SECTION 1 | OVERVIEW AND BACKGROUND

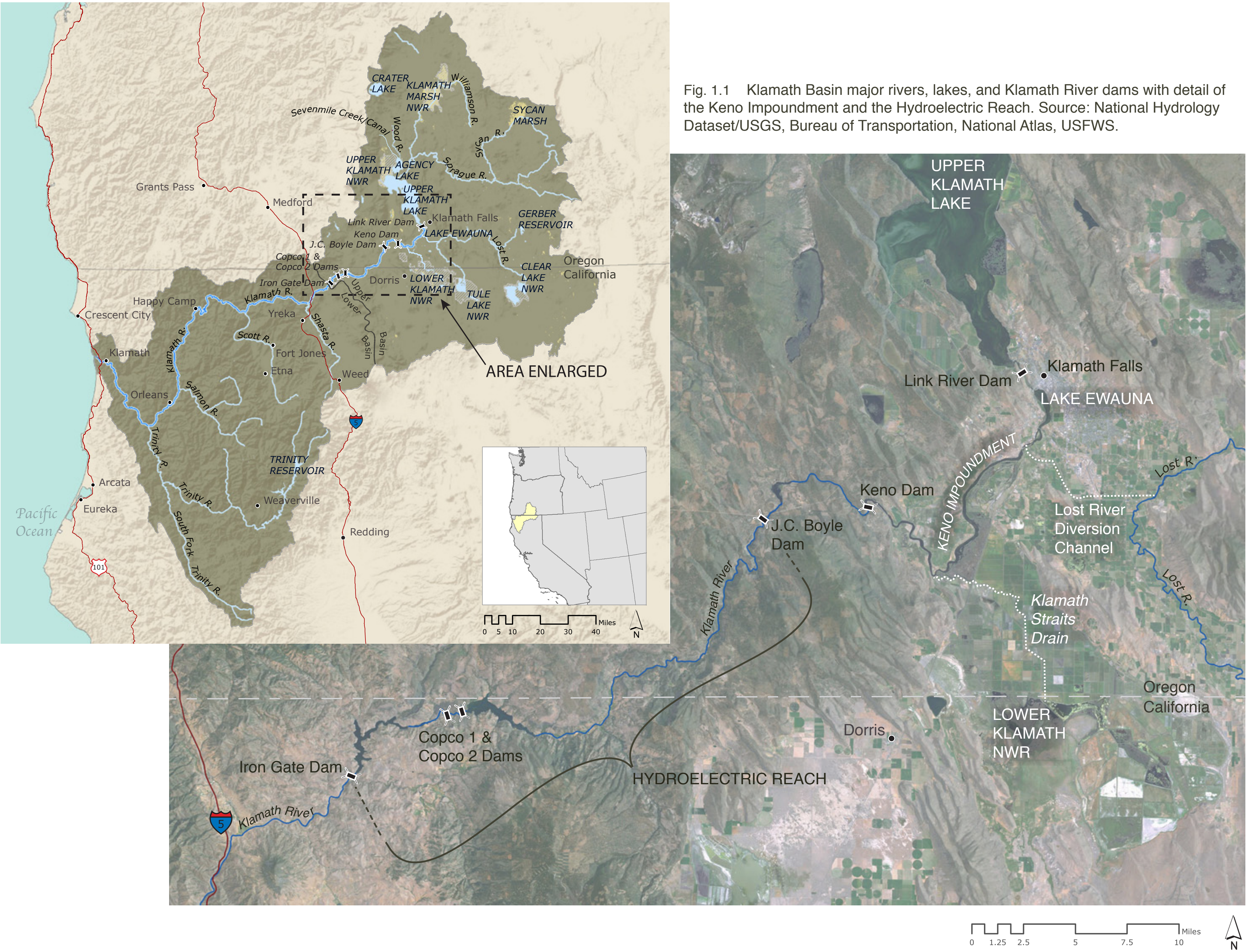


Fig. 1.1 Klamath Basin major rivers, lakes, and Klamath River dams with detail of the Keno Impoundment and the Hydroelectric Reach. Source: National Hydrology Dataset/USGS, Bureau of Transportation, National Atlas, USFWS.

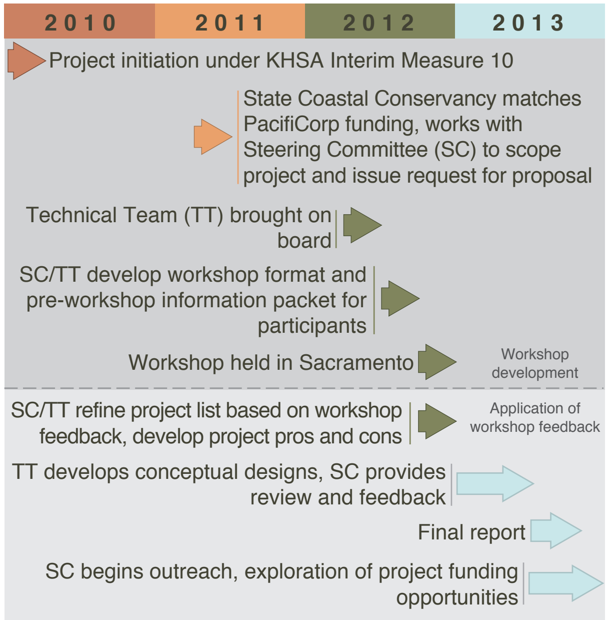


Fig. 1.2 (Far left) Klamath River Water Quality Workshop and report four-year timeline, from project initiation to post-report outreach.

