more than 5%, would expand treatment potential and wildlife habitat by increasing the potential cumulative wetlands area to 1,220 acres or 4% of the Wood River total valley area. This would support approximately 180 acres of creek/canal-side DSTWs, where the average wetland would be just over 10 acres in size. The majority of DSTW acreage (1,040 acres) would be mid-field





For any given parcel, a theoretical maximum of 5% of the existing land use would be converted to DSTWs, regardless of the parcel size. No individual parcels were identified for this conceptual design.

Fig. 3.9 (Above left) Potential area in the Wood River Valley for DSTWs assuming all wetlands are less than or equal to 10 acres in size.

Fig. 3.10 (Above right) Potential area in the Wood River Valley for DSTWs assuming wetlands of any size.

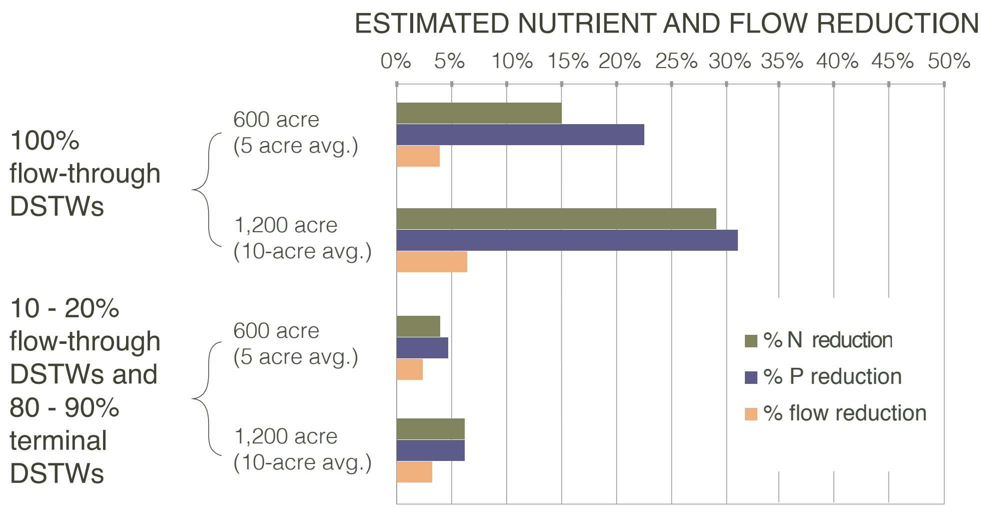


Fig. 3.11 Estimated annual reduction in nutrients and creek/canal flow for DSTWs in the Wood River Valley (see Appendix B for detailed calculations).

WATER RIGHTS

Anticipated water right requirements for creation of creek/canal-side and mid-field DSTWs in the Upper Klamath Basin are presented in Table 3.2. It is assumed that DSTWs would treat water primarily during the irrigation season (May – September) when water quality conditions in the basin are most in need of improvement. However, treatment outside of the irrigation season may be possible if existing parcel water rights support year-round water use. This would allow treatment of the first flush storm event, which would be particularly important for phosphorus removal.

Measured wetland evapotranspiration rates range 0.6 to 1.1 times those of pasture and cropland,[14] meaning that conversion from an irrigation water use to a wetland water use could either slightly decrease or increase overall consumptive water use for a given parcel. However, if land conversion to DSTWs remains at or less than 5% of the total parcel area, any net change in consumptive water use would be correspondingly small and would not likely require a change in the existing water right. For DSTW conversions greater than a small percentage of the total parcel area, additional land may need to be removed from irrigation such that no net increase in consumptive use occurs for a particular parcel and its associated water right. A partial or full water right transfer may be necessary for this situation, depending on the amount of area to be converted to DSTW.

14 Cuenca et al. 1992, Bidlake 2002, Risley and Gannett 2006, Stannard et al. 2013

TABLE 3.2 - ANTICIPATED WATER RIGHTS REQUIREMENTS FOR DSTWs

DSTW TYPE	REQUIREMENT
Creek/Canal-Side	
Flow-through	No water right transfer if wetland is a small fraction of total parcel area
Mid-field	
Flow-through	No water right transfer if wetland is a small fraction of total parcel area
	Partial to full water right transfer depending on how much area is used as a wetland. No net increase in consumptive use.
Terminal	No water right transfer if wetland is a small fraction of total parcel area
	Partial to full water right transfer depending on how much area is used as a wetland. No net increase in consumptive use.

systems and the valley as a whole would support 31,040 acres or 96% of existing land uses (Figure 3.10).

Increasing the area of flow-through wetlands by including wetlands greater than 10 acres in size would increase cumulative annual phosphorus and nitrogen reduction to roughly 5-30% in the Wood River Valley. However, this scenario may also increase flow reduction in the creeks/canals to values on the order of 3-7% (Figure 3.11) (calculations are shown in Appendix B).

Pilot Project Sites

The pilot project would establish proof-of-concept test sites for both DSTW types—flow-through and terminal (Table 3.3). Test sites would be identified and implemented in the Wood River Valley over a period of five years, to allow for site selection, permitting, construction and operation (Figure 3.14). The pilot sties would be used to test the efficacy of design elements, nutrient removal performance, and the potential for unintended consequences such as invasive species and mosquitos.

TABLE 3.3 - PROOF OF CONCEPT TEST SITES FOR DSTWs

DSTW TYPE	NUMBER OF TEST SITES FOR PILOT PROJECT
Creek/canal-side flow-through	2
Mid-field flow-through	2
Mid-field terminal	2

Prior to development of final site designs, the capacity of the soil to bind or adsorb phosphorus would be determined at each DSTW pilot site using an

LOW INTENSITY CHEMICAL DOSING (LICD)

LICD systems can be used in existing stormwater basins and wetlands to make them more effective at removing phosphorus from waters. LICD involves the addition of small amounts of coagulants to waters in wetlands or stormwater treatment systems. Coagulants are important for a variety of human uses and can be applied in a safe way. LICD coagulants are typically aluminum-based, iron-based, or a type of organic chemical called a polymer that contains almost exclusively carbon and hydrogen. The coagulants cause dispersed particles in a liquid to come together and form a larger particle called a "floc" (see also Figure 2.23). The floc, a soft, semi-solid, or solid mass, settles out of the water column and becomes a part of the wetland sediments. For LICD, small doses of coagulants are used to minimize costs and to avoid the potential for toxicity to aquatic species.

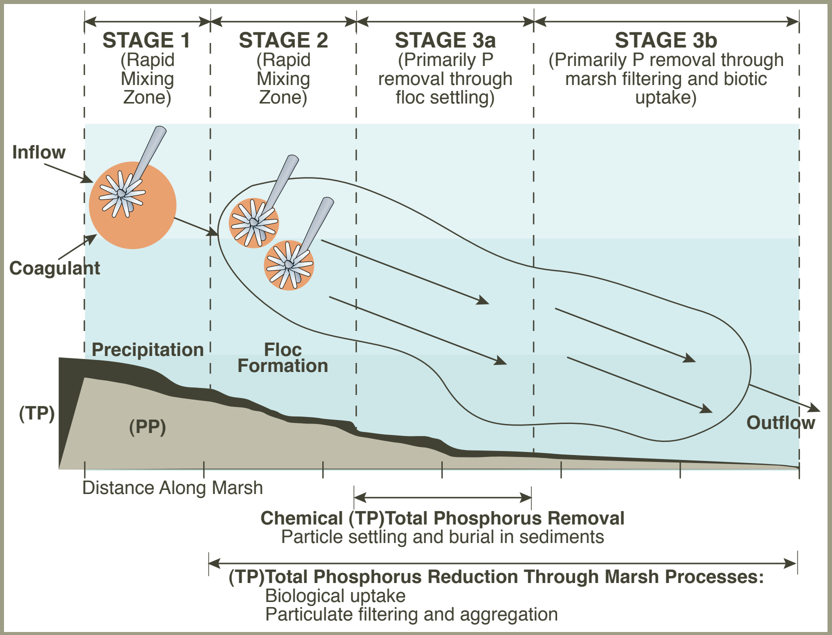


Fig. 3.12 (Left) Phosphorus removal stages for a storm water basin or wetland in the Lake Tahoe basin, California, using LICD. STA = storm water treatment area. Source: Bachand et al. 2006.

Fig. 3.13 (Below) LICD wetland system for enhanced removal of dissolved organic carbon and mercury in the Sacramento-San Joaquin River Delta, California. Photo: Philip Bachand.

LICD can enhance the removal of phosphorus in wetlands where incoming phosphorus is either dissolved in the water or attached to tiny sediment particles that are suspended in water. LICD systems have recently been tested for removal of phosphorus and fine sediments in stormwater in the Lake Tahoe basin, California. Studies found that existing stormwater basins and wetlands, could be more effective when used with LICD.[15] Initial tests of potential toxicity due to coagulant dosing showed no effect on algae or fish test species compared to Lake Tahoe basin stormwater.[16] Coagulant dosing increased chronic toxicity to zooplankton, which may have been due to specific test conditions or the kind of coagulant used (polyaluminum chloride). LICD systems are also being tested in the Sacramento-San Joaquin River Delta for enhanced removal of dissolved organic carbon and mercury in wetlands (Figure 3.13).

15 Bachand et al. 2010

16 Lopus et al. 2009

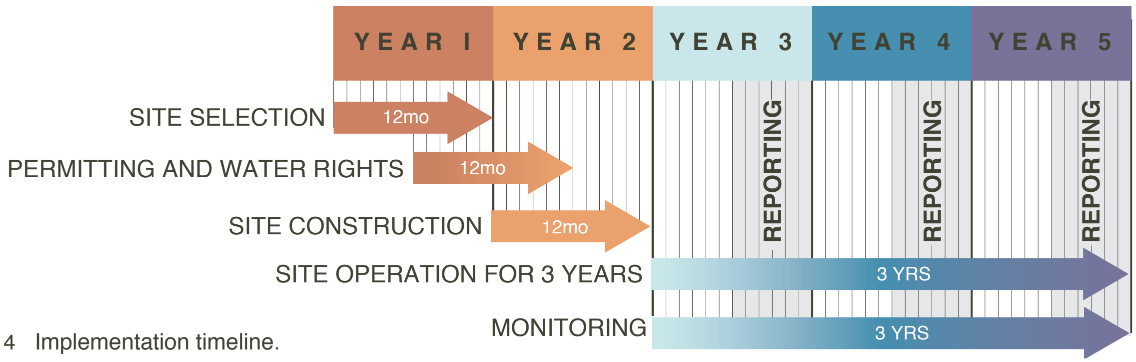


Fig. 3.14 Implementation timeline.

established testing procedure called a Langmuir isotherm test.[17] Based on testing results, the need for soil amendments such as limestone, gypsum, or zeolite minerals, or low intensity chemical dosing (LICD) using aluminum- or iron-based coagulants to increase the efficiency of phosphorus removal (see text box on page 49), would be determined for each DSTW. If an increase in phosphorus removal efficiency is warranted, then the pilot study would be adjusted to include design features such as an equalization basin and/or a coagulant dosing area prior to the DSTW inflow (Bachand et al. 2006).[18] The cost of the enhanced DSTW design would be balanced against the cost per mass phosphorus removed.

At each test site, the following parameters would be monitored on a monthly basis:

- Inflow/outflow quantity (for flow-through systems)
- Water depth
- Water temperature, conductivity, dissolved oxygen, pH, oxidation-reduction potential
- Total suspended solids (TSS), bacteria (fecal coliform, *E. coli*)

17 Bachand and Heyvaert 2005
18 Bachand et al. 2006

- Nitrogen (total, nitrate, and ammonium for flow-through systems)
- Phosphorus (total and ortho-phosphorus for flow-through systems)
- Vegetation cover by species
- Mosquito presence/absence

Wetland nutrient removal performance would be calculated using inflow and outflow quantity and nutrient concentrations. If soil amendments or LICD are incorporated into the pilot DSTW design, concentrations of the coagulant of choice would also be measured at the inlet and outlet of the wetland along with the other water quality parameters.

Environmental, Regulatory and Permitting Requirements

The following permits would be required for the pilot project:

- Water rights transfer through Oregon Division of Water Rights, as needed
- Water Quality Certification from Oregon Department of Environmental Quality (ODEQ)
- Oregon Department of State Lands Standard Exemption for certain voluntary habitat restoration projects (if DSTW creation would involve less than 50 cubic yards of removal-fill volume) or a General Authorization (if DSTW would involve more than 50 cubic yards)[19]

Implementation Timeline and Estimated Costs

The anticipated timeline for implementing the conceptual design for a DSTW pilot project spans approximately 3 years (Figure 3.14). Estimated costs for a pilot project are presented in Table 3.4.

TABLE 3.4 - ESTIMATED COSTS FOR PILOT STUDY INCLUDING SIX APPROXIMATELY 1-ACRE DSTW PILOT SITES

Final site selection[20]	$10 - 15K
Permitting and water rights[21]	$20 - 30K
Sites construction[22]	$60 - 75K
Sites operation for 5 years[23]	$9 - 10K
Monitoring[24]	$120 - 130K
Total	**$230 - 270K**

19 A permit from the U.S. Army Corps of Engineers (USACE) would only be necessary if a DSTW project is connected to a navigable water, which is not anticipated.
20 Includes landowner coordination, 1-2 site visits per site, and $10-12K for soil sampling and analytical determination of soil capacity to bind or adsorb phosphorus.
21 Assumes only partial or no water rights transfers needed and standard exemptions for state lands permits apply for all sites.
22 Cost estimate includes site survey, diversion box, level control, minimal earthwork, planting, and exclusion fencing for each site.
23 Assumes $300/acre/year for operation and maintenance at each site.
24 Includes field data collection and laboratory analysis cost estimates across all sites. No reporting costs included.

LARGE WETLANDS

Workshop recommendations related to rehabilitation of large wetlands surrounding Upper Klamath Lake and along the Keno Impoundment were generally supportive, since wetlands would provide water treatment as well as fish and wildlife habitat, with a relatively low degree of infrastructure challenges and energy use. In addition, workshop participants ranked wetland rehabilitation as having a high degree of synergy with other restoration projects and technologies being considered in the Klamath Basin, with a particular emphasis on rehabilitation of habitat for the endangered shortnose and Lost River suckers (Section 2, pages 19-20). This section describes conceptual pilot studies for large wetland rehabilitation projects at three locations in the Upper Klamath Basin: on the margins of Upper Klamath and Agency lakes, along the Keno Impoundment, and along the Klamath Straits Drain. The level of detail presented for each conceptual design is a reflection of the amount of readily available information for the three considered locations.

OBJECTIVE - To evaluate the potential for large-scale removal of nutrients and habitat rehabilitation using large (10s to 1,000s of acres) wetlands in the Upper Klamath Basin in order to decrease external loading of phosphorus and nitrogen to downstream water bodies, decrease nuisance algal blooms, increase general water quality (i.e., dissolved oxygen), and provide habitat for the endangered shortnose and Lost River suckers.

EXISTING WETLANDS

Existing large wetland rehabilitation projects along the Upper Klamath Lake and Agency Lake shorelines, such as the Wood River Wetland (Figure 3.15) and the Williamson River Delta (Figure 3.16) are generally managed for water storage, subsidence reversal and/or wildlife habitat (Table 2.1 and Figure 2.6). Water quality improvement is a secondary, albeit important, management goal, with recent data indicating that nutrient retention is occurring at the Wood River Wetland,[25] the Williamson River Delta,[26] and the Upper Klamath Lake National Wildlife Refuge. The Fourmile Canal property, just under 1,900 acres in size, is located along the northern edge of Agency Lake and was recently acquired by The Nature Conservancy for the purposes of wetland restoration. Design planning for this site is currently underway. While these existing wetland systems already meet the majority (if not all) of the physical siting requirements for treatment wetlands and would not require additional land acquisition or water rights allocations, major changes to physical conditions (e.g., changes in the ratio of open water to vegetated stands, use of supplemental techniques to enhance nutrient removal) or management approaches (e.g., flood frequency, water depth) to accommodate increased water treatment efficiency may not be compatible with current habitat goals. For this reason, existing large wetland rehabilitation projects, including the Wood River Wetland, Williamson River Delta, Fourmile Canal, Upper Klamath National Wildlife Refuge, Miller Island National Wildlife Refuge, and the Lower Klamath National Wildlife Refuge, are excluded from this conceptual design until their dual habitat and water treatment values are more fully determined.

