Klamath River Hydroelectric Project

Interim Measures Implementation Committee:

Interim Measure 11

Development of a Priority List of Projects:

Phase 1 Final Report

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Appendix A: Matrix of Project Candidate Categories

1 Introduction

The Klamath Hydroelectric Settlement Agreement (KHSA; as amended on April 6, 2016) includes Interim Measure 11 (Interim Water Quality Improvements), which is intended to address water quality improvement in the Klamath River during the interim period leading up to potential dam removal by a designated Dam Removal Entity (DRE). Regarding Interim Measure (IM) 11, the KHSA states "The emphasis of this measure shall be nutrient reduction projects in the watershed to provide water quality improvements in the mainstem Klamath River, while also addressing water quality, algal and public health issues in Project reservoirs and dissolved oxygen in J.C. Boyle Reservoir." IM 11 calls for PacifiCorp to fund such projects in consultation with the Interim Measures Implementation Committee[1] (IMIC).

One of the IM 11 activities during the 2016-2017 period includes the *Development of a Priority List of Projects*. The purpose of this effort is to develop a Priority List of Projects (PLP) to be implemented after the DRE's acceptance of a surrender order from the Federal Energy Regulatory Commission (FERC; per the KHSA). The PLP is being informed by, among other things, the information gained from the specific studies conducted to-date under IM 11. Following the DRE's acceptance of the FERC surrender order, PacifiCorp shall provide funding of up to $5.4 million for implementation of projects (as recommended by the PLP) and subsequently approved by the Oregon Department of Environmental Quality (ODEQ), the North Coast Regional Water Quality Control Board (Regional Board), and the State Water Resources Control Board (State Board), and up to $560,000 per year to cover project operation and maintenance expenses related to those projects during the interim period.

The development and implementation of the PLP will be accomplished in four phases:

- *Phase 1: PLP selection process*. A matrix of water quality improvement projects assessed or evaluated to-date was prepared, including summary findings regarding relative effectiveness and costs. Project categories were identified that are candidates for the PLP and those project categories were ranked. Top-ranked project categories were identified that will be subject to further more detailed assessment in Phase 2.
- *Phase 2: PLP selection process refinement.* Working from the process and information collected in Phase 1, gather additional information to create quantifiable metrics on the top-ranked projects identified in Phase 1. This will allow more definitive comparisons between project categories. Working with the IMIC, identify and determine the specific PLP using Phase 1 results and the additional data and information gathered in Phase 2. Define the process and governance anticipated to be necessary to fund, contract, and implement specific project activities from the PLP. Determine estimated funding allocations for the project categories to be implemented from the PLP. As per IM 11, final approval of the PLP will come from ODEQ, Regional Board, and State Board.
- *Phase 3: Establish implementation framework.* Put in place the governance process, including possible fiscal agent, for project implementation (as defined in Phase 2). Issue Requests for Proposals soliciting potential contractors to develop plans and designs of specific projects to be implemented from the PLP. Select contractors for project implementation, obtain necessary permits, and other regulatory approvals of projects.
- *Phase 4: Implementation.* Using projects selected in Phase 3, apply funding and implement projects from the PLP.

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[1] The IMIC is comprised of representatives from PacifiCorp and other parties to the KHSA (as amended on April 6, 2016). The purpose of the IMIC is to collaborate with PacifiCorp on ecological and other issues related to the implementation of the Non-Interim Conservation Plan Interim Measures set forth in Appendix D of the amended KHSA.

This report describes the approach and results of Phase 1 activities. As documented in this report, PacifiCorp coordinated and facilitated a process with the IMIC to complete Phase 1, including to: (1) prepare a matrix of water quality improvement projects assessed or evaluated to-date; and (2) conduct a workshop (PLP Workshop in Yreka, California on February 22, 2017) and other communications with the IMIC to gather information, identify project categories that are candidates for the PLP, and rank the project categories.

Within this report, the term "projects" is used as a general term applicable to various water quality improvement projects, technologies, or activities that have been (or are being) assessed or evaluated for implementation in the upper Klamath Basin. These projects include both techniques for water quality improvement without a yet-known or identified physical location as well as specific projects proposed at particular locations. Also within this report, the projects or project-types identified in Phase 1 as candidates for PLP consideration are referred to as "project categories", since they do not yet represent specific Priority Projects.

2 Matrix of Candidate Project Categories

To facilitate IMIC's development of the PLP, PacifiCorp compiled a matrix of candidate project categories (Attachment A). The matrix includes 12 candidate project categories that have been assessed, evaluated, or studied to-date, including summary findings regarding relative effectiveness and costs. This matrix provides a basis for the IMIC to assess and score the various candidate project categories and to ultimately develop the final PLP (anticipated in Phase 2).