Fig. 1.3 (Left) Satellite photo of Upper Klamath Lake showing typical summer lake-wide blooms of the blue-green algae *Aphanizomenon flos-aquae*. Upper Klamath Lake is broad and shallow, which affects water temperatures, circulation, and mixing patterns. Photo: NASA Earth Observatory, June 14, 2000.

OVERVIEW AND BACKGROUND

On February 18, 2010, the United States, the States of California and Oregon, PacifiCorp, tribal nations, and a number of other stakeholder groups signed the Klamath Hydroelectric Settlement Agreement (KHSA). The KHSA lays out the process for additional studies, environmental review, and a determination by the Secretary of the Interior regarding whether removal of four dams owned by PacifiCorp on the Klamath River (including Iron Gate, Copco 1 and 2, and J.C. Boyle dams [Figure 1.1]) would help restore the salmonid fisheries of the Klamath Basin, and if dam removal is in the public interest.

The KHSA includes provisions for the interim operation of the dams and mitigation activities prior to removal of the dams or the termination of the KHSA. One of the provisions involved funding of the Klamath River Water Quality Workshop, which was held on September 10-13, 2012 in Sacramento, California. The purpose of the workshop was to evaluate large-scale approaches for improving water quality in the Upper Klamath Basin and to inform decision-making on nutrient reduction approaches. During the workshop, experts gave presentations on six large-scale pollutant reduction techniques or approaches that were pre-selected by the project Steering Committee. These techniques have demonstrated success in other systems challenged by nutrient pollution, including Chesapeake Bay, the Florida Everglades, and the Salton Sea in California. The six large-scale techniques evaluated by workshop participants included:

- Wetland restoration (habitat focus)
- Treatment wetlands (water quality focus)
- Diffuse source (decentralized) treatment wetlands
- Algal filtration
- Sediment dredging
- Sediment sequestration of phosphorus and aeration/oxygenation

Workshop participants then broke into groups to evaluate and rank the six different techniques as applied to water quality problems in the Upper Klamath Basin. Using results of the project evaluations, participant breakout groups designed a hypothetical 20-year program that would reduce nutrient and organic matter loads to the Upper Klamath River and improve water quality in the basin.

Outcomes of the workshop are summarized in Section 2 of this report. Detailed documentation of the workshop project evaluation sessions, including comments and observations of workshop participants, is presented in Appendix A. Lastly, a pre-workshop information packet, which was distributed to all participants prior to the workshop to provide technical information regarding the evaluation and design of water quality improvement projects, is available for download from the project website (http://www.stillwatersci.com/case_studies.php?cid=68).

WHAT ARE THE WATER QUALITY PROBLEMS IN UPPER KLAMATH LAKE AND THE KLAMATH RIVER?

Water Quality in Upper Klamath and Agency lakes and their tributaries the Wood, Williamson, and Sprague rivers (see Figure 1.1 for tributary locations), has been significantly degraded by human activities and has not met water quality standards for a

Fig. 1.4 (Above) shortnose sucker. Photo: USGS.

Fig. 1.5 (Below) Lost River sucker. Photo: USGS.

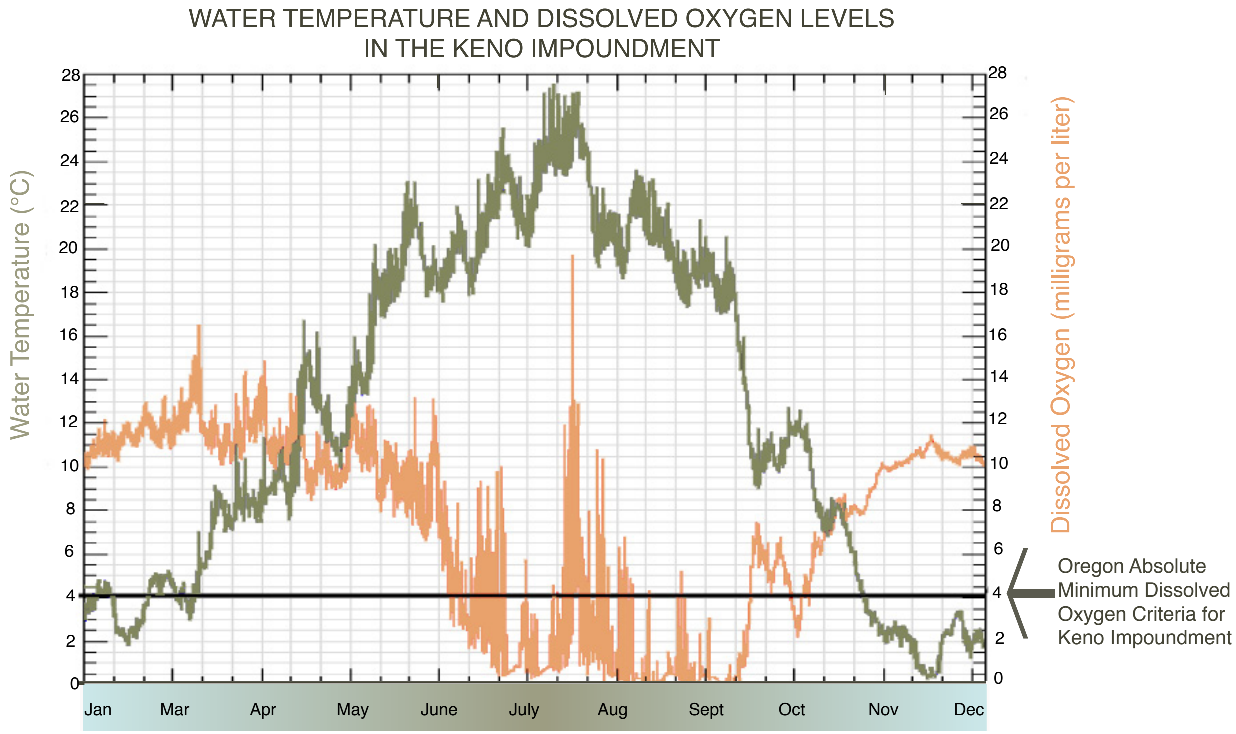


Fig. 1.6 Water temperature and dissolved oxygen concentration near the water surface at Island in the Keno Impoundment.