Fig. 3.15 The Wood River Wetland, post-restoration in 2011. Photo: Andy Hamilton, BLM.

Fig. 3.16 The Williamson River Delta following flooding as a restoration measure in 2012. Photo: Chauncey Anderson, USGS.

25 Hamilton 2011
26 Wong et al. 2011, Hayden and Hendrixson 2013

SUCKER HABITAT REQUIREMENTS

Shortnose and Lost River suckers utilize a variety of aquatic habitats in Upper Klamath Lake and its tributaries during different times of the year, and their habitat needs vary by life stage. Sub-adult and adult suckers seek deeper water than younger fish, generally occupying water depths of 3 feet or deeper (Figure 3.17). They are generally limited to lake habitats when not spawning, although small river-resident populations have been documented. During the months of February through May, adult suckers migrate from the deep, quiescent waters of Upper Klamath Lake into the faster flowing waters of Upper Klamath Lake tributaries to spawn. Areas with gravel bottoms are preferred spawning habitat.[27] A significant number of Lost River suckers also spawn over gravel substrates at shoreline springs along the margins of Upper Klamath Lake.[28]

From roughly April to July, larval suckers are dispersed by currents from their hatching areas to shallow (0.5-1.5 feet deep) waters along the shoreline of Upper Klamath Lake (Figure 3.18). They seek habitat in or near emergent wetland vegetation, which provides cover from predators, protection from currents and turbulence, and abundant food for the growing fish.[29] Juvenile suckers also utilize a wide variety of near-shore habitat, including emergent wetlands and non-vegetated areas as they grow and slowly migrate off-shore (Figure 3.17).

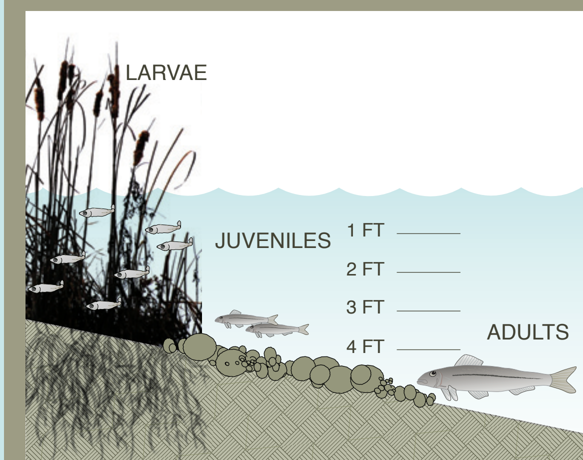


Fig. 3.17 Simplified schematic of habitat use by different sucker life stages. Source: USFWS 2008.

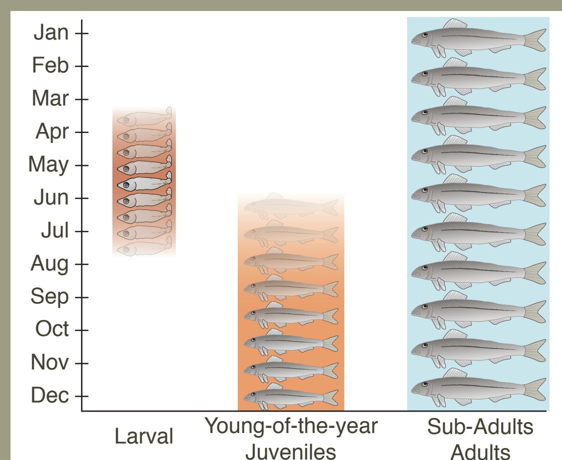


Fig. 3.18 Presence of sucker critical lifestages in Upper Klamath Lake by month. Larval and first year young-of-the-year juveniles are only present during certain months. Source: USFWS 2008.

27 USFWS 2008
28 USFWS 2011
29 USFWS 2008

Wetlands on the Margin of Upper Klamath and Agency Lakes

Site Characteristics

The target area for large wetlands in the Upper Klamath Basin is located along the shores of Upper Klamath and Agency lakes. The target area was chosen for the following reasons:

- Several large parcels of land in the target area are previously drained wetlands[30] that possess hydrology and soils characteristics of these ecosystems. In the long term, the reconnection of these wetlands to the lake would provide rehabilitated habitat for larval and juvenile suckers,[31] as well as peat accumulation and nutrient accumulation.[32]

- Several parcels in the target area currently possess surface water diversions for irrigation use and given landowner willingness, these sites may be eligible for water rights transfer to wetland use during the irrigation season.

The proposed pilot site is located along the west shoreline of Agency Lake near the mouth of Sevenmile Canal and the Wood River (additional site description is provided on page 66).

The location of the Agency Lake Ranch and Barnes Ranch parcels near the mouth of the Wood River and along the Agency Lake shoreline offers the potential for rehabilitation of larval and juvenile sucker rearing habitat during spring and summer months (see text

30 Wood et al. 2009
31 USFWS 2008
32 Lindenberg and Wood 2009

box on page 52), as well as refuge habitat for adult and subadult suckers to avoid extreme poor water quality in Upper Klamath Lake during July through September.[33] Agency Lake Ranch and Barnes Ranch are also included in the conceptual design for targeted dredging of Upper Klamath Lake sediments (Section 3, pages 65-71), whereby the parcels would receive dredged lake sediments to increase the elevation of subsided areas for habitat improvement and for levee maintenance.

Pilot Project Conceptual Design

Pre-project Surveys

Prior to wetland construction, review of existing bathymetric and LiDAR data, existing inlet and outlet structures, agricultural canals/ditches, and associated berms/levees for the Agency Lake Ranch and Barnes Ranch parcels would be conducted to ensure that conceptual habitat and water treatment design elements can be supported.

Additionally, as described for the DSTWs, site-specific soil testing would be conducted to determine the potential need for soil amendments or LICD (see text box on page 49) to increase the efficiency of phosphorus removal. If an increase in phosphorus removal efficiency is warranted, then the conceptual design would be adjusted to include design features such as an equalization basin and/or a coagulant dosing area prior to the treatment cell inflow. The cost of the enhanced phosphorus removal design would be balanced against the cost per mass of phosphorus removed. Additionally, testing would be included to determine the potential for soil expansion upon re-wetting and, if warranted, account for an adjusted soil volume in the final design of wetland terraces/slopes.

TABLE 3.5 - WETLAND ZONES FOR A TERRACED/SLOPED WETLAND REHABILITATION CONCEPTUAL DESIGN ON THE MARGINS OF UPPER KLAMATH AND AGENCY LAKES

TERRACED/ SLOPED WETLAND ZONE	SUCKER LIFESTAGE SUPPORTED	WATER TREATMENT POTENTIAL	AVERAGE WATER DEPTH (FT)	PERCENT OF TOTAL WETLAND AREA	VEGETATION TYPE/ SUBSTRATE
Zone 1	Larvae	High	0.5	10%	Emergent aquatic (e.g., bulrush, cattail), fine sediment
Zone 2	Larvae, juveniles		1.5	10%	Emergent aquatic (e.g., bulrush, cattail), fine sediment to small gravel
Zone 3	Juveniles		2.5	20%	Emergent aquatic (e.g., bulrush, cattail), small gravel
Zone 4	Subadults, adults	Moderate	3.5	30%	None, small gravel to fine sediment
Zone 5	Subadults, adults	Low	>3.5	30%	

Design Elements

Terraced or gradually sloped wetlands can be an efficient way to meet the dual objectives of water treatment and habitat improvement for shortnose and Lost River suckers, given that different life stages require particular water depths and vegetation cover (Figure 3.17). Maximum water treatment efficiency in wetlands typically occurs at 2-2.5 ft water depth, which supports dense growth of emergent aquatic vegetation such as cattail and bulrush and overlaps with known habitat needs for juvenile suckers.

In order to maximize habitat availability and treatment efficiency in the rehabilitated wetland, re-contouring of the sediment surface would be undertaken to create terraced or gradually sloped zones, each with a different design water depth (Table 3.5). It is anticipated that some degree of sediment augmentation would be required to support differing water depths, which is primarily due to the amount of subsidence that has occurred at many parcels surrounding Upper Klamath and Agency lakes, including at the pilot site. The conceptual design assumes an average subsidance depth of 3-4 feet across the entire pilot site, which would need to be confirmed through review of existing bathymetric and LiDAR data. Currently, lake levels vary by 3-5 feet annually, with the highest levels in April/May and the lowest levels in October/November.[34] Larval suckers tend to move into shoreline rearing habitat from April through July (see text box on page

33 USFWS 2011

34 USFWS 2008

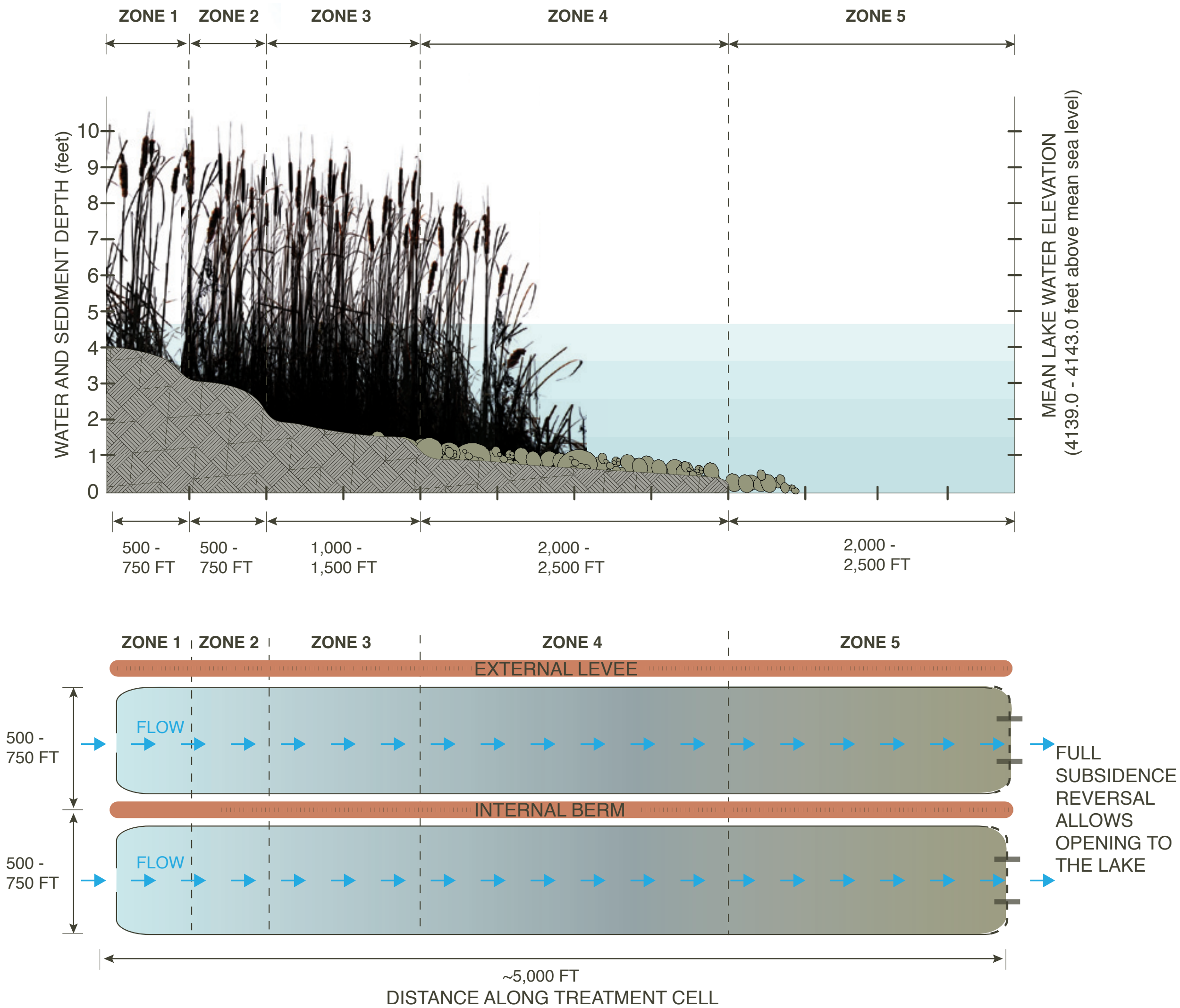


Fig. 3.19 Phase I conceptual design for terraced/sloped wetland rehabilitation along the perimeter of Upper Klamath Lake.

52), coinciding with the period when lake levels are relatively high. Thus, final maximum water depths for the wetland would be tied to mean lake water surface elevations during April through July (4,141 to 4,143 feet)[35] (Figure 3.19). The final design would also need to consider the effects of above normal, below normal, dry, and critically dry water year types on habitat and treatment capacity.

Sediment augmentation for terraced or sloped surfaces would utilize dredged sediments from Upper Klamath Lake (see Section 3, pages 65-71) or another suitable source. Sediment augmentation could be undertaken to fully reverse subsidence such that the augmented sediment depth for wetland Zone 1 would be 4-5 ft, and for Zones 2 through 4 it would be 1 to 2.5 ft (Figure 3.19). Under this scenario, the external levees for the parcels could be breached early in the project, to allow the rehabilitated wetland area to be reconnected with Upper Klamath/Agency Lake almost immediately.

However, due to the relatively high cost of sediment dredging and/or sediment placement, particularly for a site as large as Agency Lake Ranch/Barnes Ranch (~10,000 acres), partial subsidence reversal, which minimizes sediment requirements for building terraces or slopes, may be a more likely scenario. Partial subsidence reversal would involve a lower level of initial sediment augmentation followed by several decades of natural peat accumulation. The conceptual design assumes a rate of peat accumulation of 0.2 inches per year in the vegetated treatment cells. This rate represents an average of several measurements from undrained wetlands around Upper Klamath

35 USFWS 2011

TABLE 3.6 - CONCEPTUAL ESTIMATES OF NUTRIENT REMOVAL POTENTIAL FOR A 1,000-1,200-ACRE TERRACED/SLOPED PILOT TREATMENT AND HABITAT WETLAND ON THE MARGINS OF UPPER KLAMATH AND AGENCY LAKES

ESTIMATED NUTRIENT CONCENTRATIONS AND REMOVAL POTENTIAL	TREAT ALL OF SEVENMILE CREEK FLOW (115 CFS)[36]	TREAT ROUGHLY 40% OF SEVENMILE CREEK FLOW (45 CFS)
Concentration nitrate entering wetland (mg/L)[37]	0.6	0.6
Concentration nitrate leaving wetland (mg/L)[38]	0.2	0.06
Estimated nitrate removal	50 - 55%	80 - 85%[39]
Concentration total phosphorus entering wetland (mg/L)[37]	0.2	0.2
Concentration total phosphorus leaving wetland (mg/L)[40]	0.15	0.06
Estimated phosphorus removal	40 - 45%	65 - 70%[39]

36 Annual mean flow at "7 Mile" Dike Station for water years 2002-2010 (from Figure D5 in Walker et al. 2012).
37 Assumes annual mean concentration at "7 Mile" Dike Station for water years 2002-2010 (from Figure D5 in Walker et al. 2012). Mean concentrations at upstream locations along Sevenmile Creek/Canal can be an order of magnitude lower (Walker et al. 2012; Rick Carlson, personal communication, 2013), resulting in lower annual mean percent removal estimates (35-65%) if water from upstream locations were diverted directly into a wetland.
38 See Appendix B for detailed calculations and assumptions.
39 Removal efficiency increases in the wetland due to increased hydraulic residence time at a lower flow.
40 See Appendix B for detailed calculations and assumptions.