The attached matrix of candidate project categories (Appendix A) includes the following information:

- **Name of Technique or Project.** The short name used to define each of the particular candidate project categories.
- **Location.** The physical spot on the ground where the candidate project categories would be placed (if known). Locations could be site-specific (e.g., at Link River dam) or more broadly implemented (e.g., in the Wood River basin).
- **Goals, Objectives, Assumed Capability.** Summary of the goals, objectives, and assumed capability of the candidate project category. The goals and objectives indicate what the candidate project category is intended to achieve in terms of water quality benefits. The assumed capability addresses anticipated effectiveness of the candidate project category in achieving the intended water quality benefits.
- **Design Features and Elements.** Summary of the anticipated conceptual layout, facilities, and operation of the candidate project category.
- **Potential Adverse Impacts and Uncertainties.** Summary of the potential adverse environmental impacts, if any, that might be associated with construction and operation of the candidate project category. Summary of the uncertainties of the candidate project category regarding its potential implementation and effectiveness.
- **Estimated Cost of Project.** Estimated costs of the candidate project category are itemized for potential pilot and full-scale application of the candidate project (if applicable). Each of these itemizations include design, construction, operation and maintenance, if data is available. Where sufficient cost information is available, an 'Annualized Cost Metric' (ACM) is estimated. The ACM is calculated as the sum total of all estimated costs for the project category (including for design, construction, operation and maintenance, if available) divided by the estimated duration of the project in years[2]. The ACM

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[2] In some cases, the total costs and project life-spans used in the ACM calculation are based on a number of years that differs from the estimated duration of the project category. For example, the costs for the Riparian Fencing and Grazing Management project category are estimated over 10 years (rather than 20 years as the long-term duration assumes). The main reason for difference is to maintain consistency with the source of cost information

provides an approximate cost per-year metric that can be used for cost comparisons across the project categories. For calculation simplicity, the ACM values reported in the matrix were not adjusted for inflation.

- **Duration.** The estimated lifetime or longevity of the candidate project category reported in months or years, if available. When years are not available duration is qualitatively referred to as 'short-term', 'intermediate term', or 'long-term'. For use in this matrix, short-term is a duration of 3 years or less; for example, pilot projects fall into this duration category. Long-term is a duration of 20 years or more (and including potentially permanent); for example, wetlands restoration falls into this duration category. Intermediate is any duration in-between (more than 3 and less than 20 years); for example, potential use of oxygenation facilities fall into this duration category.
- **Collaboration, Synergy, or Conflict.** If pertinent to a priority project category, information is provided on relevant practitioners in the area so as to allow consideration of possible collaboration, synergies, or conflicts. When there is the potential for additive benefits between two project categories, they are said to have synergistic benefits. For example, a demonstration wetland facility (DWF) would have potential synergies with diffuse source treatment wetlands (DSTWs) or natural wetlands restoration, because a DWF could provide research opportunities for assessing effectiveness of DSTWs or restored natural wetlands. Conflicts between two project categories are when the benefit of one project category is not possible if another project category is undertaken. An example of a conflict could be where two wetland projects, say a DSTW and a restored natural wetland are targeted at the same physical location. Another example could be the conflict between algae biomass removal which targets the same material as particulate organic matter removal making them potentially redundant in terms of their purpose and need.
- **Information Sources.** Key reference sources that describe or support the summary statements in the matrix for a given project category.

3 Approach to Identify, Screen, and Rank Potential Project Categories

A simple structured approach was used to identify, screen, and rank potential project categories to consider advancing for consideration for the final PLP (anticipated in Phase 2). This structured process featured the direct input and involvement of the IMIC to address screening and ranking of the candidate project categories in an understandable, objective, and transparent way. This process provided the additional benefit of promoting discussion and agreement among stakeholders about the objectives to be addressed and to help resolve potentially differing perspectives within the IMIC concerning potential projects categories.

3.1 Step 1: Identify Potential Project Categories for Consideration

Based on initial discussion with the IMIC, PacifiCorp compiled a comprehensive list of potential project categories for consideration (Table 1). This comprehensive list was created from available source material that includes previous IM 11 technical reports (CH2M 2014; Lyon et al. 2009; Watercourse 2013, 2014a, 2014b), the IM 10 Klamath Water Quality Conference report (Stillwater et al. 2013), and reports from water quality

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which is sometimes different than the duration used in the matrix. Extension of costs for life-spans beyond those in the source material did not seem appropriate.

research work by the Bureau of Reclamation and U.S. Geological Survey (Deas and Vaughn 2006; Mahugh et al. 2008; Sullivan et al. 2012, 2013).

Table 1. List of Candidate Project Categories and Their Relationship to the Primary Intent of IM 11

Candidate Project Category		IM 11 Emphasis and Benefits		
		Provide Nutrient Reduction Benefits to the Klamath River	**Address Water Quality and Algal Public Health Issues in Project Reservoirs**	**Improve Dissolved Oxygen in J.C. Boyle Reservoir**
1	Demonstration Wetland Facility (DWF)	X		
2	Diffuse Source (Decentralized) Treatment Wetlands (DSTWs)	X		
3	Natural Wetlands Restoration	X		
4	Riparian Fencing and Grazing Management	X		
5	Irrigation Efficiency and Water Management Projects	X		
6	Sediment Removal (Dredging) from Upper Klamath Lake	X		
7	Coagulant Injection to Sequester and Inactivate Nutrients	X		
8	Algal Filtration	X	X	
9	Algae Biomass Removal (Harvesting) at Link Dam	X	X	X
10	Particulate Organic Matter Removal from Klamath Source Water	X	X	X
11	Combined Sediment Sequestration and Oxygenation in Keno	X	X	X
12	Aeration/Oxygenation Systems at Keno Reservoir			X
13	J.C. Boyle Reservoir Dissolved Oxygen Improvement			X
14	Intake Barrier System for Water Quality Control at Iron Gate Dam		X	
15	Algal Conditions Management within Reservoir Coves		X	
16	Environmentally-Safe Algaecide Treatments in Reservoirs		X	

Notes:
X = Candidate Project or Technique addresses the indicated aspect of IM 11 intent.