number of years.[1] Water quality is worst during the summer and early fall, with large blooms of algae and cyanobacteria[2] in Upper Klamath Lake (Figure 1.3) leading to depressed dissolved oxygen, high pH and ammonia concentrations, and problematic levels of algal toxins. Acute water quality conditions have been linked to redistribution and even large die-offs of native fish populations in the upper basin, including the shortnose sucker (*Chasmistes brevirostris*), the Lost River sucker (*Deltistes luxatus*), and the interior redband trout (*Oncorhynchus mykiss* ssp.). The endangered shortnose and Lost River suckers (Figures 1.4 and 1.5) have experienced substantial declines in the abundance of spawning fish in recent decades because an insufficient number of juvenile fish are surviving to become mature adults.[3] Overall, degraded water quality resulting from algal blooms is a significant threat to the long-term viability of the endangered suckers and other aquatic life in Upper Klamath Lake, not only because of fish-kill events, but also because of reduced fitness and long-term survival as a result of chronic stress[4] and possibly exposure to algal toxins.[5]

Water quality problems also affect fish and other aquatic species living in the Klamath River downstream of Upper Klamath Lake. Lake Ewauna and the Keno Impoundment (Figure 1.1) experience acutely low dissolved oxygen concentrations during the summer and fall (Figure 1.6). pH can also exceed water quality standards during this period, increasing potential for ammonia toxicity in this lake and reservoir. Although it is not well known how suckers utilize habitat in Lake Ewauna and the Keno Impoundment, water quality improvement in these waterbodies will help support the survival and return of a large number of juvenile suckers swept downstream of the Link River Dam each year from Upper Klamath Lake.[6]

1 WQST 2011
2 Cyanobacteria are photosynthetic organisms and can often be a nuisance aquatic species, occurring as large seasonal blooms that alter surrounding water quality. They are often referred to as blue-green algae, although they are actually bacteria.

3 Hewitt et al. 2011, Janney et al. 2009
4 ODEQ 2002
5 VanderKooi et al. 2010

6 USFWS 2008, NMFS and USFWS 2013

Further downstream, in the Hydroelectric Reach, construction of four dams (J.C. Boyle, Copco 1 and 2, and Iron Gate) (Figure 1.1) created reservoirs that slow the downstream movement of water and intercept or otherwise alter the natural transport of sediment, nutrients, and other constituents to downstream waters. When compared to free-flowing river reaches, the two larger reservoirs (Copco 1 and Iron Gate) experience large blooms of blue-green algae and exhibit altered seasonal water temperatures. Water quality in the Hydroelectric Reach and the Klamath River downstream of Iron Gate Dam does not meet applicable standards for the states of Oregon and California, with primary water quality concerns including seasonally altered water temperatures, low dissolved oxygen, high pH, and high chlorophyll-a and algal toxin concentrations.[7] Numerous fish species use the Klamath River and major tributaries downstream of Iron Gate Dam during all or some portion of their life cycle, including salmon, steelhead, lamprey, sturgeon, suckers, minnows, and sculpin. Many other species are present in the Klamath Estuary. Of the five populations of anadromous salmonid species in the Klamath River downstream of Iron Gate Dam, which include Chinook salmon, coho salmon, steelhead, and coastal cutthroat trout, all but coastal cutthroat have experienced reductions greater than 50% from historical levels.[8] Poor water quality, which contributes to incidences of fish disease downstream of the hydroelectric dams, is one important reason for the decline of fisheries in the Klamath Basin.[9]

Poor seasonal water quality also impacts cultural and recreational uses of waterbodies in both the Upper and Lower Klamath Basin. For example, known and/or perceived concerns over health risks associated with seasonal algal toxins have resulted in the alteration of traditional cultural tribal practices, such as gathering and preparation of basket materials and plants, fishing, ceremonial bathing, and ingestion of river water.[10]

7 ODEQ 2010, NCRWQCB 2010
8 Moyle 2002, Moyle et al. 1995, Ackerman et al. 2006, Leidy and Leidy 1984, Busby et al. 1994
9 Hamilton et al. 2011

Fig. 1.7 (Above left) Photo of *Aphanizomenon flos-aquae*. Photo: S. Poulson, UNR.

Fig. 1.8 (Above right) Scientists collected sediment cores in Upper Klamath Lake to determine when *Aphanizomenon flos-aquae* spores first appeared in the lake (Eilers et al. 2004). Photo: Jacob Kann.

WHAT ARE THE REASONS FOR POOR WATER QUALITY?

The relatively low topographic relief and volcanic terrain in the Upper Klamath Basin support large, shallow natural lakes and wetlands, with soils that are naturally high in phosphorus. Water quality in the basin is affected by this natural source of phosphorus as well as nonpoint sources (NPS) of pollution that result from human activities. NPS pollution is caused when runoff from rainfall, snowmelt, and irrigation moves over and through the ground, picking up and carrying natural and human-made pollutants and depositing them into lakes, rivers, wetlands, coastal waters and ground waters.[11] In the Upper Klamath Basin, phosphorus is the NPS pollutant of primary concern because this nutrient enables excessive blooms of cyanobacteria in the lake and in downstream reaches of the Klamath River.