Lake.[41] In order to support design water depths, partial subsidence reversal would require that existing external levees remain in place until peat accumulation in the wetland has sufficiently raised the land surface. Access points for suckers along the external levees, particularly those nearest to spawning habitats, would be required for the partial subsidence reversal scenario.

As an additional cost consideration, the relative amount of wetland area in treatment cells requiring sediment augmentation would be balanced against the higher treatment potential and habitat value of these zones. Thus, the conceptual design assigns 70% of the wetland area in Zones 1-4, which support high to moderate water treatment potential, and 30% of wetland area in Zone 5, which is primarily habitat for subadult/adult suckers due to deeper waters and lack of emergent vegetation (Table 3.5).

Several possibilities for wetland cell configuration at sites along the margins of Upper Klamath and Agency lakes would support the dual water treatment and sucker habitat goals. Costs of the different cell configurations would vary, depending on the level of sediment augmentation and internal berm construction needed to support consistent flow paths and desired treatment levels. Surface information gathered during the pre-project data review would be used to select the most appropriate cell configuration for the project. Estimated nitrogen (nitrate) and phosphorus (total phosphorus) removal in the terraced/sloped wetlands would range from 50-85% and 40-70%, respectively, depending on inflowing nutrient concentrations and how much of the Sevenmile Creek flow is diverted into the wetlands (Table 3.6).

41 Graham et al. 2005, Aldous 2013

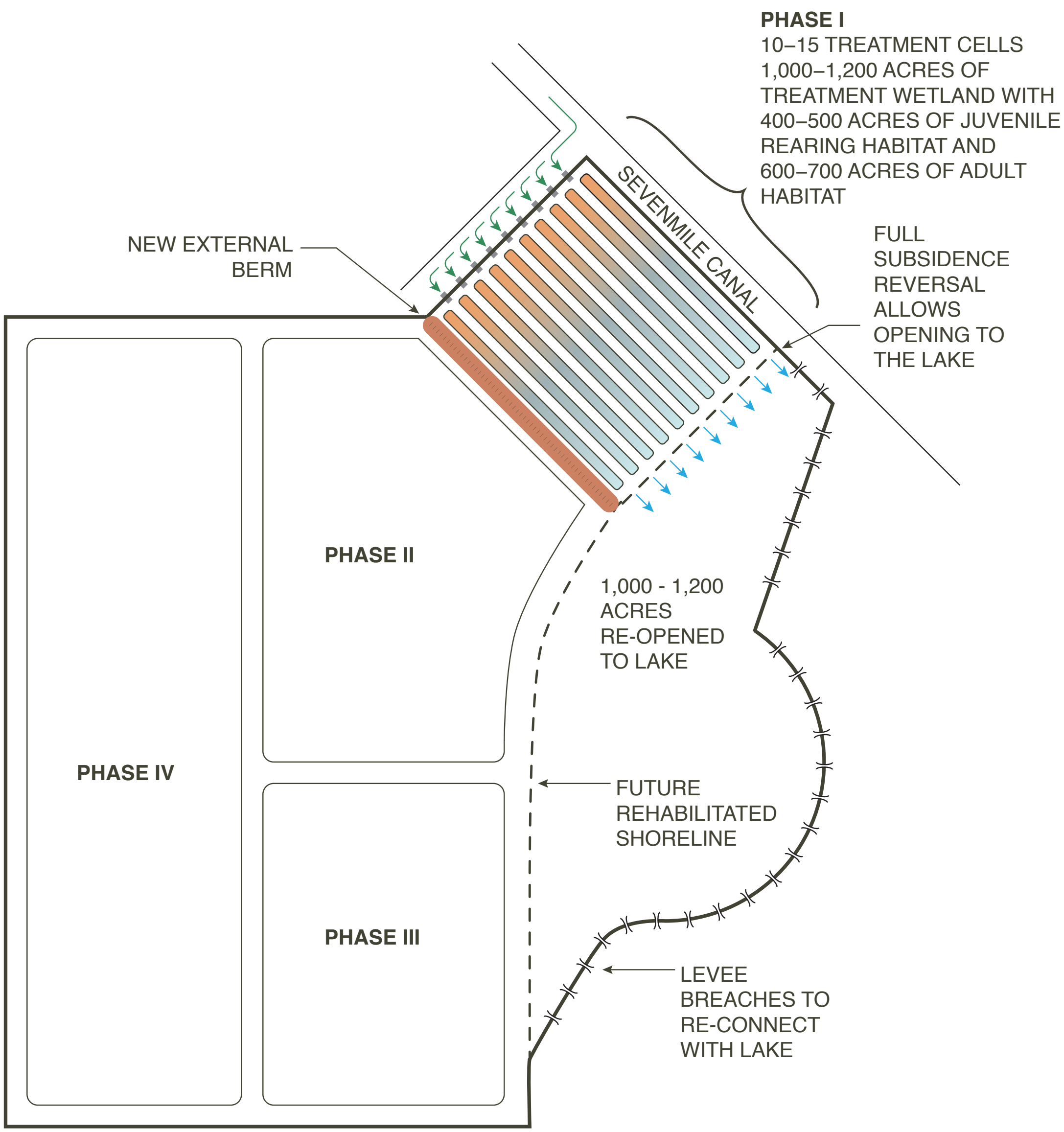


Fig. 3.20 Conceptual design for phased wetland rehabilitation along the perimeter of Upper Klamath/Agency Lake. Drawing not to scale. Phase I cell configuration is one possibility for supporting water treatment and habitat goals.

Phased Implementation

The pilot project conceptual design makes use of a phased approach to constructing dual water treatment and habitat cells throughout the large area (9,830 acres) of the Agency Lake/Barnes Ranch parcels. During Phase I, 1,000 to 1,200 acres of subsided land nearest the mouth of the Sevenmile Canal would serve as a pilot site for wetland rehabilitation. Phase I would also involve levee breaches to re-connect an approximately equal area to Agency Lake and construction of a new external levee along a future re-oriented shoreline (Figures 3.19 and 3.20). Lastly, Phase I would include an investigation of the most effective interim uses of the remaining 7,400-7,800 acres at the Agency Lake/Barnes Ranch parcels that would not be immediately rehabilitated as wetland cells or areas re-connected to Agency Lake (see text box on page 57). During Phases II to IV, additional acreage adjacent to the pilot site would be rehabilitated, starting with roughly 1,800 acres of subsided lands directly west of the pilot site (Figure 3.20). The amount of acreage ultimately rehabilitated to dual water treatment and sucker habitat cells would be dependent on the success of interim land uses and adaptive management.

Wetlands Along Lake Ewauna, the Keno Impoundment and the Klamath Straits Drain

Site Characteristics

Smaller Upstream Wetlands

Wetlands located at the upstream end of the Keno Impoundment would be relatively small (10s of acres) due to limited land and water rights availability

ASSESSMENT OF INTERIM LAND USES

As part of Phase I, the following potential interim land uses would be considered and developed as proof-of-concept projects at the Agency Lake/Barnes Ranch parcels. Depending on the project results, one or more of the interim land uses would be selected for implementation during Phases II through IV.

Nutrient Harvest and Export – Growing crops can remove nutrients from agricultural soils because nutrients incorporated into plant material during growth are exported from the field when the crop is harvested and transported off-site. Nutrient uptake and export rates vary and are specific to crop type, as well as local soil and climate conditions and degree of fertilization. In general, forage crops such as alfalfa, clover, and vetch exhibit relatively high phosphorus and nitrogen export rates, followed by field crops such as cotton, corn, and peanuts. Vegetable crops, such as potatoes and tomatoes, tend to exhibit the lowest rates of nutrient export (IPNI). Of the agricultural crops typically grown in the Upper Klamath Basin (i.e., hay, wheat, alfalfa, potatoes), alfalfa may have the greatest potential for nutrient export given its published values (12 lbs phosphorus per ton on a dry weight basis).[42]

Phase I would involve the development of a study plan for using small (1-2 acre) experimental plots to test the phosphorus export capacity of 2-3 kinds of locally grown crops in the Upper Klamath Basin, as well as one or more new crop types that could be readily grown for increased phosphorus export. The study would evaluate the amount of water that would need to be pumped off the fields to facilitate growing crops, because such pumping could also export phosphorus to Upper Klamath Lake and negate the benefit of crop uptake.

Flooding and Wetland Rehabilitation – Wetland rehabilitation via direct reconnection to Upper Klamath Lake hydrology (i.e., flooding) has recently been undertaken at the Williamson River Delta (see also Figure 3.28). Phase I would involve an investigation of the potential for long-term rehabilitation of lake hydrology and wetland function in a portion of the Agency Lake/Barnes Ranch parcels not slated for immediate transfer to treatment wetland/sucker habitat cells.

Flooding as a means for wetland rehabilitation would require monitoring of phosphorus release from flooded soils following reconnection with Upper Klamath Lake.

Fig. 3.21 The "Walking Wetland" cycle. (Below, from left) First year after flooding; second year after flooding; third year after flooding; first year following wetland cycle. Photo: USFWS.

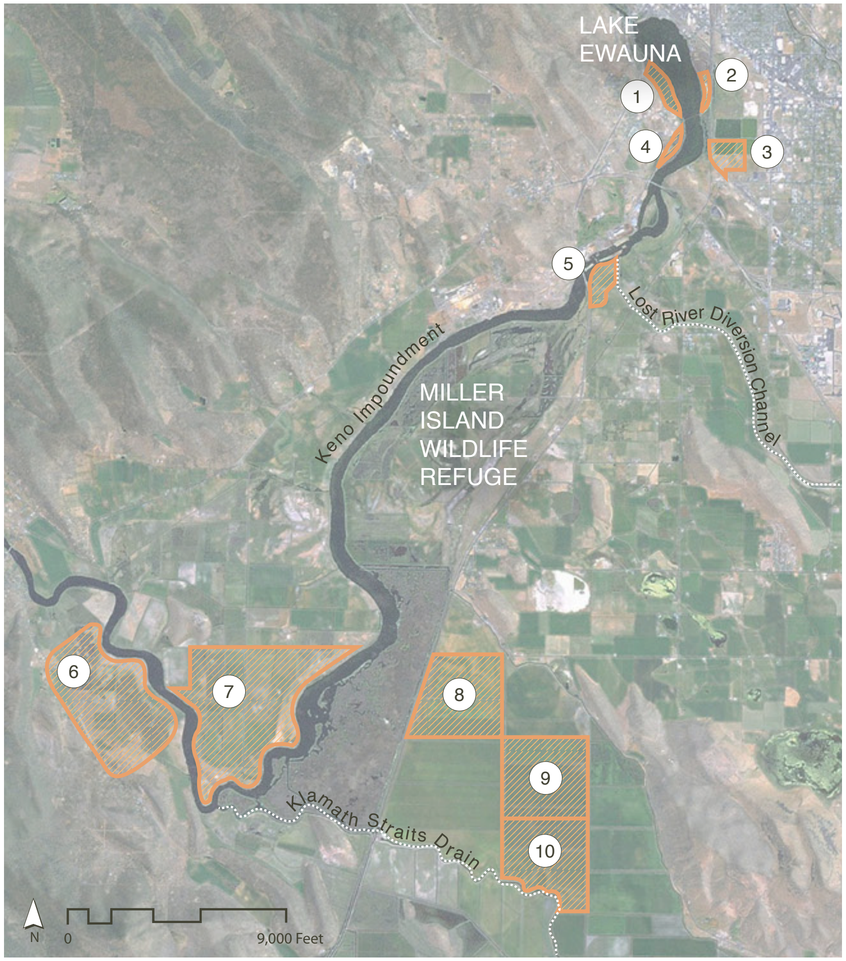
42 International Plant Nutritional Institute (http://www.ipni.net/)

Recent data collected at the Williamson River Delta indicate that the initial pulse of phosphorus from flooded soils was far less than anticipated (2.5 tons released versus the 64 tons predicted) and seasonally averaged total phosphorus concentrations became progressively more stable and lower over the five year monitoring period.[43] As with DSTWs, site-specific soil testing would be conducted to determine the potential need for soil amendments or LICD (see text box on page 49) to increase the efficiency of phosphorus removal under a flooding scenario.

Walking Wetlands – The USFWS' Walking Wetlands program is currently in use in the Lower Klamath National Wildlife Refuge and involves rotating areas of agricultural production with areas of marsh or treatment wetlands on refuge lands. Program proponents indicate that higher crop yields are maintained in farmed areas with lower inputs of fertilizers and pesticides and at the same time, high-quality wetlands are available for wildlife. While the two land uses (i.e., agricultural and wildlife habitat) are traded, such that the net habitat area remains the same at any given point, the decrease in use of fertilizers and pesticides in the watershed is likely an overall benefit to water quality. The use of Walking Wetlands would combine habitat benefits from partial flooding and wetland rehabilitation approach with phosphorus export benefits from nutrient harvest and export approach.

Phase I would involve an investigation of the potential for the use of Walking Wetlands in a portion of the Agency Lake/Barnes Ranch parcels not slated for immediate transfer to treatment wetland/sucker habitat cells or re-connection to Agency Lake.

43 Wong et al. 2010, Hayden and Hendrixson 2013



SITE 1 (Mahugh et al. 2009)
- 63 acres
- Some water conveyance structures (no pumps)
- Road access
- Configured favorably for linear treatment cells
- Supports wetland soils and plants
- Water rights unknown

SITE 2 (Mahugh et al. 2009)
- 30 acres
- Some water conveyance structures (no pumps)
- Road access
- Supports wetland soils and plants
- Existing slough habitat

SITE 3 (Mahugh et al. 2009)
- 100 acres
- Ownership and water rights unknown

SITE 4 (Mahugh et al. 2009)
- 32.5 acres
- Road access
- Supports wetland soils and plants
- Water rights unknown

SITE 5 (Mahugh et al. 2009)
- 54 acres
- No water control structures or pumps
- Existing surface water right for irrigation
- Adjacent to Lost River Diversion Channel

SITE 6 (Lyon et al. 2009)
- 600 acres
- Water conveyance structures
- Wetland soils
- Existing primary surface water right for irrigation use

SITE 7 (Mahugh et al. 2009)
- 1,300 acres
- 11 individual parcels
- Water conveyance structures
- Road access
- Supports wetland soils and plants
- Portions of the site possess existing surface water diversion for irrigation use from March through October, while other portions are pending adjudication

SITES 8 - 10 (Mahugh et al. 2009)
- Total ~1,800 acres
- Close proximity to the Keno Impoundment
- Existing primary surface water rights for irrigation use
- If used for treating Klamath Straits Drain, possible augmentation of winter and/or spring flows to avoid seasonal periods of drying and soil oxidation

Fig. 3.22 Ten potential wetland locations along Lake Ewauna and the Keno Impoundment.

in the vicinity of Link River Dam and Lake Ewauna.[44] Placement of wetlands near Lake Ewauna and the upstream end of the Keno Impoundment is desirable because the number of suckers tends to be relatively greater than elsewhere in the reach.[45] Additionally, placement of wetlands upstream in the reach could improve water quality downstream and provide increased habitat for suckers.

Target sites include five parcels identified in a prior study of potential treatment wetland locations along Lake Ewauna and the Keno Impoundment (sites 1-5 in Figure 3.22). For the pilot project, one of the five parcels would be selected to test conceptual design elements for the smaller upstream wetland systems.