3.2 Step 2: Screen to Ensure the Primary Intent of IM 11 is Addressed

This step helped the IMIC to first screen potential project categories to ensure that they address the primary intent of IM 11, which is:

> *"…nutrient reduction projects in the watershed to provide water quality improvements in the mainstem Klamath River, while also addressing water quality, algal and public health issues in Project reservoirs and dissolved oxygen in J.C. Boyle Reservoir".*

Based on this objective, the initial screening step helped to decide which candidate project categories to carry forward. This was accomplished by asking the question "Does the potential project or technology address the primary intent of IM 11 and in what manner of emphasis?"

The way these potential project categories address the intent of IM 11 was evaluated by comparing the purposes of these projects relative to the three stated component objectives of IM 11:

1. Provide nutrient reduction benefits to the Klamath River
2. Address water quality and algal public health issues in Project reservoirs
3. Improve dissolved oxygen in J.C. Boyle reservoir

Each of the potential project categories was first evaluated relative to which of the three IM 11 component objectives are addressed. From the comprehensive list of 16 potential candidate project categories (Table 1), the IMIC decided on a subsequent list of 12 candidate project categories that would be further evaluated using subsequent ranking steps (as described further below). The subsequent list of 12 candidate project categories include those listed in rows 1 to 12 in Table 1. Given the prospect of dam removal, the IMIC chose to not consider those potential project categories that apply principally to Project reservoirs (e.g., those listed in rows 13 to 16 in Table 1), although it was noted that the technologies represented by those potential project categories possibly could be transferrable to other waters in the basin (e.g., Upper Klamath Lake).

3.3 Step 3: Determine Specific Objectives that Projects Will Address

For the candidate project categories that passed the initial screening in Step 2, the IMIC's ranking approach then considered a series of key clearly-stated objectives that address a combination of important performance, operability, and cost factors. The intent of these objectives is to represent a straightforward, yet robust set of considerations by which the IMIC can assess the relative merit of candidate project categories. All of the objectives included in this analysis are considered by the IMIC as both important and necessary.

Each of these suggested objectives are defined in the form of specific questions (as stated below). These questions ask for a professional judgment on the relative ability of the candidate project category to address each objective, particularly relative to the other candidate project categories.

3.3.1 Performance Objectives

Performance objectives are as follows:

- Magnitude of Benefits. At the peak of functionality, how extensive and large (in magnitude) would Project benefits be relative to others?
- Sustainability of Performance. How would the Project benefits last over time and how would those benefits change as the project aged relative to others?
- Performance Uncertainty. How would the Project rate relative to others in the ability to avoid or manage risk and uncertainties (e.g., risks of cost overruns, time delays or treatment failures)?
- Potential Environmental Impacts. What is the potential of the Project to avoid, minimize, or mitigate negative impacts to the environment relative to others?

3.3.2 Operability Objectives

Operability objectives are as follows:

- Timeliness to Achieve Function. How soon can the project be implemented and operational?
- Ease of Implementation. How easy will the project be to design and construct relative to others?
- Ease of Permitting. How easy will the project be to permit (i.e., obtain regulatory approvals) relative to others?
- Ease of Operation and Maintenance. How easy and how flexible will project operations and maintenance be relative to others?

- Associated Safety Risk. How would the Project rate relative to others in the ability to avoid, minimize, or otherwise address potential safety risks to employees or the public?

3.3.3 Economics Objectives

Economics (or cost) objectives are as follows:

- Capital Costs Relative to Performance. What is the best cost value to design and build (implement) the project (i.e., best "bang for buck") relative to others?
- Operations and Maintenance (O&M) Costs Relative to Performance. What is the best cost value to operate and maintain the project (i.e., best "bang for buck") relative to others?

3.4 Step 4: Rank Candidate Project Categories Relative to Objectives

The final step in the ranking process was to score the relative ability of each proposed candidate project category to address the objectives from Step 3. The scoring for the candidate project categories was done at the PLP Workshop (held in Yreka, California on February 22, 2017) by nine workshop participants, which included representatives from the Oregon Department of Environmental Quality, North Coast Regional Water Quality Control Board, State Water Resources Control Board, Karuk Tribe, Klamath Tribe, Yurok Tribe, U.S. Fish & Wildlife Service, California Department of Fish & Wildlife, and PacifiCorp. Workshop participants discussed the PLP candidate project categories, and ranked the project categories based on the overall relative potentials of the candidate project categories to address the designated performance, operability, and cost objectives.

Each of the nine workshop participants estimated relative scores for each candidate project category on a scale of 1 to 5. A maximum score of 5 was assigned to the candidate project category (or categories) that will best address a specific objective relative to all the candidate project categories (i.e., best relative performer). Conversely, a minimum score of 1 was assigned to the candidate project category (or categories) that will least address a specific objective relative to all the candidate project categories (i.e., worst relative performer). Intermediate scores of 2, 3, or 4 were assigned to the other candidate projects in accord with how the workshop participants judged they align between the best and worst performers in terms of addressing the objectives. Because scores are relative to the project categories being evaluated it is possible to have scores of the same value for multiple projects (multiple 5's for example for project categories that could be equally the 'best' in a particular objective).

The spread of 1 to 5 used for the relative scoring scale is subjective. The 1 to 5 scale was straightforward to apply (i.e., less nuance in the numbers and gradations to consider than a scale with a greater spread), while also providing sufficient differentiation in total scores for a robust overall ranking of candidate projects.

4 Ranking Results

Scores from the nine workshop participants were averaged to generate a rank order of the candidate project categories (Table 2). The scores and resultant rank order indicates that there are definite top-ranked, mid-ranked, and bottom-ranked groupings of project categories.