10 USDOI and NMFS 2012

Upper Klamath Lake has historically been a highly productive or *eutrophic* lake even prior to land use by European Americans, as evidenced by 19th century accounts. However, the lake was not always dominated by high levels of the blue-green alga *Aphanizomenon flos-aquae* (Figures 1.3 and 1.7), as is the case today. Evidence from lake sediment cores (Figure 1.8) looking back approximately 1,000 years indicates that *Aphanizomenon flos-aquae* did not appear in Upper Klamath Lake until the latter part of the 19th century, increasing substantially after that time and becoming the dominant summertime algal species. Today, Upper Klamath and Agency lakes are considered to be *hypereutrophic*

Fig. 1.9 Upper Klamath Lake sucker during a fish die-off. Photo: Jacob Kann.

11 USEPA 2005

given their massive seasonal blooms of blue-green algae.[12] Such large algal blooms further exacerbate poor seasonal dissolved oxygen and pH levels in lake water, creating adverse conditions for fish and other aquatic species (Figure 1.9).

Excessive additions of phosphorus to Upper Klamath and Agency lakes from both natural sources and NPS pollution are an important reason for the current conditions. Both phosphorus and nitrogen are essential nutrients for algal growth, but *Aphanizomenon flos-aquae* can provide its own source of nitrogen through a cellular process called nitrogen fixation in which the algae removes nitrogen directly from the atmosphere and converts it into a biologically useful form. Nitrogen is present in relatively low concentrations in Upper Klamath Lake's tributary streams (although its concentrations have also increased over time due to human activities). High phosphorus and low nitrogen conditions give the nitrogen-fixing *Aphanizomenon flos-aquae* a competitive advantage over other algal species and allow it to dominate the algal community in the lake. When the *Aphanizomenon flos-aquae* bloom subsides, decaying algal cells release nitrogen and phosphorus that is then available to fuel growth of a another species of blue-green algae, *Microcystis aeruginosa* (Figure 1.10). Although never approaching the biomass levels of *Aphanizomenon flos-aquae* in Upper Klamath Lake, *Microcystis aeruginosa* blooms are responsible for production of a toxin (microcystin) that can cause irritation, sickness, or in extreme cases, death to exposed organisms, including humans, pets, or livestock[13] and can bioaccumulate in aquatic organisms.[14,15]

Fig. 1.10 Microcystis aeruginosa. Photo: Susan Corum.

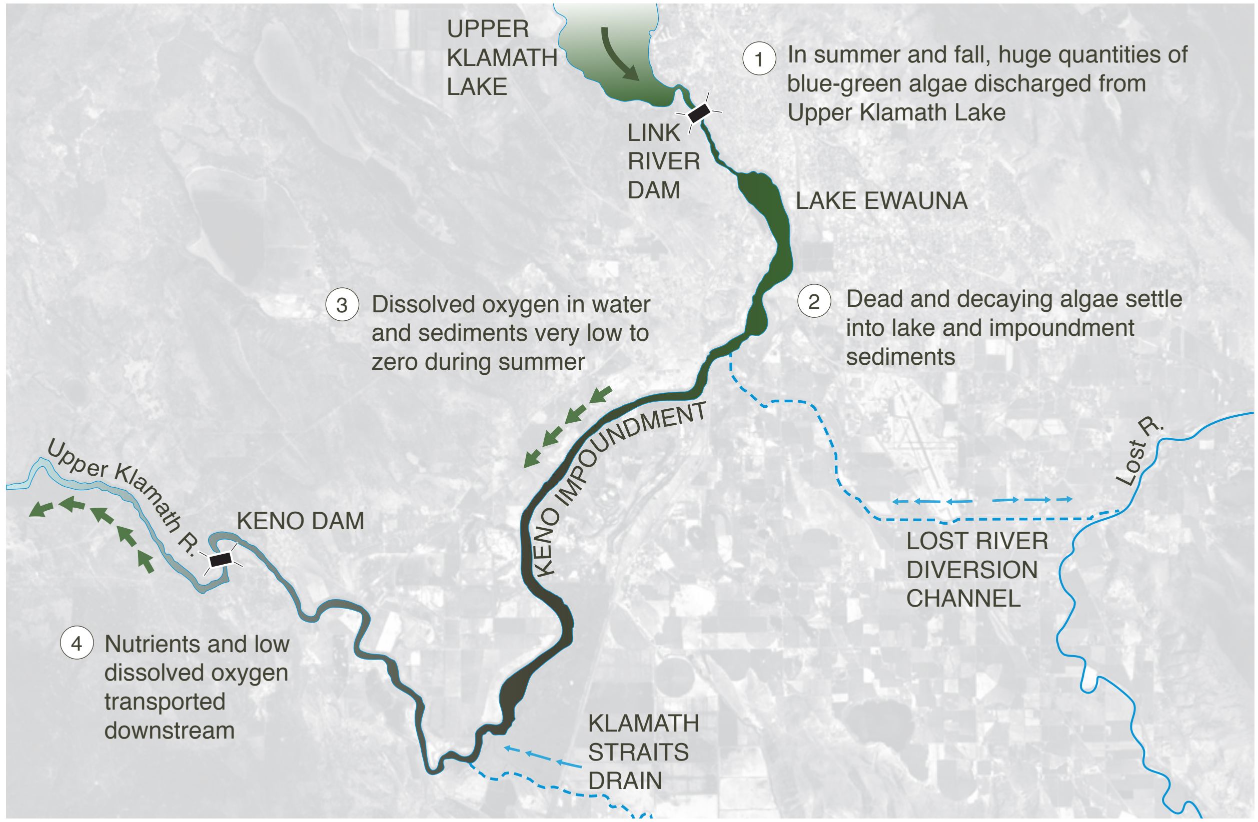


Fig. 1.11 Water quality issues downstream of Link River Dam.