Larger Downstream Wetlands

Potential treatment wetland sites on larger parcels (100s to 1,000s of acres) in the middle and towards the downstream end of the Keno Impoundment and the downstream end of the Klamath Straits Drain were

44 The floodplain area between Link River Dam and Miller Island is relatively narrow, parcels are relatively small (<100 acres), and there are few existing individual water rights for surface diversion.

45 Terwilliger et al. 2004, Kyger and Wilkens 2011

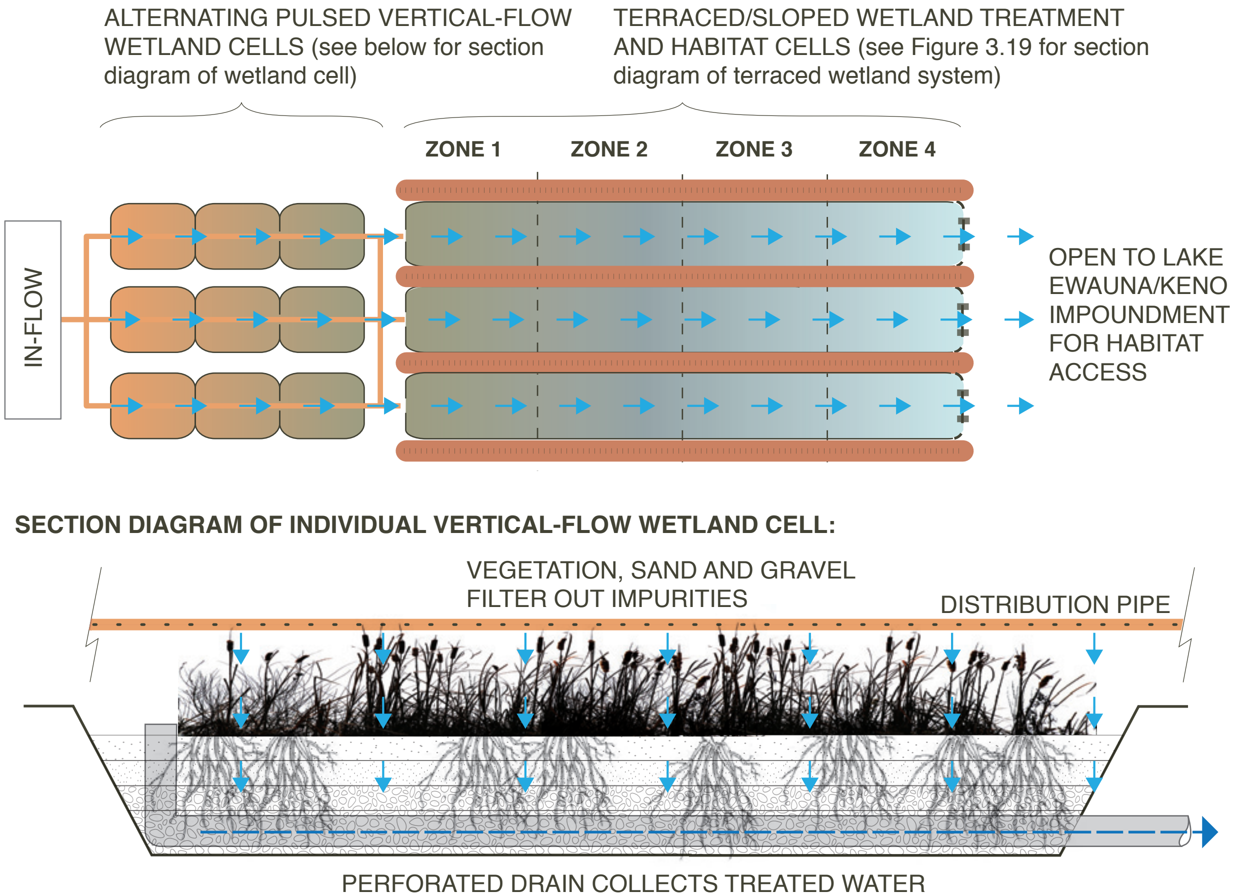


Fig. 3.23 Conceptual design for small hybrid treatment wetlands along Lake Ewauna.

identified in prior studies.[46] Recent modeling shows that routing Klamath River flow through large (1,400 to 2,950-acre) treatment wetlands located between Miller Island and the Klamath Straits Drain would improve summertime water quality. The wetlands would filter and remove biochemical oxygen demand (BOD) and algal particulate organic matter originating primarily from Upper Klamath Lake and would increase dissolved oxygen and decrease ammonia and orthophosphorus in Keno Impoundment downstream of the wetlands. Whether the water-quality standard can be met (and thereby support fish habitat) using this approach is still a matter for more research; preliminary model results indicate that treatment wetlands may need to remove 50 to 90% of BOD and algal particulate organic matter. Treatment of Klamath Straits Drain flows prior to discharge into the Keno Impoundment would also improve water quality in the reservoir itself.

46 Mahugh et al. 2009, Lyon et al. 2009

Target sites include five parcels identified in a prior study of potential treatment wetland locations along Lake Ewauna and the Keno Impoundment, and the downstream end of the Klamath Straits Drain (sites 6-10 in Figure 3.22). For the pilot project, one of the five parcels would be selected to test conceptual design elements for the larger downstream wetland systems.

Pilot Project Conceptual Design

Pre-project Surveys

Prior to wetland construction, review of existing bathymetric and LiDAR data, existing inlet and outlet structures, agricultural canals/ditches, and associated berms/levees would be conducted to ensure that conceptual habitat and water treatment design elements can be supported.

Design Elements

Smaller Upstream Wetlands - Given the very high organic loads in Lake Ewauna and the upstream end of the Keno Impoundment during the summer and early fall (see Figure 1.11), wetlands located along Lake Ewauna and the upstream end of the Keno Impoundment would be designed to filter high concentrations of suspended solids and allow rapid oxidation of the filtered biomass. The inlet portion of each wetland would be designed as a high-efficiency vertical flow cell, where water would be distributed across the surface of a gravel bed planted with native vegetation and percolate through the plant root zone.[47] A similar

47 Kadlec and Wallace 2009

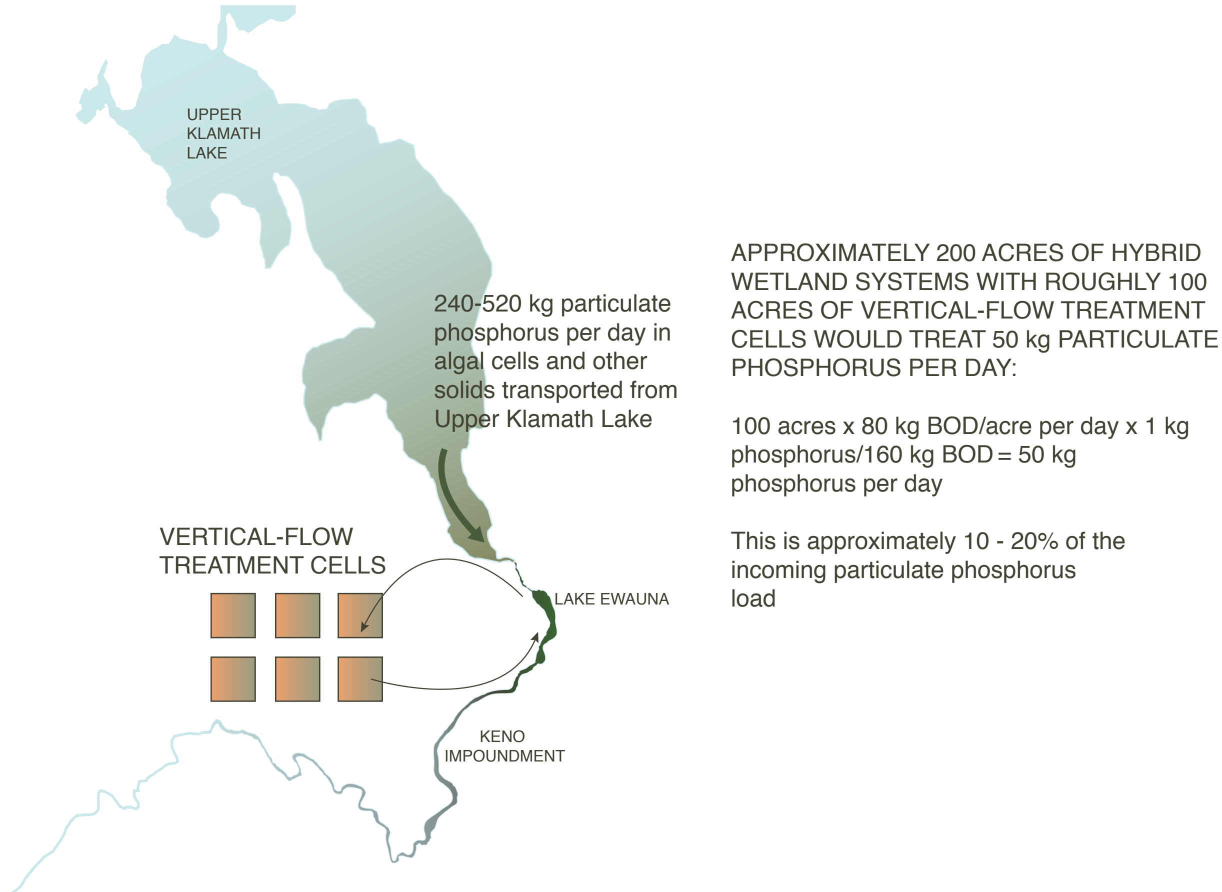


Fig. 3.24 Multiple hybrid vertical flow and terraced/sloped wetland treatment and habitat systems would be required to treat particulate phosphorus loading from Upper Klamath Lake.

type of system, called an infiltration-based vegetated swale system, was presented as a conceptual project type for areas adjacent to Copco and Iron Gate reservoirs in the Hydroelectric Reach, in order to remove algae from accumulations at reservoir cove sites.[48] To avoid clogging of the gravel matrix with biomass and to promote oxygenated pore spaces to support rapid decomposition of algal cells, the vertical flow cells alongside Lake Ewauna and the Keno Impoundment would operate as pulse-flow systems, with intermittent wetting and drying cycles (Figure 3.23). The number of daily pulse cycles would be seasonally dependent and would be optimized as part of the pilot study.

While vertical flow wetland cells are efficient at treating ammonia and total nitrogen, they do not treat

48 Lyon et al. 2009

TABLE 3.7 - ESTIMATED AREA OF VERTICAL-FLOW WETLAND TREATMENT CELLS, LAKE EWAUNA AND THE UPPER KENO IMPOUNDMENT

	JUNE - OCTOBER[49]
Average oxygen demand in outflow from Upper Klamath Lake (mg/L)[50]	15
Daily average flow at the Link River USGS gage WY1991-2010 (cfs)[51]	790-1,400
Area of vertical flow wetland treatment cells required to treat all of the Link River flow (acres)[52]	360-630
Area available for small wetlands around Lake Ewauna and the Upper Keno Impoundment (acres)[53]	200
Ratio of area in vertical flow wetland treatment cells to area in surface flow wetland cells	50/50
Area available for vertical flow wetland cells (acres)	100
% of daily oxygen demand treated by vertical flow wetland cells	15-30%

49 As conceptual design estimates, the values below are reported to 1-2 significant figures.
50 Includes biochemical oxygen demand (BOD5) + nitrogeneous BOD (NBOD5). Summertime Link River estimates from Table 4 in Sullivan et al. (2011). Samples collected in August to early Sept (2006), late June to early Sept (2007), July to August (2008).
51 Data from USGS gage no. 11507500 for water years 1991-2010. Flows do not include contributions from Westside Canal.
52 Assumes a rate of 20 grams of biochemical oxygen demand (BOD) per m^2 per day based on the range of 10–40 $g/m^2/d$ reported in Crites and Tchobanoglous (1998), as cited by Kadlec and Wallace (2009), page 734. Most vertical flow wetland designs use a rate less than 25 $g/m^2/d$.
53 Assumes 30% of the available land area would be used for berms, roads, and other infrastructure.

nitrate, nor do they provide aquatic habitat. Thus, the vertical wetland cells would discharge to free-water surface wetland cells that would function much as Zones 1-3 in the conceptual design for the Agency Lake Ranch and Barnes Ranch parcels (Figure 3.23). The free-surface water cells would provide nitrate removal and habitat for juvenile suckers.

Based on the relatively high efficiency of hybrid wetland systems, it is anticipated that the approximately 200 acres of land potentially suitable for creation of wetlands along Lake Ewauna and the upper portion of the Keno Impoundment (Figure 3.24) would be capable of removing 10-20% of the oxygen demand created by algal blooms transported from Upper Klamath Lake (Table 3.7).

The pilot study would test important removal assumptions about the amount of algal material and particulate phosphorus that can be applied to the vertical flow wetland treatment cells, gravel size, pulsing rates, and whether recirculation of water is needed for optimal treatment.

Larger Downstream Wetlands - Further downstream in the Keno Impoundment, generally larger parcels allow for increased hydraulic residence time for wetlands and may negate the need for high efficiency filtration and oxidation of suspended solids in the smaller parcels surrounding Lake Ewauna. However, organic matter and phosphorus loads can still be relatively high during the summer and early fall in downstream reaches of the Keno Impoundment (see Figure 1.11). Wetlands located along the middle and lower reaches of the Keno Impoundment are also likely to benefit from design features that enhance water treatment under these conditions, such as hybrid systems with pre-filtration vertical flow wetland cells.

Relative to water in the Keno Impoundment, water leaving the Klamath Straits Drain (KSD) has lower total suspended solids, higher total and dissolved phosphorus, and higher dissolved organic carbon.[54] Based on this mixture of water quality constituents, it is anticipated that treatment in the KSD would likely benefit from a LICD system to improve the efficiency of phosphorus and dissolved organic carbon (DOC) removal in the wetland. Since potentially available parcels near the downstream end of the drain are also located along the Keno Impoundment (Figure 3.22), a wetland system that is designed to treat flows from both the Klamath Straits Drain and the Keno Impoundment may be the best opportunity to provide flexible water treatment in this location. The US Bureau of Reclamation is currently working on potential KSD recirculation projects that could change the amount and timing of flow and nutrients leaving the drain.[55] Further development of a pilot treatment wetland project in this location would require coordination with the US Bureau of Reclamation regarding future management of flows in the KSD.

Environmental, Regulatory and Permitting Requirements

The following permits would be required for a pilot "large wetland" project:

- Water rights transfer through Oregon Division of Water Rights, as needed
- Water Quality Certification from Oregon Department of Environmental Quality (ODEQ)
- General Authorization or Individual Permit from the Oregon Department of State Lands
- Permit from the U.S. Army Corps of Engineers (USACE) if the wetland project is connected to a navigable waterway. USACE consults with the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) on endangered species concerns.

Monitoring

Since monitoring programs for small and large wetland rehabilitation projects are dependent on specific design criteria, including total area, design flows, and treatment cell configuration, the conceptual-level monitoring program (Table 3.8) would necessarily be adjusted based on the final design for wetlands located along the margins of Upper Klamath and Agency lakes, Lake Ewauna, the Keno Impoundment and/or the Klamath Straits Drain. Specific monitoring associated with sediment augmentation in wetland rehabilitation projects along Upper Klamath and Agency lakes is presented in Section 3 Sediment Removal (Dredging) (pages 65-71).

Wetland nutrient removal performance would be calculated using inflow and outflow quantity and nutrient concentrations. If LICD is incorporated into the pilot project wetland designs, concentrations of the coagulant of choice would also be measured at the inlet and outlet of the wetland along with the other water quality parameters.