The top-ranked grouping of four project categories includes: Diffuse Source (Decentralized) Treatment Wetlands (DSTWs); Riparian Fencing and Grazing Management; Irrigation Efficiency and Water Management Projects; and Natural Wetlands Restoration. These four project categories were consistently ranked relatively highly by all nine workshop participants. However, based on further discussion of these results, the workshop participants decided that the information in the matrix combined with their understanding of the top-ranked project categories, lacked the resolution to differentiate project categories for further development of the PLP. Therefore, at this point in the PLP selection process, the four project categories within this top-ranked grouping are considered comparable in terms of relatively ranking for PLP consideration.

Table 2. Scores and Rankings of Candidate Project Categories from the PLP Workshop Participants

Candidate Project Categories	Average Score	High Score Across Participants[1]	Low Score Across Participants[2]	Rank by Average Score
Diffuse Source (Decentralized) Treatment Wetlands (DSTWs)	4.9	5	4	1
Riparian Fencing and Grazing Management	4.8	5	4	2
Irrigation Efficiency and Water Management Projects	4.3	5	3	3
Natural Wetlands Restoration	4.0	5	2	4
Algae Biomass Removal (Harvesting) at Link Dam	2.2	4	1	5
Demonstration Wetland Facility (DWF)	2.1	4	1	6
Algal Filtration	1.4	3	1	7
Particulate Organic Matter Removal from Klamath River	1.3	3	1	8
Coagulant Injection to Sequester and Inactivate Nutrients	1.2	2	1	9
Oxygenation in Keno Reservoir	1.2	2	1	9
Sediment Removal (Dredging) from Upper Klamath Lake	1.2	3	1	9
Combined Sediment Sequestration and Oxygenation in Keno	1.1	2	1	12

1: Highest total score for that project category amongst the individual organizations that scored the project.

2: Lowest total score for that project category amongst the individual organizations that scored the project.

The mid-ranked grouping of two project categories includes: Algae Biomass Removal (Harvesting) at Link Dam; and Demonstration Wetland Facility (DWF). These two project categories were ranked at a relatively high score by some workshop participants, but at a relatively low score by other participants. Based on further discussion of these results, the workshop participants decided that the Algae Biomass Removal (Harvesting) at Link Dam project category should be forwarded for further PLP consideration because of the current commitment under IM 11 to evaluate the feasibility of conducting a pilot study (demonstration) of this project category. Therefore, the Algae Biomass Removal (Harvesting) at Link Dam project category will be included in the top-ranked grouping for further PLP consideration in Phase 2. Conversely, the workshop participants decided that the DWF project category should not be forwarded for further PLP consideration because a specific location, sponsors, and funding sources for the DWF are not evidently available (as discussed further in Section 4.2 below).

The remaining six project categories comprise the low-ranked grouping. These six project categories were consistently ranked at relatively low or middling scores by all nine workshop participants. Based on further discussion of these results, the workshop participants decided that these six candidate project categories should not be included in further PLP consideration for reasons as discussed further in Section 4.2 below.

4.1 Top-Ranked Project Categories

The top-ranked PLP candidate project categories (in no particular order) include:

- Diffuse Source (Decentralized) Treatment Wetlands
- Natural Wetlands Restoration

- Riparian Fencing and Grazing Management
- Irrigation Efficiency and Water Management Projects
- Algae Biomass Removal (Harvesting) at Link Dam

The rationale that workshop participants gave for the relative ranking of these project categories, based on designated performance, operability, and cost objectives are summarized below.

4.1.1 Diffuse Source (Decentralized) Treatment Wetlands

4.1.1.1 Performance

The rationale for the ranking of the DSTWs project category relative to designated performance objectives includes:

- DSTWs are a well-researched restoration technique that could be very effective in reducing nutrient and sediment load, particularly relative to other candidate project categories. Constructed treatment wetlands such as DSTWs have been shown to be effective at removing a range of pollutants from incoming waters, including total suspended solids, phosphorus, nitrogen, metals, organic compounds, and bacteria and pathogens.
- Individual DSTWs have a relatively small footprint, which could allow for more efficient targeting and scaling of treatments using DSTWs in the basin or particular areas in the basin. They would allow wetland-based water treatment to occur throughout a watershed, rather than at the bottom or just prior to discharge into a large receiving water body. Design and implementation of networks of small-scale DSTWs can achieve the benefits of larger contiguous wetland ecosystem that is functioning in multiple locations throughout a watershed.
- DSTWs can be targeted to address nutrient loading upstream of and into Upper Klamath Lake, which is key to achieving nutrient reduction goals as specified in the Upper Klamath Lake and Klamath River Total Maximum Daily Loads (TMDLs). A network of DSTWs would decrease external loading of phosphorus and nitrogen to Upper Klamath and Agency lakes and may help decrease nuisance algal blooms in these waterbodies. Thus, DSTWs upstream of and into Upper Klamath Lake have greater benefits relative to projects intercepting and treating nutrient loads farther downstream.
- DSTWs would have a high level of synergy with riparian fencing, grazing management, irrigation efficiency, and water management project categories, which are other top-ranked project categories as summarized below. All of these project categories would synergistically lead to a reduction of nutrients entering Upper Klamath Lake and thereby address the primary cause of water quality impairments in the basin.
- DSTWs scored high in Rankings of the 2012 Klamath River Water Quality Workshop (Stillwater et al. 2013).
- Uncertainties: To generate the necessary nutrient reduction, many DSTWs would be necessary. The number of available and willing sponsors and landowners required to support the number of necessary DSTWs seems uncertain. Other uncertainties are associated with the magnitude and reliability of effectiveness.