Huge quantities of algae produced in Upper Klamath Lake are discharged into Lake Ewauna and the Keno Impoundment during summer and early fall months (Figure 1.11). For reasons that are

12 Bradbury et al. 2004a, 2004b, Colman et al. 2004, Eilers et al. 2004

13 WHO 1999
14 Eldridge et al. 2012
15 Kann 2008, Miller et al. 2010, Kann et al. 2011, Vanderkooi et al. 2010

Fig. 1.12 Aerial photo of *Microcystis aeruginosa* bloom in Copco Reservoir in September 2007. Photo: Jacob Kann.

Fig. 1.13 Aerial photo of *Microcystis aeruginosa* bloom in Iron Gate Reservoir in September 2007. Photo: Jacob Kann.

Fig. 1.14 (Above right) Farm land along the shore of Upper Klamath Lake. Photo: David Garden.

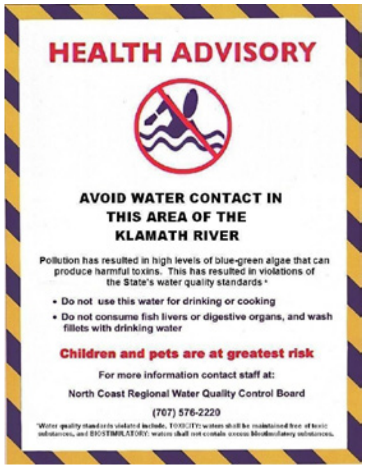
Fig. 1.15 (Below) Health advisory postings occur in June-October during intense blue-green algal blooms in Copco 1 and Iron Gate Reservoirs, and downstream reaches of the Klamath River.

unclear, algal production is not well-supported in the Keno Impoundment and algal biomass declines with increasing distance downstream of Link River Dam.[16] Particulate organic matter, derived from the upstream-generated blue- green algae, die and decay, settling to become reservoir sediments that require large amounts of oxygen to decompose (Figure 1.6). Modeling results indicate that sediment oxygen demand in the Keno Impoundment is the largest contributor to oxygen depletion in this portion of the Klamath River, followed in importance by organic matter that is suspended in the water column as both particulate and dissolved forms.[16] There are also numerous agricultural drains flowing into the Keno Impoundment including the Klamath Straits Drain (KSD), which has historically operated year-round, and the Lost River Diversion Channel, which generally diverts flow away from the reservoir during the irrigation season but discharges to the reservoir for the remainder of the year (Figure 1.11). The effects of the KSD and the Lost River Diversion Channel on the Keno Impoundment nutrient concentrations are important and variable by year,[17] depending on their relative flow contributions, but their effect on dissolved oxygen is substantially less than that of algae from Upper Klamath Lake.[18]

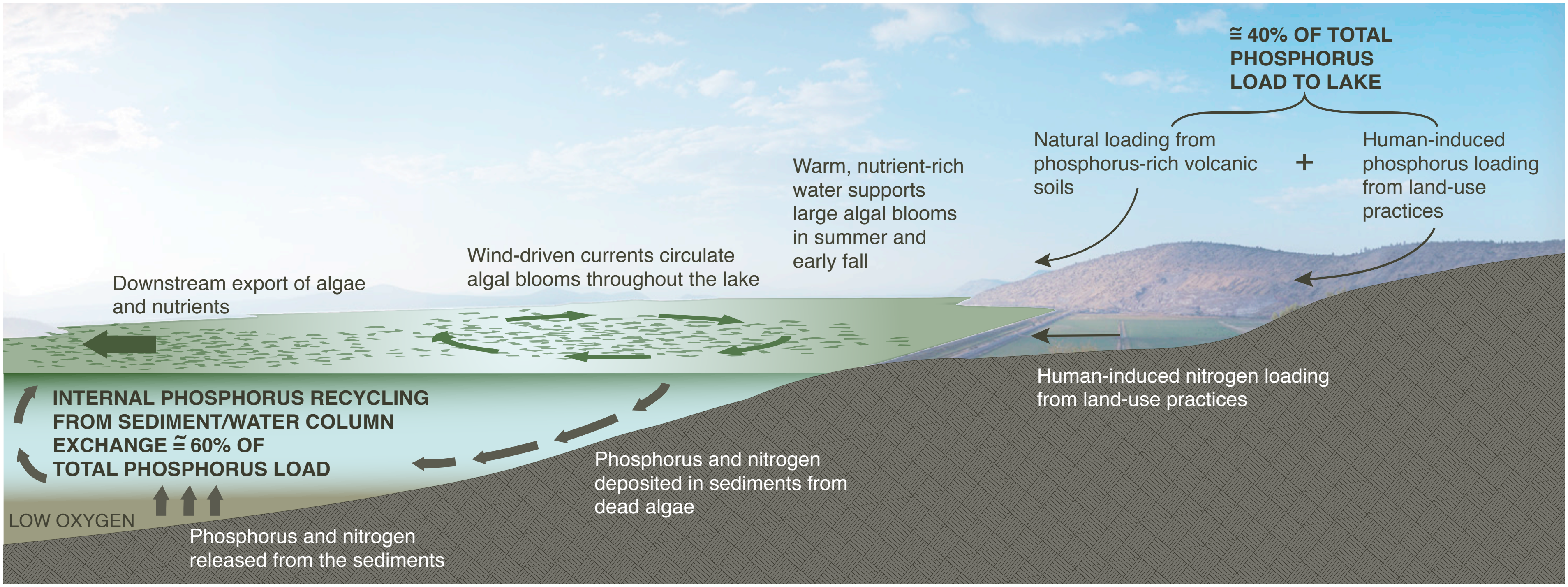
16 Sullivan et al. 2011
17 Stillwater Sciences et al. 2012