54 Appendix C, Figure C-35, in Stillwater Sciences et al. 2012
55 Rick Carlson, personal communication, 2013.

TABLE 3.8 - ANTICIPATED MONITORING ELEMENTS FOR A WETLAND REHABILITATION CONCEPTUAL DESIGN ALONG THE MARGINS OF UPPER KLAMATH AND AGENCY LAKES, LAKE EWAUNA, THE KENO IMPOUNDMENT, AND THE KLAMATH STRAITS DRAIN

PARAMETER	SAMPLING STRATEGY	SAMPLING FREQUENCY
Inflow/outflow	In each treatment cell	• Continuously during April through October • Monthly November through March
Evapotranspiration	Representative number of treatment cells and zones	Monthly
• **Water temperature** • **Conductivity** • **Dissolved oxygen** • **pH** • **Oxidation-reduction potential**	In each treatment cell	• Bi-weekly during April through October, with 2-3 continuous 48-hr monitoring events • Monthly November through March
• **Total suspended solids** • **Nitrogen (total, nitrate, and ammonium)** • **Phosphorus (total and ortho-phosphorus)**	In each treatment cell	• Bi-weekly during April through October[56] • Monthly November through March
Vegetation cover and species distribution	Representative number of treatment cells and zones	Quarterly
Abundance/ distribution of sucker life stages[57]	Representative number of treatment cells and zones	May, September, December

56 Some periods, such as first flush, may require more frequent monitoring.
57 Assumes 30% of the available land area would be used for berms, roads, and other infrastructure.

Implementation Timeline and Estimated Costs

The anticipated timeline for implementing one or more of the large wetland conceptual designs spans approximately 5-7 years depending on the duration of site operation for each pilot study (Figure 3.25).

Anticipated costs for the conceptual design of rehabilitated wetlands along Upper Klamath and Agency lakes include some degree of subsidence reversal in order to support both nutrient removal and sucker habitat in the short-term and a phased implementation with investigation of interim land uses (Table 3.9). Further downstream, anticipated costs for a smaller (5-10 acre) pilot project for a hybrid wetland system include testing of design elements to support vertical flow treatment cells and terraced/ sloped wetland cells supporting sucker habitat (Table 3.9).

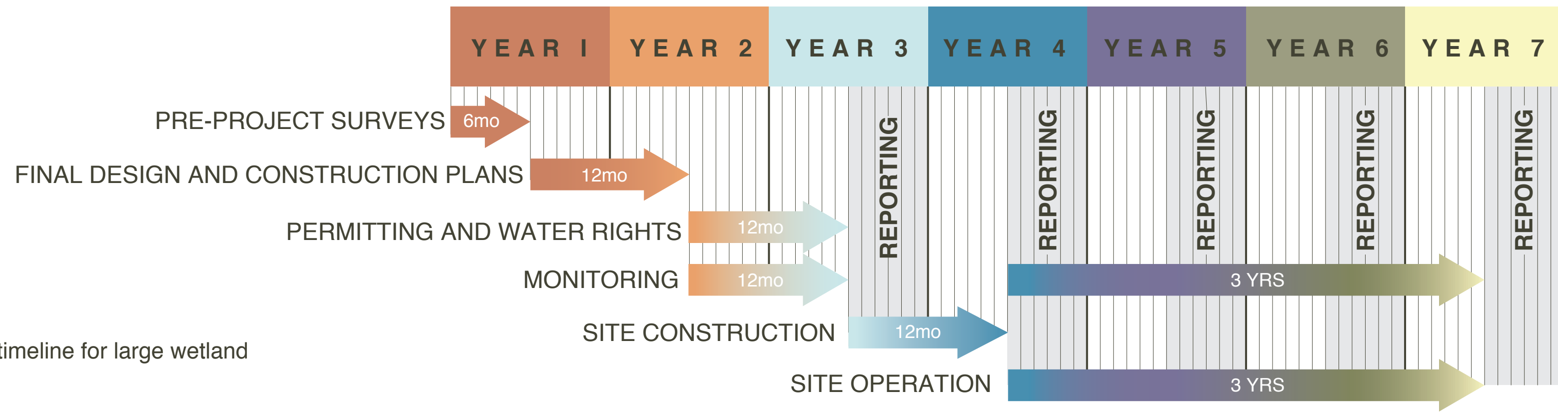


Fig. 3.25 (Right) Implementation timeline for large wetland conceptual design.

TABLE 3.9 - COST ESTIMATES FOR PILOT WETLAND REHABILITATION DESIGNS

	A TERRACED/SLOPED WETLAND REHABILITATION CONCEPTUAL DESIGN AT AGENCY LAKE RANCH/ BARNES RANCH	PILOT HYBRID WETLAND SYSTEMS FOR A 5-10 ACRE PILOT SITE ALONG LAKE EWAUNA, THE KENO IMPOUNDMENT, AND THE KLAMATH STRAITS DRAIN
Pre-project survey[58]	$5-10K	$5-7K
Final design and construction plans[59]	$50-100K	$25-50K
Permitting and water rights[60]	$20-30K	$20-30K
Site construction (sediment augmentation, earthmoving, planting)[61]	$5-20M	$50-100K
Site operation for 3 years[62]	$800-950K	$4-8K
Monitoring for 3 years[63]	$130-200K	$50-80K
Total	**$6-21M**	**$150-275K**

58 Includes review of existing data and minimal to no new surveys.
59 Assumes some degree of subsidence reversal included in design of terraced/sloped cells for Agency Lake/Barnes Ranch, plus pumping or water diversion from Sevenmile Canal.
60 Assumes partial to full water rights transfers needed for each parcel, general authorization for state lands permits applies, and the majority of potential impacts from any sediment placement to combat subsidence reversal are analyzed outside of this budget (i.e., as part of any associated dredging project).
61 Assumes $5-20K per acre, depending on the degree of sediment augmentation and number of treatment cells.
62 Assumes operation and maintenance is $260/acre/year (average value from SFWMD [2004]).
63 Includes field data collection and laboratory analysis costs based on monitoring elements presented in Table 3.8. No reporting costs included.

Fig. 3.26 Williamson River Delta Preserve. Photo: David Garden.

SEDIMENT REMOVAL (DREDGING)

Workshop recommendations related to sediment removal in Upper Klamath Lake and the Keno Impoundment were that whole-lake or whole-reservoir dredging are infeasible from a cost and sediment disposal perspective (Section 2, pages 25-26). Instead, targeted dredging of phosphorus "hotspots" in Upper Klamath Lake sediments with in-basin reuse of sediments offers the potential for water quality improvement and simultaneous reversal of subsidence in agricultural lands and wetlands adjacent to Upper Klamath Lake. Lake sediments could also be used as an agricultural soil amendment, since the sediments have elevated levels of phosphorus (Section 1, pages 8-9).

This section describes a conceptual pilot project to dredge a portion of Upper Klamath Lake just south of Goose Bay and re-deposit the sediments in adjacent areas targeted for wetland rehabilitation, as well as local agricultural areas that would benefit from subsidence reversal and soil amendment (Figure 3.28). The pilot project includes testing to determine applicable sediment properties for each of these potential uses.

OBJECTIVE - To evaluate the potential for large-scale removal of sediments in Upper Klamath Lake containing relatively high concentrations of phosphorus, thereby decreasing the potential for internal loading of phosphorus to the lake and subsequent nuisance algal blooms.

Fig. 3.27 Williamson River Delta Preserve. Photo: Rick McEwan.

SITE CHARACTERISTICS

Proposed Dredge Site

The proposed dredge site is located within a target area immediately adjacent to Goose Bay, which, along with Tulana Bay on the northwest side of the Williamson River Delta, has recently been restored to its historical status as wetlands as part of The Nature Conservancy's Williamson River Delta Restoration Project. The target area for dredging was chosen for the following reasons:

1. It is immediately downstream of the Sprague and Williamson rivers, which together contribute 44% of the external total phosphorus load to Upper Klamath Lake.[64]

2. It is characterized by relatively high phosphorus per unit area of wet sediment.[65] Under typical

64 Walker et al. 2012
65 Simon and Ingle 2011

spring and summer conditions, water from the Williamson River flows into the lake and moves clockwise along the shoreline.[66] As water velocity slows in the lake, sediments containing elevated phosphorus can be deposited in the lake bed. Recent sediment sampling results suggest that phosphorus concentrations in the dredging target area are among the highest in Upper Klamath Lake (Figure 3.28).[67,68]

3. It is located near subsided agricultural lands and wetlands currently managed for water storage, so dredged sediments could be deposited with minimal transport costs and energy use.

Proposed Deposition Sites and Uses

Reuse sites and beneficial uses of dredged sediments for the pilot project are described below.

- *Agency Lake Ranch and Barnes Ranch parcels* These two parcels are located on the west side of Agency Lake and total 9,830 acres. The parcels were historically wetlands and were converted to agricultural croplands and pasture. Following their acquisition by USBR (1998 for Agency Lake Ranch; 2006 for Barnes Ranch) the parcels were converted to pumped water storage facilities for the Klamath Project. The parcels have been turned over to the USFWS for management as part of the Upper Klamath NWR. USFWS is currently developing

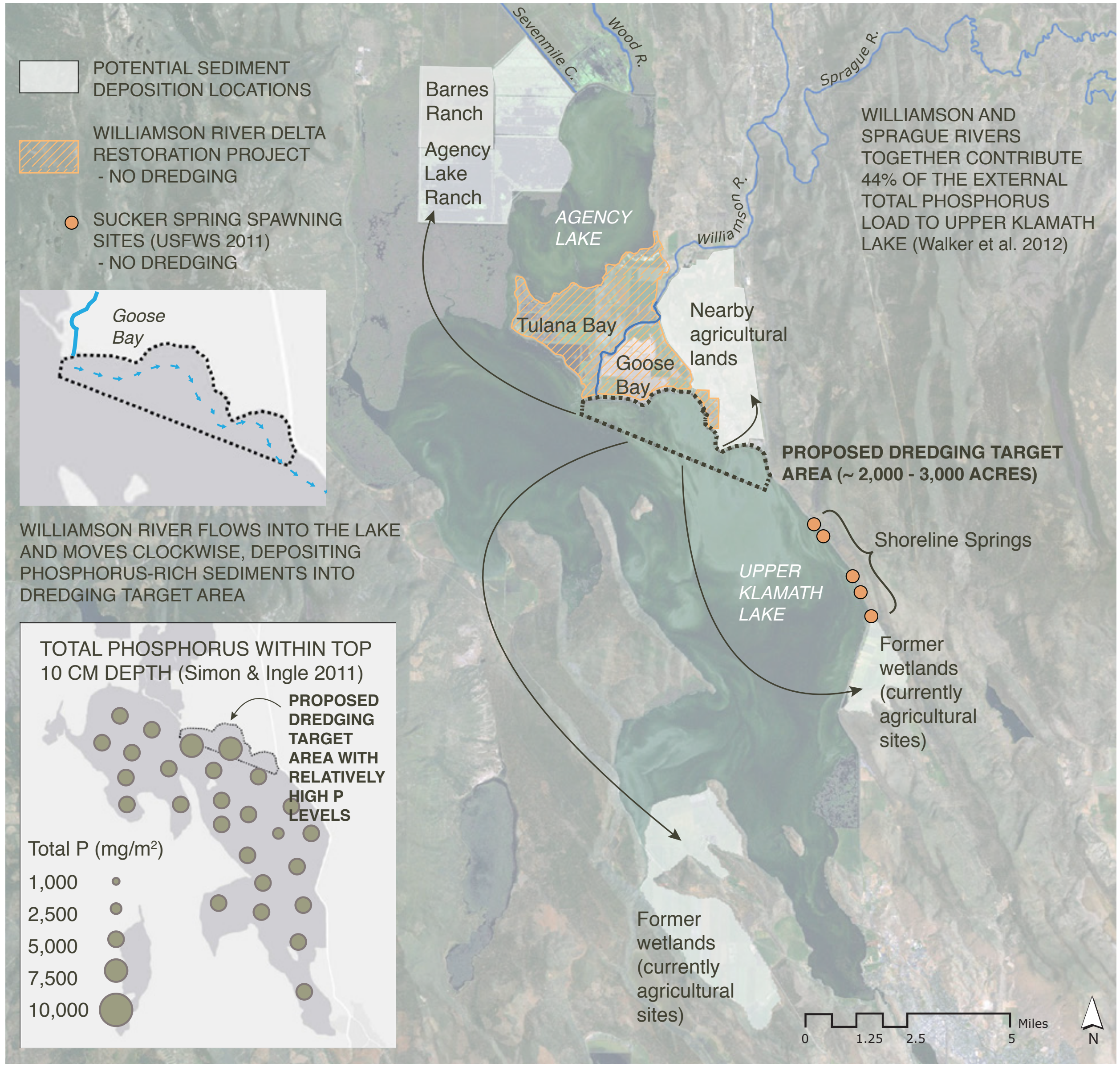


Fig. 3.28 Proposed dredging area and sediment deposition locations adjacent to Upper Klamath Lake.

66 Wood 2012
67 Simon and Ingle 2011
68 Another possible location for the target area is near the inflow from Agency Lake. USGS is currently analyzing sediment cores to determine if a relatively high fraction of bioavailable phosphorus is associated with sediments in this general area (Simon and Ingle 2011).

DREDGED SEDIMENT REUSE EXAMPLES

Dredged sediments have often been used to construct and repair levees in the San Francisco Bay and Sacramento-San Joaquin Delta. There are also several examples of successful application of dredged sediments for habitat creation/restoration,[69] including the Sonoma Baylands in San Francisco Bay, where mud from dredging the Port of Oakland was applied to subsided tidal wetlands (Figures 3.29 and 3.30).

The majority of agricultural lands in the Upper Klamath Lake area are irrigated pasture for cattle grazing; crops grown in the basin include hay, wheat, alfalfa and potatoes. Multiple studies have shown positive impacts of dredged sediments on crop yields. Lake-dredged sediments applied to pasturelands in south Florida led to significantly higher forage yields of bahiagrass.[70] Sediments dredged from the Potomac River and applied to a reclaimed sand and gravel mine (Shirley Plantation) resulted in reasonable wheat yields and outstanding corn yields.[71] Other studies produced similar results when sediment was mixed with soil, compost, biosolids, and/or sand, for crops including corn,[72] snapbeans and barley,[73] lettuce[74] and other field and forage crops, including alfalfa.[75] As a regional example, implementation of the Salt River Ecosystem Restoration Project in nearby Humboldt County, California, involves the re-use of excavated Salt River sediments in upland agricultural pasturelands in the surrounding area. For the Salt River restoration project, the sediment is viewed as a beneficial resource that various farmers and ranchers are interested in receiving for agronomic re-use (California Coastal Commission 2011).

69 Craig Vogt, Inc. 2010
70 Sigua 2009
71 Daniels et al. 2007
72 Lembke et al. 1983
73 Diaz and Darmody 2004
74 Canet et al. 2003
75 Woodard 1999

Fig. 3.29 (Left top) Restored wetlands in Sonoma Baylands, San Francisco Bay. Photo: Gahagan & Bryant Associates.

Fig. 3.30 (Left bottom) Wetland created from dredged materials in Sonoma Baylands. Photo: Gahagan & Bryant Associates.

Fig. 3.31 (Right top) Wheat harvest. Photo: GoldDustFarms.com.

Fig. 3.32 (Right bottom) Alfalfa grown in the Klamath Basin. Photo: OPB.org.

a management plan that includes both parcels. Potential beneficial reuses for the lake sediment at these sites are to maintain the dikes around the parcels and to increase the elevation of subsided areas for wetland restoration.

- *Agricultural lands surrounding Upper Klamath Lake* Of closest proximity to the proposed dredge site are former wetlands, currently in agricultural production, in the Williamson River floodplain, west of Highway 97 and north of Goose Bay. There are also agricultural lands along the southeast and southwest shores of the lake that may be good locations to receive dredged lake sediments as a soil amendment or fill for subsided areas (Figure 3.28).