4.1.1.2 Operability

The rationale for the ranking of the DSTWs project category relative to designated operability objectives includes:

- Because DSTWs have a relatively small footprint and are typically located in pastures, they have relatively low impact on land owner operations and infrastructure, and they are less likely to face permitting issues relative to other candidate project categories.

- Once built, DSTWs operate mostly passively, and thus have relatively modest operations and maintenance requirements over time.
- The relatively small footprint of individual DSTWs means that many DSTWs would likely need to be implemented in a systematic or packaged fashion to contribute significantly to nutrient and sediment reduction at the basin scale. Therefore, implementation timeliness is considered relatively low because it may take many years to reach build-out. However, once the individual DSTWs are all in place, the complete network would function much like a landscape-level natural wetland-type filtration system.
- The DSTWs project category is one of five categories whose functional life-span is projected to be long-term lifetime. This means that projects implemented under this category are expected to have a duration on the order of 20 years or more, and ideally permanent.

4.1.1.3 Economics

The rationale for the ranking of the DSTWs project category relative to designated cost objectives includes:

- The ACM for the DSTWs project category is estimated at $223,300 per 50 units (each DSTW being 1 acre in size), which ranks 1st lowest (least expensive) of the 12 candidate project categories.
- Although DSTWs require some engineering and earth-moving, they are relatively cheap to construct compared to other PLP candidate project categories. Construction costs are estimated at $663,000 per 50 units (Stillwater et al. 2013).
- Once built, DSTWs operate mostly passively, and thus have relatively low operations and maintenance costs. O&M costs are estimated at $130,000 over 10 years[3] for 50 units (Stillwater et al. 2013).

4.1.2 Natural Wetlands Restoration

4.1.2.1 Performance

The rationale for the ranking of the Natural Wetlands Restoration project category relative to designated performance objectives includes:

- This project category ranked high because the benefit of fringe wetlands in Upper Klamath Lake and Agency Lake is well known and widely recognized (Snyder and Morace 1997; Aldous et al. 2005; Stevens and Tullos 2011; CH2M Hill 2012; Hayden and Hendrixson 2013; Stillwater Sciences et al. 2013). This type of project is highly sustainable in the long-term because it requires little maintenance and is designed to function without intervention or management.
- Natural wetlands restoration can be targeted to address nutrient loading to Upper Klamath Lake and Agency Lake, which is key to achieving nutrient reduction goals as specified in the Upper Klamath Lake and Klamath River TMDLs. Thus, natural wetlands restoration around Upper Klamath Lake and Agency Lake have greater benefits relative to projects intercepting and treating nutrient loads farther downstream. Note that because it is envisioned to be located at Upper Klamath Lake or Agency Lake, this project category would not have the additional benefit of reducing the nutrient loads and potentially achieving the goals of the Sprague River TMDL, relative to other project categories.
- Once implemented, natural wetlands restoration would provide long-term nutrient reduction and water quality improvements in the Klamath River system, while restoring important habitat and potentially ecosystem function. Wetland restoration would be designed to decrease external loading of phosphorus and nitrogen to Upper Klamath Lake, Agency Lake, and Keno reservoir.

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[3] Although DSTWs are considered a long-term project category (i.e., durable over a period of 20 years or longer), 10 years are reported here to maintain consistency with Stillwater et al. (2013) source of cost information.

- Wetlands restoration also could provide habitat for the endangered shortnose and Lost River suckers if located in Agency Lake or Upper Klamath Lake.
- This project category has potential synergies with other wetland restoration actions (e.g., DSTWs, DWF) because resulting nutrient removal would be additive.
- Natural wetlands restoration scored high in Rankings of the 2012 Klamath River Water Quality Workshop (Stillwater et al. 2013).
- Uncertainties: location and property for wetlands restoration; sponsors and funding sources; magnitude and reliability of effectiveness; extent of routine maintenance and how maintenance relates to function over time (i.e., does an unmaintained wetland decrease in function?).

4.1.2.2 Operability

The rationale for the ranking of the Natural Wetlands Restoration project category relative to designated operability objectives includes:

- Wetland projects can be small-scale (1 acre to 10s of acres), large-scale (100s to 1,000s of acres) or in-between, depending on resource management needs and site constraints. Projects can be located anywhere degraded naturally-occurring wetlands already exist. This could be in downstream portions of a watershed to capture pollutants before they leave the system or are discharged into a receiving waterbody, or they can be scattered throughout a watershed to provide on-site treatment and habitat.
- The time required to construct Natural Wetlands Restoration projects could be relatively long because it would be necessary to identify and secure lands. Additionally, because levee removal and flooding are part of these projects, permitting may be a lengthy process even though stakeholders possibly to be involved in these projects may have gone through similar processes for the nearby Williamson River Delta wetland restoration project.
- Once built, Natural Wetlands Restoration projects operate mostly passively, and thus have relatively modest operations and maintenance requirements over time. This type of project is highly sustainable in the long-term because it requires virtually no maintenance and is designed to function without intervention or management.
- The Natural Wetlands Restoration project category is one of five categories whose project life is projected to be long term. This means that it is expected to have a project life on the order of 20 years or more, and ideally be permanent.