In the Upper Klamath River, downstream of the Keno Impoundment, levels of algae rapidly decline as the system changes from a lake to a turbulent river environment that is not favorable for growth of free-floating algae.[19] Nearing the Oregon-California stateline, the river and J.C. Boyle Reservoir are not impaired by algal growth, perhaps due to short residence times and generally shallow water. However, once the river reaches the larger Copco and Iron Gate reservoirs, the lake environment, with deep waters and longer residence times, supports significant levels of the toxigenic species *Microcystis aeruginosa* (Figures 1.12 and 1.13). The timing of *Microcystis aeruginosa* blooms appears to be related to an influx of a specific form of nitrogen (nitrate) that is a breakdown product of algal proteins following die-offs of *Aphanizomenon flos-aquae* blooms in Upper Klamath Lake.[20] The summer/fall blooms of *Microcystis aeruginosa* in the reservoirs produce cell densities and microcystin toxin levels that can exceed public health guidelines (Figure 1.15) during summer and early fall within the reservoirs[21] and in the river downstream,[22] which

18 Sullivan et al. 2009
19 Kann and Asarian 2006
20 Kann and Asarian 2007, Asarian and Kann 2011



21 Jacoby and Kann 2007, Kann and Corum 2009, Raymond 2010a
22 Kann and Bowman 2011, Fetcho 2008



can result in the bioaccumulation of microcystin in a variety of fish species and freshwater mussels.[23]

WHERE DO THE EXCESSIVE AMOUNTS OF PHOSPHORUS IN UPPER KLAMATH LAKE COME FROM?

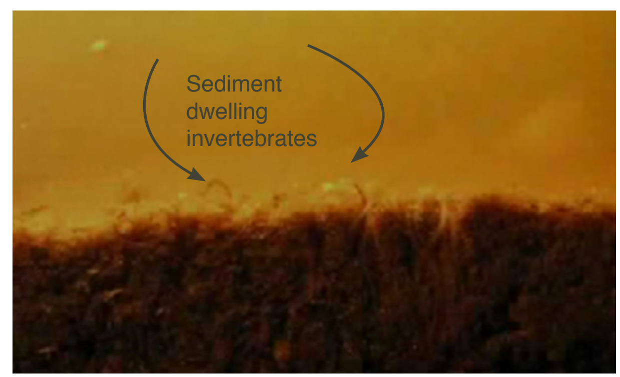
Watershed activities beginning in the late 1800s and accelerating though the 1900s, such as timber harvest, wetland draining, livestock grazing, cropland irrigation, water diversions, and stream channelization increased loading of nutrients, particularly phosphorus, to the lake. Phosphorus in Upper Klamath Lake originates from both *external* and *internally recycled* sources. An external source is one that comes from outside of the lake, such as tributaries carrying nutrients from surface runoff and erosion, or drainage pumped from lakeside farms (Figure 1.14). An internal source is one where externally loaded phosphorus retained within the lake sediments is then recycled back to the water column. Currently, external sources of total phosphorus to Upper Klamath Lake account for approximately 40% of the total phosphorus load (Figure 1.16).[24] The three major tributaries to the lake, the Wood River, Sprague River, and Williamson River, each contribute roughly a fifth of the lake's total external phosphorus load, despite their relative differences in drainage area and somewhat lesser differences in flow volume to the lake. Recent studies indicate that total phosphorus increases as water

23 Fetcho 2006, 2011; Kann 2008, et al. 2010, et al. 2011; Mekebri et al. 2009, CH2M Hill 2009a, 2009b; Prendergast and Foster 2010

24 Walker et al. 2012

Fig. 1.16 (Above) Seasonal nutrient and algae mechanisms in Upper Klamath Lake.

Fig. 1.17 (Below) Upper Klamath Lake sediments with invertebrates and bioturbation. Source: USGS, Kuwabara et al. 2007.