PILOT PROJECT CONCEPTUAL DESIGN

Pre-dredging Surveys and Testing

Prior to dredging, review of existing bathymetric and LiDAR data for the site would be conducted in order to determine whether the site can accommodate a loaded barge and tug unit. Physical and chemical analyses of the sediments would also be undertaken to:

- Characterize sediment quality for permitting
- Ensure phosphorus and/or contaminants do not leach from sediments
- Inform selection of the most appropriate dredge
- Refine sediment area and volume of the proposed dredge site
- Confirm that potential beneficial reuses would be supported (outside of the research questions presented below)

Precision dredging using small hydraulic dredges would be among the techniques considered since it is optimal for removing thin layers of sediment (especially fine sediment) and for dredging along shorelines without removing existing rooted aquatic vegetation.

Dredging Operations

Based on aerial images and available bathymetry data, the target area for sediment dredging in Upper Klamath Lake spans 2,000-3,000 acres. Within this target area, the dredge site would be approximately 15 acres in size, and sediment would be removed from the top 1 ft (30 cm) of the lake bed (Figures 3.28 and 3.33). Recent studies of Upper Klamath Lake indicate P concentrations are highest in the upper 10 cm of sediment[76] (Figure 3.33) and drop off considerably below 20 cm.[77]

The dredging site would be delineated using steel pipes and pilings to cordon off the area and guide dredging operations. Based on refinements to the proposed dredging area identified during the pre-dredging surveys, phased dredging may be employed to maximize efficiency and minimize impacts. Dredging would be done on consecutive days until the desired quantity of dredged sediments is obtained. Methods to control turbidity, such as silt screens and other turbidity barriers, would be utilized such that turbidity would not exceed relevant Oregon standards. In addition, dredging operations would be timed to avoid periods of rough water and high winds that increase turbidity levels.

Dredging operations would avoid sucker impacts by conducting dredging outside of critical life history periods for this species. In the spring months, adult suckers congregate in the northern end of the lake near Goose Bay and Modoc Point prior to moving into tributaries or shoreline areas for spawning.[78] Spawning occurs February through May and juveniles move away from the spawning grounds from April through July. Therefore, dredging operations may need to occur from August through January. Other

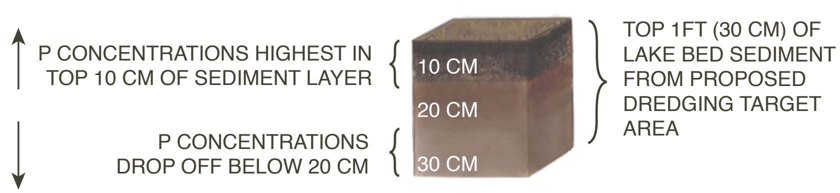


Fig. 3.33 Thirty centimeters of sediment, where the phosphorus concentration is deepest, would be removed from the proposed dredging area.

76 Simon et al. 2009, Simon and Ingle 2011
77 Eilers et al. 2004
78 Hendrixson et al. 2004

factors would be taken into consideration for the final timing of dredging operations, including the life history stages of other special status aquatic species and seasonal lake levels. Lake depth in the target dredging area is estimated to range from 3 to 7.5 feet during October, which is sufficient for operating a hydraulic dredge.

Deposition and Beneficial Reuse

The pilot project would generate approximately 15 acre-ft (approximately 24,000 cubic yards) of sediments for reuse. The potential for beneficial reuse of the sediment would be determined based in part on sediment quality characterization conducted during the pre-dredging surveys.[79] Additionally, the pilot project would simultaneously test the effectiveness of the dredged sediments for multiple beneficial uses to determine the preferred use (Figures 3.34).

A temporary confined disposal facility (CDF) or re-handling facility is necessary to store the sediments after dredging and before placement (Figure 2.18). The CDF would be designed to accommodate the quantity of sediment to be removed plus sufficient freeboard (estimated at 2-15 acres of land dependent upon the water volume content of dredged materials). Ideally the CDF would be constructed on land that is adjacent to the shoreline in the vicinity of the dredging area, making transport much easier and less expensive. Once in the CDF, the dredged material is allowed to dewater, which can take several weeks to months depending on the water content and the beneficial reuse option. The water fraction of the total weight of the sediment ranged from 0.84 to 0.94 in the samples closest to Goose Bay in a study

79 Harding Lawson Associates 2000, San Francisco Bay Regional Water Quality Control Board 2000

PILOT TESTING FOR DETERMINING LOCAL SEDIMENT REUSE OPPORTUNITIES

In addition to the standard sediment quality characterization and leaching nutrient and contaminant leaching test conducted as part of the pre-dredging surveys (see page 68), the pilot project would include the following research questions to address key uncertainties in the opportunities for local beneficial reuse of dredged lake sediments:

General - *Is phosphorus in the sediments to be dredged in Upper Klamath Lake mainly present as a bioavailable or non-bioavailable form of phosphorus?*

Are the high concentrations of silica in the dredged sediments recoverable through simple drying and separation techniques such that they might be used as a marketable source of this mineral?

Site(s) for Wetland Rehabilitation Through Subsidence Reversal - *Do elevated phosphorus content and percent fines in dredged lake sediments affect the growth of native wetland vegetation (e.g., bulrush, cattail) in wetland rehabilitation projects?*

Does the application of dredged lake sediments for increasing land surface elevation in wetland rehabilitation projects affect water quality, including nutrient levels (i.e., phosphorus, nitrogen) and toxins (e.g., mercury, arsenic, pesticides), in wetland surface water and site outflow?

Are there toxins (e.g., mercury, arsenic, pesticides) present at low levels in lake sediments that would be biomagnified in the wetland food web to levels of concern?

Site(s) for Maintenance of Existing Levees and Berms Using a Local Source of Sediments - *Do dredged and dried lake sediments possess physical properties that support their use as a local source of levee strengthening and/or building material?*

Site(s) for Agricultural Soil Amendments and Subsidence Reversal - *Do elevated phosphorus content and percent fines in dredged lake sediments affect the growth rate and yield of primary crops grown in the Upper Klamath Basin (hay, wheat, alfalfa, potatoes)?*

Does the application of dredged lake sediments as an agricultural soil amendment affect water quality, including nutrient levels (i.e., phosphorus, nitrogen) and toxins (e.g., mercury, arsenic, pesticides), in agricultural runoff?

Does application of dredged lake sediments as a soil amendment affect local soil hydrologic conductivity and site hydrology?

Are there toxins (e.g., mercury, arsenic, pesticides) present at low levels in lake sediments that would be biomagnified in crops to levels of concern?

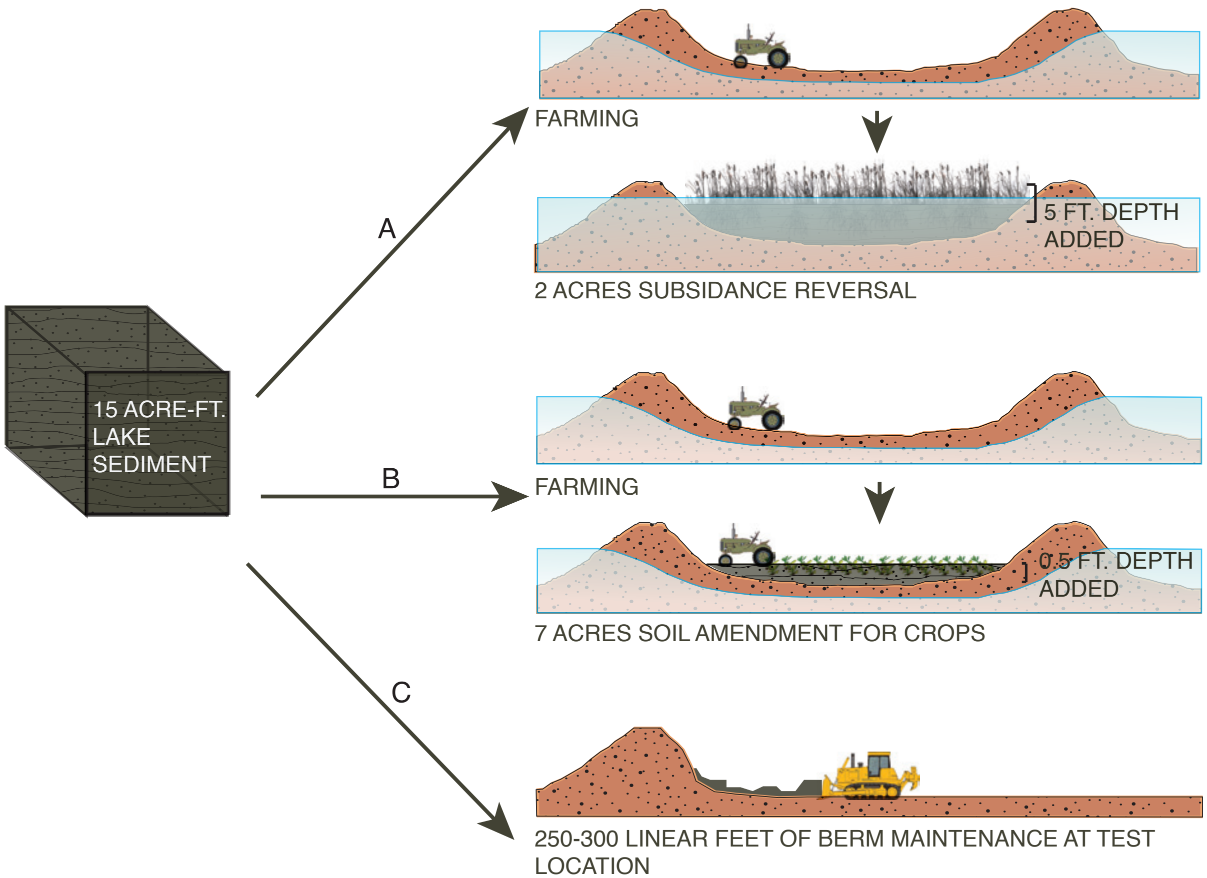


Fig. 3.34 Pilot project experimental applications for sediment re-use.

by Simon and Ingle (2011). Other techniques exist for rapid dewatering (e.g., geotextile tubes); however, they are more expensive.

For agricultural and levee application, the dredged sediments would be dried prior to use. Wetland application does not require as much dewatering; however, perimeter levees and interior dikes would need to be constructed at the deposition site to temporarily contain the dredged material, as well as water control systems to reduce sedimentation.

Assuming that the pre-dredging surveys and tests support multiple uses of the dredged sediments,[80] the total dredged volume would be applied to the following:

- 1-2 wetland rehabilitation sites in Agency Lake Ranch and Barnes Ranch parcels (or other similar parcels) totaling 2 acres (see Figure 3.34A)
- 1-3 agricultural soil amendment sites totaling 7 acres (see Figure 3.34B)
- 250-500 linear feet of levee/dike sites (see Figure 3.34C)

MONITORING

Prior to dredging, and as part of pilot project permitting, sediment quality characterization would include testing for levels of common sediment contaminants of concern, including pesticides, herbicides, metals, and PCBs, as well as algal toxins. Routine water quality monitoring would be

80 The final design should include a plan to manage dredged sediments if the results of the pre-dredging surveys and tests do not support multiple re-use options.

conducted in the vicinity of the dredge site before, during, and after dredging operations to ensure the dredging operation meets permit requirements (see below). Routine water quality monitoring would focus on turbidity and quantification of re-suspended phosphorus.

In addition to routine monitoring, the pilot project would also include targeted monitoring at multiple test sites to answer questions regarding the potential for beneficial reuse of dredged sediments (see text box on page 69).

Lastly, the net effect of dredging on phosphorus concentrations and recycling rates in the target area would be assessed by monitoring total phosphorus in multiple locations. Replicated sediment cores would be collected from the target area prior to, immediately following, and 1 to 2 years following dredging activities. Core sediments would be sampled for total phosphorus and phosphorus associated with different geochemical phases at multiple depths between 0 and 60 cm within each core. It is anticipated that 10-15 sediment cores would be collected to allow for the normal level of variability between core sites. The number of cores would be determined as part of the pilot study final design.

In order to provide information on the external phosphorus load coming into the target area before, during, and after dredging activities, total phosphorus concentrations and river flow would be measured every two weeks at the mouth of the Williamson River. Total phosphorus concentrations would also be measured in the water column within the target area. This study component would be coordinated with ongoing efforts to model phosphorus dynamics in Upper Klamath Lake and may also include determination of silica concentrations and bioturbation rates in the sediment cores (see Figure 1.18).

LAND AND WATER RIGHTS REQUIREMENTS

The following land and water rights requirements would be required for the pilot project:

- Approval from landowner(s) for application of dredged sediments
- Approval from landowner(s) for temporary use for CDF construction and operation (if rented)
- Waterside access for barge/dredge entry to lake

ENVIRONMENTAL, REGULATORY AND PERMITTING REQUIREMENTS

The following permits are anticipated necessary for the pilot project:

- Permits from Oregon Division of State Lands (DSL) and U.S. Army Corps of Engineers (USACE) for dredge and fill activities in U.S. waters, using a joint permit application. USACE consults with the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) on endangered species concerns.
- Water Quality Certification from Oregon Department of Environmental Quality (ODEQ)
- Certification from local city or county planning department that proposed project is consistent with local comprehensive plan and applicable zoning.

IMPLEMENTATION TIMELINE AND ESTIMATED COSTS

The anticipated timeline for implementing the conceptual design for a sediment dredging pilot project spans approximately 7 years (Figure 3.35).

The production rate of a hydraulic dredge ranges from 500 to 1,000 cubic yards per day to pump the dredged material to the CDF. Assuming a production rate of 500 cubic yards per day with the dredge operating 24 hours per day, it would take 48 days to dredge the estimated 24,000 cubic yards of material.

The time required for sediment deposition depends on its beneficial reuse and the extent to which it has to be dewatered. As noted earlier, dewatering may take several weeks to months depending on the water content and the beneficial reuse option. Given high water fractions in the sediment samples closest to Goose Bay (Simon and Ingle 2001), dewatering times could be at the high end of the range.

Estimated costs for a pilot project are presented in Table 3.10.

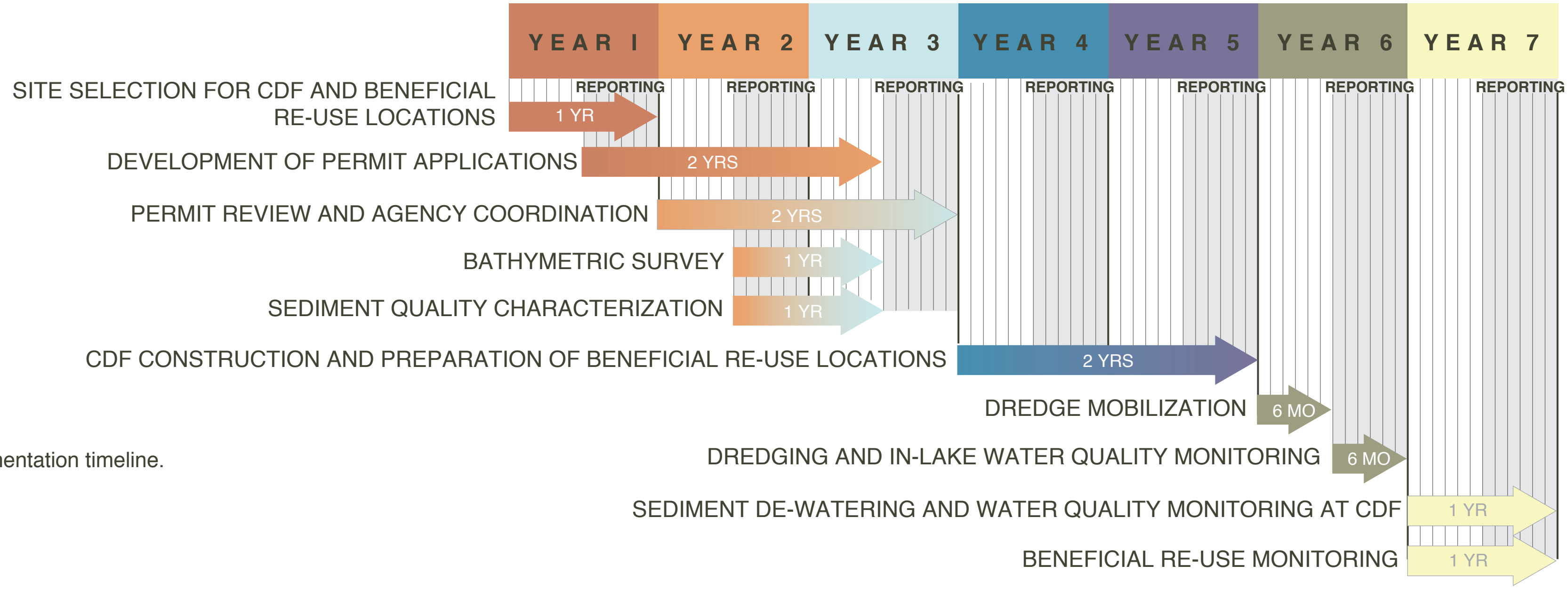


Fig. 3.35 (Right) Implementation timeline.