4.1.2.3 Economics

The rationale for the ranking of the Natural Wetlands Restoration project category relative to designated cost objectives includes:

- The ACM for the Natural Wetlands Restoration project category is estimated at $765,500, which ranks 4th lowest of the 12 candidate project categories (including a $275,000 pilot project).
- The Natural Wetlands Restoration project category would require significant construction costs. For example, for restoration of wetlands in the upper Klamath Basin, Stillwater et al. (2013) estimated construction costs of $17,000,000 for 1,600 acres. Once built, natural wetlands would operate mostly passively; however, Stillwater et al. (2013) estimated operations and maintenance costs at $21,000,000 over 50 years for 1,600 acres.
- In considering the above cost estimates, it is noteworthy that costs for wetland creation and restoration projects can be highly variable, depending on project size, complexity, and site-specific conditions. Rehabilitation of wetlands may be more cost effective that wholesale creation of new wetlands. For context, additional information on reported costs for wetland creation and restoration

projects elsewhere in the U.S. is provided in Appendix A. It is worth noting that none of these costs (e.g., Stillwater et al 2013; Appendix A) include land acquisition costs.

4.1.3 Riparian Fencing and Grazing Management

4.1.3.1 Performance

The rationale for the ranking of the Riparian Fencing and Grazing Management project category relative to designated performance objectives includes:

- This project category is ranked relatively high given that the benefits of riparian fencing and grazing management are well known and widely recognized (Barry et al. 2010; Upper Klamath Basin Comprehensive Agreement 2014; TFT 2015). A number of studies indicate that Riparian Fencing and Grazing Management can be very effective at managing sediment loads in surface runoff (Welsch 1991; Wenger 1999; Kallestad and Swanson 2009). Walker et al. (2015) closely correlated sediment load and total phosphorus in the Upper Klamath Basin.
- Restoration and management of riparian corridors along streams that flow into Upper Klamath Lake would reduce sediment loads (and sediment-bound nutrients) in the streams. Reducing sediment loads is a priority in the Upper Klamath Basin because of the relatively high phosphorus content of soils and the fact that both the Upper Klamath Lake Drainage and Klamath River TMDLs point to external phosphorus loading from the basin above Upper Klamath Lake as a driver of water quality throughout the system (Upper Klamath Basin Comprehensive Agreement 2014; ODEQ 2002, 2010).
- Specific projects in the Sprague River valley and tributaries have demonstrated substantial improvements in river form and function and riparian condition will appropriate riparian buffers and grazing management (Barry et al. 2010; Upper Klamath Basin Comprehensive Agreement 2014). Additionally, because these projects target nutrient loading upstream of Upper Klamath Lake, this type of project has greater benefits relative to projects intercepting and treating nutrient loads farther downstream.
- Protection and restoration of riparian buffers is functionally similar to (and therefore synergistic with) wetland restoration and enhancement. Like wetlands, riparian buffers can provide water quality enhancement through retention or filtering of sediments and nutrients (although the specific mechanisms causing this retention or filtering in riparian buffers may differ from wetlands). Like wetlands, riparian buffers also can provide habitat value. For these reasons, riparian buffers are considered to be of a similar functional category as Natural Wetlands Restoration and DSTWs.
- Uncertainties: To generate the necessary nutrient reduction, many miles of riparian protection and enhancement would be necessary. It is uncertain at this time if sufficient willing sponsors and landowners are available to meet this need. Riparian Fencing and Grazing Management would need to be implemented through voluntary landowner actions or agreements (perhaps through something like the Upper Klamath Basin Comprehensive Agreement). Other uncertainties are associated with the magnitude and reliability of effectiveness of nutrient and sediment reductions from Riparian Fencing and Grazing Management projects.

4.1.3.2 Operability

The rationale for the ranking of the Riparian Fencing and Grazing Management project category relative to designated operability objectives includes:

- For ease of implementation, this category ranks relatively high because projects are relatively simple, design and permitting requirements are limited or not necessary, operation and maintenance is limited, and there is little risk associated with this type of restoration work. However, timeliness will depend on willing landowners and the time it will take to get all the fencing in place, which would increase the time necessary to achieve full function.

- The Riparian Fencing and Grazing Management project category is one of five project categories whose project life is projected to be long-term. This means that it is expected to have a project life on the order of 20 years or more, and ideally permanent.

4.1.3.3 Economics

The rationale for the ranking of the Riparian Fencing and Grazing Management project category relative to designated cost objectives includes:

- The ACM for the Riparian Fencing and Grazing Management project category is estimated at \$3,560,600, which ranks 6th lowest (at the midpoint) of 12 candidate project categories.
- The Riparian Fencing and Grazing Management project category would require substantial implementation costs, estimated at \$35,606,000 over 10 years[4], assuming broad geographic coverage in the Sprague, Williamson, and Wood River subbasins, including main stems and tributaries. These cost estimates are based on Barry et al. (2010), who estimated implementation costs in the above subbasins over a 10-year period for riparian corridor management agreements; construction of 318 miles of fencing and offstream watering; maintenance of 548 miles of existing fences and managing of riparian corridor plants.