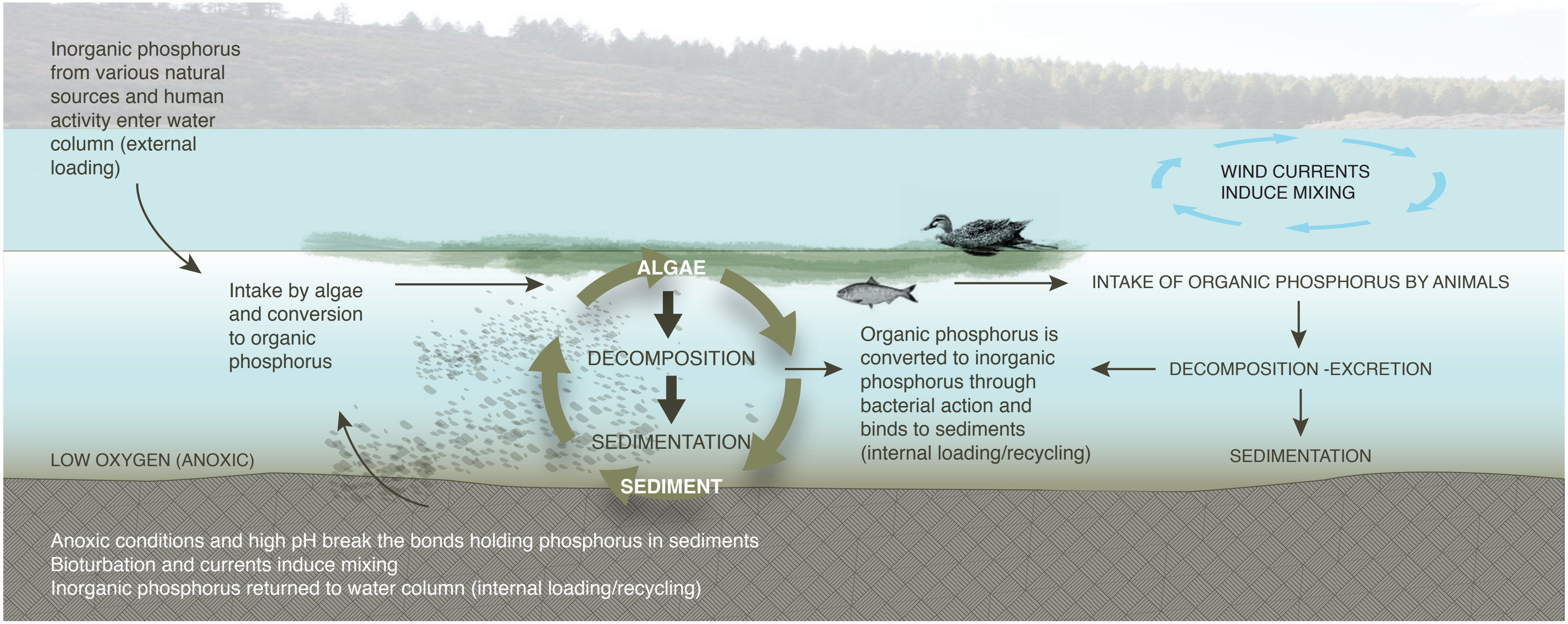


Fig. 1.18 Coupled sediment-water interactions.

moves downstream through pastures and irrigated grazing lands in each of these tributaries.[25]

The internal or recycled source of phosphorus to Upper Klamath Lake is its sediments, which release historically deposited phosphorus into the water column on a seasonal basis. During the summer and early fall when algae blooms occur, internal recycling from the sediments is the largest source of phosphorus for algae in Upper Klamath Lake, accounting for just over 60% of total loading (Figure 1.16).[26] A number of physical, chemical, and biological factors are responsible for the high rates of internal phosphorus loading. These include algal growth and decay, low oxygen conditions, processing by microbes, high pH, burrowing and/or mixing by sediment dwelling organisms (Figure 1.17), diffusion, and re-suspension of sediments by wind and/or wave action. These processes operate at varying time and spatial scales in the lake.[27] However, phosphorus in lake sediments and phosphorus in the water column are coupled, meaning that disturbing one component of the system will cause other components to adjust (Figure 1.18). Because sediment and water column phosphorus concentrations are in equilibrium, complete depletion of sediment phosphorus may not be necessary in order to see improvements in Upper Klamath Lake water quality.[28] Scientists are working to determine if there is a critical threshold for phosphorus levels in Upper Klamath Lake sediments, below which large seasonal algae blooms would no longer be supported by internal recycling rates.

CAN THE PHOSPHORUS AND ALGAE PROBLEM BE FIXED?

As part of the analyses conducted for development of the Upper Klamath Lake TMDL (see text box on page 10), utilizing extensive water quality monitoring

25 Walker et al. 2012
26 Kann and Walker 1999, ODEQ 2002
27 Barbiero and Kann 1994; Laenen and LeTourneau 1996; Kuwabara et al. 2007, et al. 2009, et al. 2012; Simon et al. 2009; Simon and Ingle 2011
28 Wood et al. 2012

TOTAL MAXIMUM DAILY LOADS (TMDLs) IN THE UPPER KLAMATH BASIN

Section 303(d) of the Clean Water Act (CWA) requires states to identify water bodies that do not meet water quality standards (objectives) and are not supporting their designated beneficial uses. These water bodies are considered to be impaired with respect to water quality. Oregon Department of Environmental Quality (ODEQ) and California North Coast Regional Water Quality Control Board (NCRWQCB) have both included the Upper and Lower Klamath Basin and specifically, the Klamath and Lost Rivers on their CWA Section 303(d) lists of water bodies with water quality impairments. For water bodies included on the 303(d) list, the state with jurisdiction over the water body must develop total maximum daily loads (TMDLs) to protect and restore beneficial uses of water. TMDLs (1) estimate the water body's capacity to assimilate pollutants without exceeding water quality standards; and, (2) set limits on the amount of pollutants that can be added to a water body while still protecting identified beneficial uses. ODEQ and NCRWQCB cooperated on the development of TMDLs for the impaired water bodies of the Upper and Lower Klamath Basin. TMDLs have been adopted for Upper Klamath Lake and its tributaries. TMDLs have also been adopted for the Klamath River in California and are pending USEPA approval for the Klamath River (and Lost River) in Oregon. Additional information regarding the Oregon TMDLs can be found on ODEQ's website (http://www.deq.state.or.us/WQ/TMDLs/klamath.htm) and for the California TMDLs on the NCRWQCB website (http://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls).