TABLE 3.10 - ESTIMATED COSTS FOR SEDIMENT REMOVAL (DREDGING) PILOT PROJECT

Site selection for CDF (Confined Disposal Facility) and beneficial re-use locations[81]	$10 - 15K
Final design[82]	$4-5K
Permitting[83]	$50-100K
Sediment quality characterization[84]	$25 - 35K
Hydraulic dredging[85], construction of open-pit CDF,[86] transport dredged material to beneficial re-use site	$360-400K
Dredge mobilization and demobilization[87]	$250 - 500K
O&M (Operation and Maintenance) of CDF and water quality monitoring[88]	$40 - 50K
Water quality and sediment monitoring at beneficial re-use locations[89]	$190 - 290K
Total	**$940K - 1.4M**

81 Includes review of existing data, landowner coordination, and 1-2 site visits. Minimal to no new surveys needed.
82 Assumes relatively simple CDF.
83 Assumes permitting needed for CDF and in-lake dredging activities.
84 Assumes collection and analysis of 25 sediment samples at approximately $1K each for combined analyses.
85 Assumes a dredging area of 15 acres, a depth of 30 cm (1 foot) and a hydraulic dredging cost of $15 per cubic yard (24,000 cubic yards of dredged material).
86 Factors that may influence the cost of the CDF include: land availability (purchase or rental cost), proximity of the land to the lakeshore and dredging area (transportation costs) and local topography of the site (number of sides needed).
87 Includes transport of dredge equipment to and from the upper basin.
88 Assumes three months of operation, weekly site visits and water quality monitoring at $1K per sample for combined constituents.
89 Assumes monthly water quality monitoring for one year at one wetland site, 1-2 agricultural sites, and one berm site at $400-600 per sample for combined constituents.

SEDIMENT SEQUESTRATION OF PHOSPHORUS AND AERATION/ OXYGENATION

CONCEPTUAL DESIGN AND PILOT STUDY

Injection of an alum micro-floc, along with aeration/ oxygenation, was considered for use in Lake Ewauna/ the Keno Impoundment by a relatively small number of workshop breakout groups (Figure 2.26). This technique was recognized for its potential to provide substantial short-term water quality benefits by adding dissolved oxygen to, and stripping phosphorus from, the water column and keeping phosphorus from being released by reservoir sediments. However, workshop attendees generally expressed a need for further scientific studies of alum dosing due to basin-specific water chemistry and toxicity concerns. Therefore, this section describes a conceptual pilot study to 1) determine the efficacy of buffered alum dosing in the low alkalinity and seasonally high pH waters of Lake Ewauna and the Keno Impoundment using bench-scale testing; 2) determine the potential for impacts to aquatic organisms in the project vicinity using toxicity tests; and 3) based on results of the bench-scale tests, to inject alum micro-floc and oxygen into a 40-acre pilot site in Lake Ewauna.

OBJECTIVE - To evaluate the potential for a large-scale effort to significantly reduce oxygen demand in Lake Ewauna and the Keno Impoundment and to sequester or inactivate phosphorus in the sediments and water column using alum micro-floc with aeration/oxygenation.

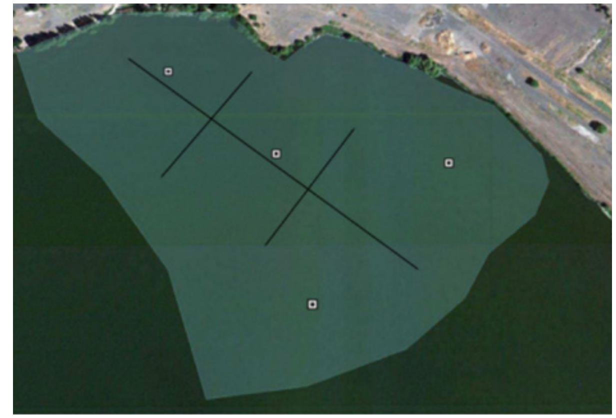


Fig. 3.36 (Right, above and below) Target area in Lake Ewauna and the upper end of the Keno Impoundment for alum micro-floc aeration/oxygenation pilot study. The alum/ air injection system would be placed in the 40-acre pilot site (green shaded area). White squares indicate water quality monitoring locations.

SITE CHARACTERISTICS

The target area for the alum micro-floc with aeration/ oxygenation pilot project is located downstream of the Link River Dam in Lake Ewauna. The area of Lake Ewauna is approximately 410 acres. The target area was chosen for the following reasons:

1. It receives large seasonal loads of algae from Upper Klamath Lake, which carry high concentrations of phosphorus and cause acutely low dissolved oxygen water column concentrations during the summer and fall (see Figure 1.11).
2. It is characterized by very high water column and sediment oxygen demand rates measured in Lake Ewauna/the Keno Impoundment.[90]
3. It experiences internal loading of phosphorus from sediments during periods of seasonal anoxia.
4. It is a relatively small, confined area with local power and road access.
5. It is situated at the upstream end of the 8-mile long Keno Impoundment, which provides

90 Doyle and Lynch 2005, Sullivan et al. 2011

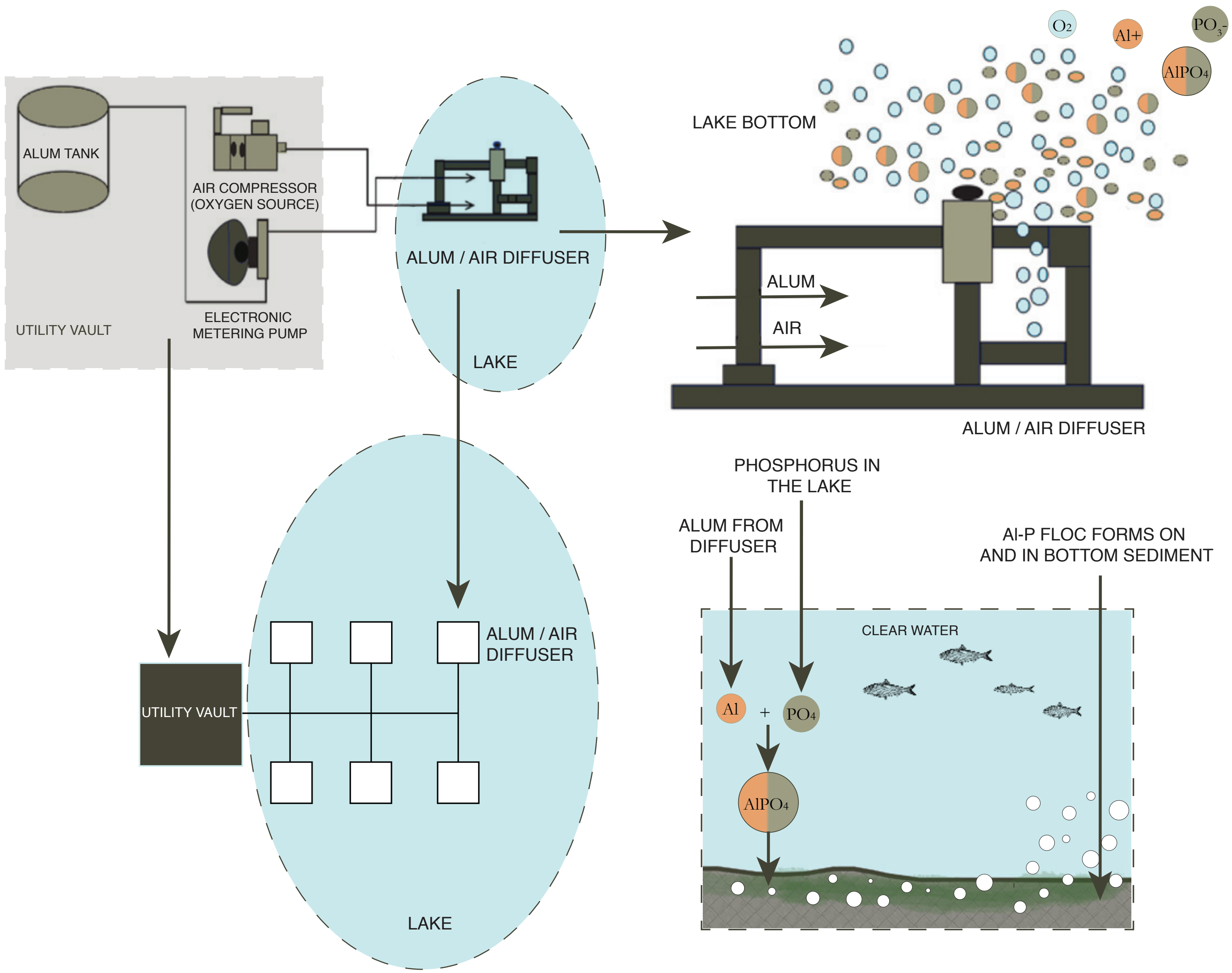


Fig. 3.37 Alum micro-floc aeration/oxygenation injection system.

a sufficient settling distance for the stable and chemically inert alum micro-floc prior to discharge at Keno Dam.

The pilot project would treat 10% of the target area, or approximately 40 acres.

BENCH-SCALE TESTING

As part of the pilot study, alum dosing tests would be conducted to ascertain how buffered alum responds to the low alkalinity, high pH, high dissolved organic matter (DOM), and high suspended solids (due to algae) concentrations present in the target area water column in summer and early fall months. The laboratory "bench-scale" dosing tests would examine alum efficacy and would determine if any dissolved aluminum, which can be toxic to aquatic organisms at high concentrations and pH less than 6, is present in the treated cells (Figure 3.38). Concentrations measured in the dosing tests would be compared against known aluminum toxicity thresholds

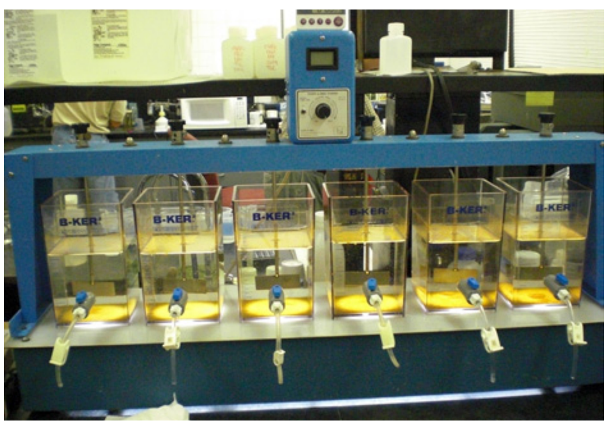


Fig. 3.38 Bench-scale dosing tests can be used to test the efficacy of alum treatment under water chemistry conditions specific to the Upper Klamath Basin. Photo: T. Kirk.

ALUM INJECTION SYSTEMS

Liquid alum[91] and sodium aluminate buffer are stored in a tank housed within a utility vault on the edge of the lake. Alum and buffer are pumped from the tank through a line and metering pump to an air compressor that adds oxygen to the liquid alum. The alum-buffer-oxygen mixture is then pumped at a specified rate through lines to alum diffusers placed strategically along the lake bottom. The buffered alum-oxygen mixture forms a floc that binds with particulate matter and the aluminum in the alum binds with soluble phosphate molecules in the water column as it is dispersed, creating an aluminum phosphate ($AlPO_4$) precipitate that settles to the bottom of the lake and incorporates into the sediments. The aluminum inactivates the phosphate in the water and sediments, clearing the water column of particulates as it settles to the bottom and reducing phosphorus recycling from the sediments. By removing the excess phosphorus from the water column, alum treatment allows greater light penetration in the water column and other species of aquatic plants may grow along the lake bottom. These plants are healthy for a balanced lake ecosystem and provide food and habitat for fish and other organisms.

Alum micro-floc injectors similar to the one described here have been designed by Tetra Tech for a pond in Tukwila, WA and have been implemented in Lake Oswego, Oregon. Micro-floc injection has also been used in several other Midwestern and Eastern States.

91 Alum is typically added as a salt of aluminum sulfate. Non-sulfate alternatives are available.

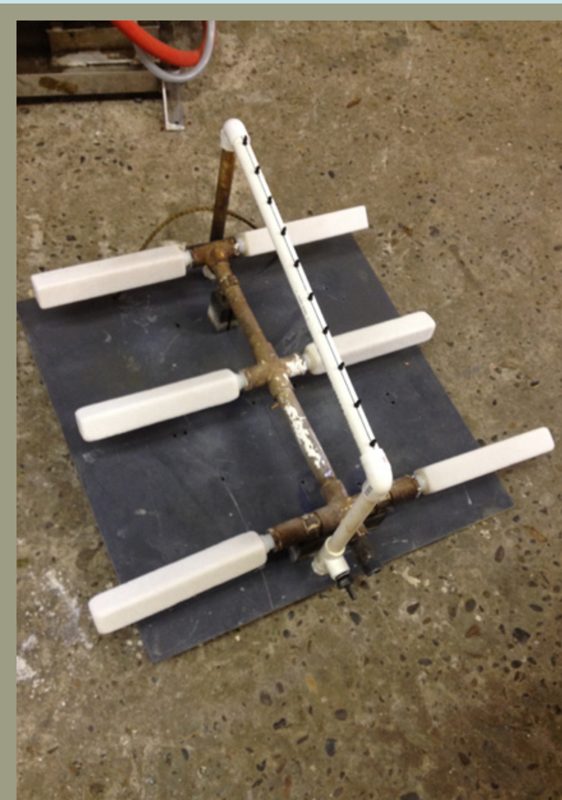


Fig. 3.39 Alum micro-floc injector unit for Lake Oswego, Oregon. Photo: M. Rosenkranz.

TABLE 3.11 - ESTIMATED DAILY TOTAL PHOSPHORUS LOAD TO LAKE EWAUNA AND THE KENO IMPOUNDMENT FROM UPPER KLAMATH LAKE

	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Average total phosphorus concentration in outflow from Upper Klamath Lake (ug/L)[92]	106	244	211	216	144
Daily average flow at Link River (cfs)[93]	1,385	1,030	944	791	815
Estimated daily total phosphorus load (kg/day)	358	615	488	418	286

92 Value represents the average for water years 1991-2010. Data collected by the Klamath Tribes at PM (Pelican Marina) and FB (Freemont Bridge) sites.