4.1.4 Irrigation Efficiency and Water Management Projects

4.1.4.1 Performance

The rationale for the ranking of the Irrigation Efficiency and Water Management project category relative to designated performance objectives includes:

- Enhanced management and efficiency of irrigation and associated return flows along streams that flow into Upper Klamath Lake can reduce sediment loads (and sediment-bound nutrients) and irrigation tailwater discharges to the streams. Minimizing return flow associated with irrigation is a potential priority in the Upper Klamath Basin because of the relatively high phosphorus content of soils and the fact that both the Upper Klamath Lake Drainage and Klamath River TMDLs point to external phosphorus loading from the basin above Upper Klamath Lake as a driver of water quality throughout the system (ODEQ 2002, 2010).
- This project category is ranked relatively high because the benefits of irrigation efficiency and more mindful irrigation practices contribute to reductions in nutrient and sediment load. Additionally, because these projects target nutrient loading upstream of and into Upper Klamath Lake and, this type of project has greater benefits relative to projects intercepting and treating nutrient loads farther downstream.
- If all potential conservation practices are implemented on irrigated lands, on-farm water use efficiency could reduce water use (and hence potential runoff) by up to 25 percent in the Upper Klamath Basin, which would result in a concomitant reduction in nutrient and sediment loadings to adjacent waterways (Reclamation 2012, 2016). An additional potential two to five percent reduction in water use could be achieved by increasing management in upland range and forestland areas.
- These irrigation efficiency and water management efforts rank relatively high because they would contribute to improved water quality in adjacent canals and streams by preventing excessive soil leaching and runoff into local water sources. Additionally, water conservation practices that reduce tailwater runoff from irrigated fields can provide extensive improvements in water quality (Shock and Welch 2011; Reclamation 2016).

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[4] Although Riparian Fencing and Grazing Management is considered a long-term project category (i.e., durable over a period of 20 years or longer), 10 years are reported here to maintain consistency with Barry et al. (2010).

- Transfer of some portion of the conserved water to environmental purposes could provide several additional benefits: reduced need to fluctuate lake levels helps to protect sucker spawning habitat in Upper Klamath Lake; reduced fluctuation can also reduce the amount of phosphorous mobilized from wetting/drying near shore lakebed; more water would be available for flushing flows in the lower Klamath River; and more water in the stream to buffer temperature changes from ambient conditions.
- Irrigation Efficiency and Water Management Projects ranked relatively high because they would address some of the same non-point sources of sediment and nutrient loads (and therefore provide synergy with) as natural wetland restoration, DSTWs, and riparian buffers. Reduced runoff could reduce the nutrient loading that these other treatment systems are intended to manage, further increasing the overall reduction as many of these different projects come on line.
- Uncertainties: It is uncertain at this time as to how much and when Irrigation Efficiency and Water Management Projects would occur in the basin, depending on landowner incentives and funding availability to undertake the projects. Other uncertainties are associated with the magnitude and reliability of effectiveness that actually result from these projects in affecting the necessary nutrient reduction.

4.1.4.2 Operability

The rationale for the ranking of the Irrigation Efficiency and Water Management project category relative to designated operability objectives includes:

- Changes in irrigation supply and piping/updating of equipment should be straightforward to design and install. However, this project category received a low score in timeliness because it is expensive and slow to implement. Timeliness will depend on willing landowners and the time it will take to get all the improvements and facilities in place, which would increase the time necessary to achieve function.
- Compared to some other project categories with more passive restoration approaches (e.g., natural wetlands), more O&M would be required because piping and irrigation systems require more O&M.
- The Irrigation Efficiency and Water Management project category is one of five categories whose project life is projected to be long-term. This means that it is expected to have a project life on the order of 20 years or more, and ideally permanent.

4.1.4.3 Economics

The rationale for the ranking of the Irrigation Efficiency and Water Management project category relative to designated cost objectives includes:

- The ACM for the Irrigation Efficiency and Water Management project category is estimated at \$37,000,000, which ranks 2nd highest (2nd most expensive) of 12 candidate project categories. NRCS (2004) estimated \$200 million in construction costs and \$27 million in operations and maintenance over 20 years. However, this assumes broad geographic coverage of irrigated lands in the upper basin. Therefore, while expensive at the basin scale, the unit cost is only about \$570 per acre for construction and about \$80 per acre in operations and maintenance over 20 years.
- The above costs are based on NRCS (2004), who estimated costs of implementing improved irrigation and water conservation practices in the Upper Klamath Basin. The estimated costs are evaluated as applied on 350,000 acres of private farm and range lands in the basin over an assumed period of 20 years. These estimated costs pertain specifically to implementation costs, and therefore do not account for potential resulting economic benefits of these actions to other resources, such as enhanced water availability and benefits to fish and wildlife habitat.

4.1.5 Algae Biomass Removal (Harvesting) at Link Dam

4.1.5.1 Performance

The rationale for the ranking of the Algae Biomass Removal (Harvesting) project category relative to designated performance objectives includes:

- The removal of organic matter loads (achieved by harvesting of algae) emanating from Upper Klamath Lake could provide substantial water quality improvements in the Klamath River, and especially in Keno reservoir. Water quality improvements would come in the form of reductions in organic matter that are sufficient to decrease nutrients and biochemical oxygen demand to levels that demonstrably improve dissolved oxygen and lessen enrichment downstream. Algae harvest and removal at Link dam would not itself resolve the dissolved oxygen or downstream nutrient-loading problems, but could provide some incremental improvement.
- Algae Biomass Removal (Harvesting) at Link Dam would mainly addresses a symptom (algal biomass from Upper Klamath Lake) of a larger issue (external nutrient loading to the lake) and therefore the magnitude of the benefits is reduced relative to other projects; for this reason, it was ranked relatively lower than some other project categories. However, this project would still address the goals of the Klamath River TMDL. The impacts could be great, but will be limited to the Link River and downstream areas only.
- Uncertainties: The Algae Biomass Removal (Harvesting) project category is proposed as a pilot study because of substantial uncertainties associated with the design, regulatory approval, implementation, and performance of algae harvest at a larger (i.e., full) scale. The pilot project would determine the potential quantities, disposition and disposal of filtered material, and possible impacts to suckers. Fish screening requirements and feasibility for operation would be clarified.