Fig. 1.19 Klamath Tribe water quality technicians measuring pumped discharge from the Wood River Ranch into Sevenmile Creek; circa 1992. Photo: Jacob Kann.

data and modeling of the phosphorus, algal bloom, and pH dynamics, the Oregon Department of Environmental Quality (ODEQ) has determined that reducing external phosphorus loads from human sources would be the most effective means of improving water quality conditions in the lake.[29]

29 ODEQ 2002

Achieving the TMDL loading target of 109 metric tons/year of total phosphorus would require a 40% reduction in external phosphorus loads. Limiting external phosphorus contributions to the lake is anticipated to decrease the extent of early season blooms of *Aphanizomenon flos-aquae*, which would bring less available nitrogen into the water column and thus limit the extent of later season blooms of other blue-green algae, including the toxin producing *Microcystis aeruginosa*. However, since internal sediment recycling of phosphorus is currently such an important source of phosphorus to summertime algal blooms, the internal sediment release must be reduced as well. If external loads could be sufficiently reduced, the internal load would also eventually be reduced, after a period of equilibration (years to decades). It may be possible to accelerate this process by applying active management techniques to directly address the internal load.

It may not be necessary to remove all of the phosphorus in the sediments (or water column) of Upper Klamath Lake. The sediment and water column are a coupled system such that decreases in sediment levels of phosphorus would result in proportional decreases in water column phosphorus, and hence available phosphorus for algae. A new equilibrium condition would be established that is characteristic of a healthier ecosystem with fewer water quality problems in Upper Klamath Lake and in downstream reaches of the Klamath River.[30]

Multiple efforts are being undertaken by agency, county, and state entities to improve water quality in the Upper Klamath Basin. Some are ongoing while others are anticipated through the TMDL and NPS reduction programs.[31] Examples of Oregon projects anticipated to have significant benefits include water quality management plans (e.g., for City of Klamath Falls), water quality restoration plans (e.g., for Upper Klamath Lake tributaries), and land use and management plans (LRMPs) (e.g., for USFS and BLM). In California, examples include the irrigated

30 T. Wood (USGS), KRWQ Workshop, September 2012
31 WQST 2011

lands discharge program (e.g., tailwater discharges, degradation of riparian areas, and destabilized stream banks), timber harvest plans (for non-federal lands), and forest management plans (for federal lands), including implementation of best management practices (BMPs).[32]

Recent data indicate that the use of BMPs on agricultural lands appears to have contributed to a decreasing trend in total phosphorus concentrations in some tributary segments upstream of Upper Klamath Lake.[33] Additionally, recent re-flooding of former lakeside wetlands has also reduced the external load to the lake.[34]

The large-scale water quality improvement approaches considered during the workshop and discussed in this report represent techniques that could be implemented at a large-scale, in concert with the continued implementation of BMPs and management plans already underway in the Upper Klamath Basin, to treat both the symptoms and causes of elevated phosphorus and nitrogen levels and substantially improve conditions in both the short- and long-term.

HOW DO SOCIAL AND CULTURAL FACTORS INFLUENCE THE PLANNING FOR KLAMATH BASIN WATER QUALITY IMPROVEMENT PROJECTS?

In addition to consideration of pollutant removal effectiveness, cost efficiency, and potential effects on aquatic dependent organisms, the successful design and implementation of basin-scale water quality improvement projects requires consideration of social and cultural factors. Fully feasible water quality improvement projects must be consistent with and support local social norms and cultural traditions within the Upper Klamath Basin.

32 WQST 2011
33 J. Kann, AES, personal communication, January 2013
34 Walker et al. 2012

For example, the Upper Klamath Basin is home to the Klamath Tribes who have historically depended on healthy fish populations as an important part of their diet and way of life. Agriculture is also an important part of the upper basin culture and economy with the production of alfalfa, hay, grains, potatoes, onions, and livestock (among others) producing valuable economic activity that extends beyond the substantial value of the commodities produced to support businesses and jobs in affiliated sectors.[35]

To ensure that recommended water quality improvement projects support local social and cultural traditions, Upper Klamath Basin experts on agricultural operations and tribal fisheries were invited to participate as contributing experts to the workshop and review of this report. Workshop participants included technical consultants to the Klamath agricultural community including the USDA Natural Resource Conservation Service, the Klamath Soil and Water Conservation District, and Klamath Water Users Association. Representatives of the Yurok, Karuk, and Klamath Tribes also participated in the workshop and review of the final report. Including input from agricultural engineers, conservationists, and operators as part of this project, along with tribal representatives, allows for the design of multi-objective projects. An inclusive approach is important for identifying and, ultimately, recommending projects that can be supported by local landowners and tribal members.

35 WEF 2011

In addition, project evaluation criteria used at the workshop included water use/water rights considerations. Consideration of water use is critical to successful project design. It also avoids placing additional burdens on an already over-allocated water supply. Other evaluation criteria included consideration of infrastructure challenges and identifiable social or cultural impacts; these types of criteria can help ensure that project designs do not disrupt or interfere with land uses such as agricultural operations. For example, the diffuse source (decentralized) treatment wetlands (DSTWs) are small and use low-tech design features, such that they can be integrated into existing agricultural operations without additional water use, and minimal- to no-water rights permitting actions or removal of existing lands from agricultural operation.

Because of the scale of potential projects, it is important to involve local experts carefully and apply a wide range of evaluation criteria such that selected projects positively contribute to the cultural and social landscape of the Upper Klamath Basin.