93 Data from USGS gage no. 11507500 for water years 1991-2010. Flows do not include contributions from Westside Canal.

for freshwater fish in the pH range of 6 to 9 and alkalinity less than 100 mg/L, which are conditions typical for the target area during summer and fall (see Section 2, pages 3-5). Note that with full-scale treatment in Lake Ewauna, alum additions would be expected to reduce photosynthetically induced high pH values so that these conditions would not exist. Although the potential for alum toxicity to aquatic species is very small (Section 2, page 28), the dosing tests would also include acute water column testing using a common laboratory toxicity test organisms such as the zooplankton *Daphnia spp*. and rainbow trout to ensure a clear understanding of the likely *in-situ* effects of alum use in the Upper Klamath Basin prior to injection at the target site. In addition, alum bench-scale dosing tests would identify the potential for increased sulfate concentrations in the target area due to alum additions,[94] which may be an important consideration related to sulfur and mercury cycling in the Upper Klamath Basin.

94 Alum is typically added as a salt of aluminum sulfate, but non-sulfate alternatives are available.

PILOT PROJECT CONCEPTUAL DESIGN

Pre-Project Surveys

Prior to alum/aeration unit installation, review of existing bathymetric and LiDAR data, as well as consideration of seasonal circulation patterns[95] for the target area, would be conducted to ensure that conceptual design elements can be supported. The pre-project surveys would also identify an available shoreline site for placement of the air compressor, alum tanks, and other required alum dosing and oxygen supply equipment. It is anticipated that approximately 300 ft^2 would be required for the aerator and 4000 ft^2 would be required for the liquid alum tanks and pumps. If necessary, the equipment could also be stored in underground vaults.

95 Sullivan et al. 2011

TABLE 3.12 - ESTIMATED ALUM DOSE FOR CONCEPTUAL PILOT STUDY IN LAKE EWAUNA

	JUNE	JULY
Whole-lake treatment		
Alum dose (kg/day)[96]	4,000	7,000
Alum dose (gal/day)[96]	18,000	31,000
Pilot study - Treat 10% of incoming total phosphorus load		
10% of daily total phosphorus load (kg/day)	35.8	61.5
Alum dose (kg/day)	400	700
Alum dose (gal/day)	1,800	3,100

96 For June and July daily average flows, this would result in an buffered alum concentration of 1-2.5 mg/L (whole-lake), and 0.1-0.25 mg/L (pilot study), in Lake Ewauna, or less than the range of 5-26 mg/L found to be safe for aquatic species in previous studies (see text box on page 28).

Additionally, replicated sediment samples would be collected from the target area and downstream locations in the Keno Impoundment prior to alum aeration unit installation in order to characterize the community of sediment-dwelling organisms under low oxygen or anoxic conditions (June – October) as well as during well-oxygenated conditions (November – May) prior to any alum dosing (see additional detail under *Monitoring*).

Alum/Aeration Unit Operation

Up to six alum/aeration injection units would be located at roughly uniform distances apart within the 40-acre pilot site (Figure 3.36). Exact placement of the units would be based on results of the pre-project surveys. Liquid alum and buffer would be pumped from onsite storage through a hose to each dispersal unit on the bottom of the lake, and then into the overlying water column (Figure 3.37). Simultaneously, air (or near pure oxygen) would be transported from the on-shore compressor to each dispersal unit and into the water column. The force of the injected air would convert the released liquid alum into a micro-floc that is mixed with overlying water and transported upward and out of each unit. Multiple injection units promote optimum dispersal and coverage of the alum micro-floc and dissolved oxygen.

Alum Dose

For this conceptual design, the required dose of alum micro-floc for the pilot study is based on the estimated daily total phosphorus load entering Lake Ewauna and the Keno Impoundment from Upper Klamath Lake during the months of June through October (Table 3.11). This is in contrast to whole-lake alum systems, which are often designed

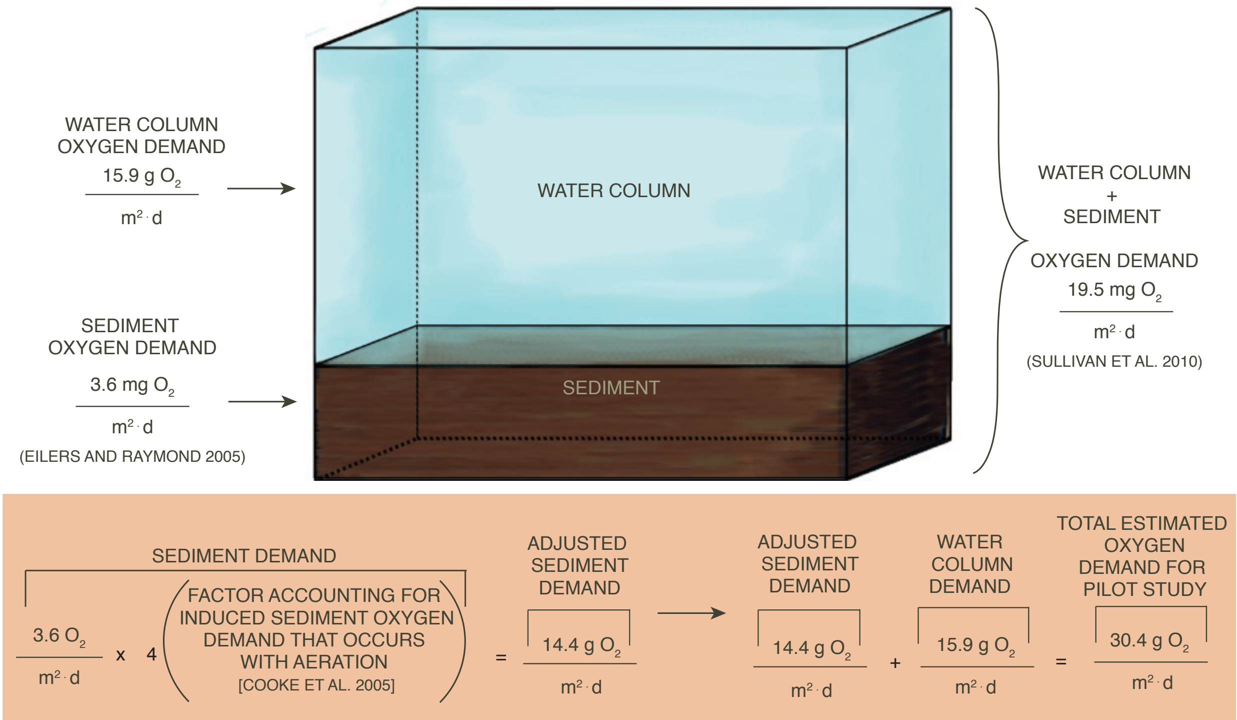


Fig. 3.40 (Above) Combined sediment and water column oxygen demand for estimating required oxygen dose for pilot study.

TABLE 3.13 - ESTIMATED OXYGEN DOSE REQUIRED FOR PILOT STUDY

COMBINED SEDIMENT AND WATER COLUMN OXYGEN DEMAND ($g\ O_2/m^2$ per day)	PILOT SITE AREA (ACRES)	REQUIRED OXYGEN DOSE (kg/d)	EFFICIENCY-ADJUSTED OXYGEN DOSE FOR AIR INJECTION (kg/d)[97]	EFFICIENCY-ADJUSTED OXYGEN DOSE FOR PURE O_2 INJECTION (kg/d)[97]
30.4	40	4,921	61,514	24,606

97 Assumes the efficiency of fine bubble delivery is 8% for air and 20% for pure oxygen.

TABLE 3.14 - ANTICIPATED MONITORING ELEMENTS FOR ALUM MICRO-FLOC AERATION/OXYGENATION PILOT STUDY

MONITORING PARAMETER	SAMPLING STRATEGY	SAMPLING FREQUENCY
• **Water temperature** • **Conductivity** • **Dissolved oxygen** • **pH**	Vertical profiles every 0.5-m	Daily during June through September
• **Total suspended solids** • **Turbidity** • **Total and ortho-phosphorus**	Surface, mid-depth (~3.0 m) and 0.5-m from the bottom sediments	Daily during June through September
• **Alum and phosphorus profiles in sediments** • **Number (abundance) and type (species) of sediment-dwelling organisms**	Replicated sediment samples from the target area and downstream locations in the Keno Impoundment	• Before and after alum dosing and aeration/oxygenation • Summer/early fall (low oxygen conditions) • Winter/spring (well-oxygenated conditions)
Number (abundance) and location (distribution) of sucker life stages	Representative number of treatment areas	1 survey during each of May, September, December

on the basis of the mass of phosphorus in the sediments.[98] It is anticipated that dosing in proportion to the incoming phosphorus load at Link River Dam would also provide adequate residual floc binding sites to inactivate a large fraction of mobile sediment phosphorus over time.

While basic chemical stoichiometry indicates that one unit of aluminum can bind with one unit of phosphate, other compounds, such as DOC and other forms of less bioavailable phosphorus found in natural waters, can compete with phosphate and reduce the efficiency of the micro-floc. A study of six lakes in Washington indicated that an average ratio of 11:1 represents the ultimate binding capacity of alum after several years of treatment.[99] As a conservative estimate, applying the ratio of 11:1 to the estimated daily total phosphorus load to Lake Ewauna and the Keno Impoundment equates to whole-lake required alum doses of roughly 4,000 to 7,000 kg/day during June and July (pilot testing period) (Table 3.12). At 0.22 kg/gallon alum, the whole-lake liquid alum dose would be roughly 18,000 to 31,000 gallon/day.

To dose the 40-acre pilot site, which is approximately 10 percent of the target area, the alum dose would be 1,800 to 3,000 gallon/day (Table 3.12). To ensure water quality stability, a sodium aluminate buffer would be added with the alum, resulting in 800 to 1,200 gallons of alum and 400 to 700 gallons of sodium aluminate per day.

Oxygen Supply

The quantity of dissolved oxygen required to offset the very high water column and sediment demand measured in Lake Ewauna and the Keno Impoundment during summer and early fall is based on a sediment-plus-water-column oxygen demand rate of 19.5 g O_2/m^2 per day (Figure 3.40). A factor of four is applied to the sediment oxygen demand rate due to additional induced sediment demand that typically occurs with aeration.[100] Oxygen supply to meet water column oxygen demand is usually doubled to account for the induced demand, but for the Lake Ewauna/the Keno Impoundment pilot study, where existing oxygen demand is extremely high, the maximum factor would be used. The efficiency-adjusted oxygen doses for an air injection option and a pure oxygen injection option for the pilot study are presented in Table 3.13.

MONITORING

During the pilot study, water samples would be collected at 8-11 monitoring sites located between Link River Dam and the upper end of the Keno Impoundment (Figure 3.36). Water samples collected at the Link River Dam would be used to determine the inflow load of total phosphorus during and after the pilot study (Table 3.14). Daily water samples collected from sites spaced along the length of Lake Ewauna and the upper end of the Keno Impoundment

98 Cooke et al. 2005

99 Rydin et al. 2000

100 Cooke et al. 2005

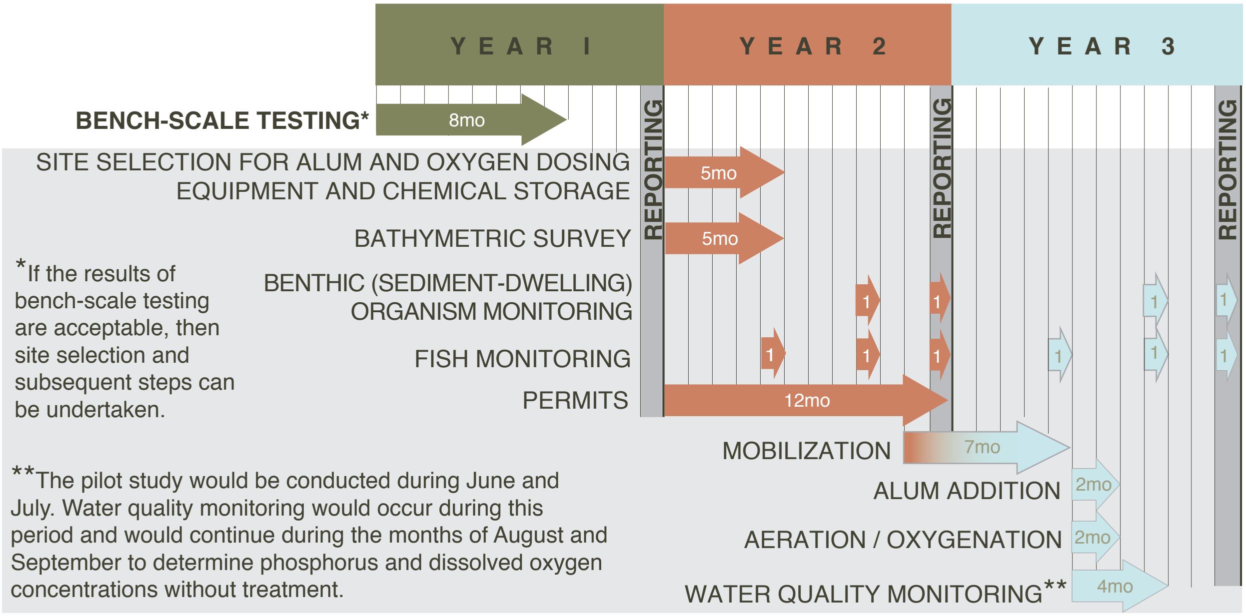


Fig. 3.41 Implementation timeline.

would be used to determine treatment effectiveness. The monitoring program includes a component to determine the potential effects of alum micro-floc and aeration/oxygenation on the community of organisms that currently inhabit the sediments (called "benthic" organisms) and on suckers that live in Lake Ewauna and the Keno Impoundment (Table 3.14).

LAND AND WATER RIGHTS REQUIREMENTS

A small shoreline staging area would be required for dosing equipment, including the air compressor (approximately 300 ft^2) and alum storage tanks and pumps (approximately 4,000 ft^2). The staging area would also need to provide easy access for supply trucks. It is anticipated that the pilot study storage capacity requirements for alum would be small compared to most lake treatments; however, if necessary, the equipment can be stored in underground vaults. There would be no diversion of water for the pilot project and no water right would be required.

ENVIRONMENTAL, REGULATORY, AND PERMITTING CONSTRAINTS

A water quality permit from Oregon Department of Environmental Quality would likely be required to add alum and air to Lake Ewauna and the Keno Impoundment.

IMPLEMENTATION TIMELINE AND ESTIMATED COSTS

The anticipated timeline for implementing the conceptual design for a phosphorus sediment sequestration and aeration/oxygenation pilot project in the Keno Impoundment spans approximately 3 years (Figure 3.41). Estimated costs for a pilot project are presented in Table 3.15.

TABLE 3.15 - ESTIMATED COSTS FOR SEDIMENT PHOSPHORUS SEQUESTRATION AND AERATION/ OXYGENATION PILOT PROJECT

Bench-scale testing dosing tests[101]	$60-75K
Site selection for alum and oxygen dosing equipment and chemical storage[102]	$6-8K
Permitting	$20-30K
Alum addition[103]	$290-350K
Aeration/oxygenation[104]	$365-437K
Water quality monitoring[105]	$94-124K
Benthic (sediment-dwelling) organism monitoring[106]	$26-38K
Fish monitoring[107]	$12-18K
Total	**$880-1.1M**

101 Includes operation and analytical costs for replicated bench-scale tests using flow-through treatment cells and toxicity testing with standardized benthic and fish test species.
102 Includes review of existing information, landowner coordination, and 1-2 site visits. Minimal to no new surveys needed.
103 Includes alum pump line, six injection units, chemical storage tanks, alum, sodium aluminate buffer, mobilization, electrical, and O&M.
104 Includes air compressor (50 HP), airline, equipment housing, electrical controls, mobilization, electrical, and O&M.
105 Assumes in situ water quality measurements plus 3 grab samples per site per day for 120 days at 8-11 sites.
106 Assumes 3-4 surveys to identify benthic macroinvertebrates at approximately 10 sites within and downstream of the target area.
107 Assumes 3 surveys to identify benthic macroinvertebrates at approximately 10 sites within and downstream of the target area.