4.1.5.2 Operability

The rationale for the ranking of the Algae Biomass Removal (Harvesting) project category relative to designated operability objectives includes:

- Because a pilot study is necessary before full implementation can proceed, this project category is ranked relatively low with regard to implementation compared to other categories. This project category will also likely require substantial engineering, construction, and permitting, which could substantially extend the timeline before full function is achieved. Finally, there will be substantial O&M effort to operate and maintain the harvesting system, and it is unknown where the disposal site will be and how that area would be affected by biomass decomposition and the potential for associated algae toxins (e.g., microcystin). There are other concerns associated with the effects of this project on ESA-listed suckers.
- The pilot study will allow important operability issues and options to be evaluated before committing to a larger-scale algae harvest project. For example, disposal of captured algae biomass into the Lost River is not an acceptable option and fish screen questions regarding the protection of sucker larvae must also be addressed. There is not enough certainty demonstrating that microcystin toxicity can be reduced to allow use of the captured material to be used as feedstock and no viable/stable option has yet been identified for disposal of algal material.
- The Algae Biomass Removal (Harvesting) project category is one of seven categories whose project life is projected to be intermediate-term. This means that this project is expected to have a project life less than 20 years. Moreover, the pilot project phase would be short-term (several months to 3 years).

4.1.5.3 Economics

The rationale for the ranking of the Algae Biomass Removal (Harvesting) project category relative to designated cost objectives includes:

- The ACM for this project category is not available pending development of more detailed information (such as via the pilot study). However, this project category is expected to have relatively high capital and O&M costs because there would be detailed design, construction, operations, and maintenance requirements.
- The cost of the pilot study is estimated at about $1,250,000 over 4 months (New Earth 2016). Additional costs are likely for detailed evaluation of pilot system function (e.g., water quality monitoring, evaluation of effects on fish, and algae disposal). These costs are not presently included in the above estimate. It is expected that the cost for a full system would scale better than linearly (i.e., a system with twice the capacity would cost less than twice as much), because some system components such as dewatering are relatively independent of scale.

4.2 Rejected Project Categories

There were several candidate project categories that workshop participants collectively decided did not need to be carried forward into a more detailed ranking (Table 2). These include:

- Demonstration Wetland Facility (DWF)
- Algal Filtration
- Particulate Organic Matter Removal from Klamath River Source Water Using Stormwater Treatment Technology
- Sediment Removal (Dredging) from Upper Klamath Lake
- Oxygenation in Keno Reservoir
- Coagulant Injection Treatment to Sequester and Inactivate Nutrients
- Combined Sediment Sequestration of Phosphorus and Oxygenation in Lake Ewauna/Keno Reservoir

The rationale that workshop participants gave for the relative ranking of these project categories are summarized below relative to designated performance, operability, and cost objectives.

4.2.1 Demonstration Wetland Facility (DWF)

4.2.1.1 Performance

The rationale for the ranking of the DWF project category relative to designated performance objectives includes:

- The DWF would provide opportunity to demonstrate approaches to and effectiveness of constructed wetlands for treatment of water quality, particularly for reductions in nutrients and organic matter in runoff to waters in the upper Klamath Basin. The DWF would include various wetland cells that would be used to test and evaluate specific design and operations criteria that maximize water treatment.
- Constructed treatment wetlands scored in the top tier in terms of group support and as a full-scale project in the rankings for the 2012 Klamath River Water Quality Workshop (Stillwater et al. 2013). However, PLP workshop participants viewed the DWF as strictly a research endeavor rather than a more broad-based water quality restoration measure.
- Uncertainties: Key uncertainties make the DWF less feasible than the other top-ranked project categories. These include topics such as: a specific location for the DWF is unknown; sponsors and funding sources for the DWF have not been identified; and lack of a sponsor for long-term operation of the facility undermines its value as an educational/research facility. Additionally, even if a site is identified in the future, it seems that similar research can be conducted at the smaller DSTWs throughout the basin.

4.2.1.2 Operability

The rationale for the ranking of the DWF project category relative to designated operability objectives includes:

- Initial DWF feasibility study has been conducted, and construction, operation, and maintenance requirements are relatively well-defined and straight-forward (CH2M HILL 2014). However, because a suitable site, funds, and sponsorship for a DWF has not been identified, it is likely that a long wait could occur before a DWF could be implemented and function is achieved. Additionally, lack of secured water right to operate the DWF may be a key barrier.
- This DWF project category is one of seven categories with estimated intermediate-term lifetime or longevity. That is, the DWF project is expected to have a duration on the order of more than 3 to less than 20 years, and are therefore not long-term or potentially permanent.

4.2.1.3 Economics

The rationale for the ranking of the DWF project category relative to designated cost objectives includes:

- Over its 10-year lifespan, the ACM for the DWF project category is estimated at $697,500, which ranks 3rd lowest of 12 candidate project categories. Total DWF construction cost is estimated at $2,275,000 (CH2M HILL 2014). Total costs of operation, maintenance, monitoring and reporting are estimated at $470,000 annually (CH2M HILL 2014).
- Although the costs are comparatively low, the DWF has a more limited scope relative to other candidate project categories. As noted above, the DWF is strictly a research endeavor rather than a more broad-based water quality restoration measure.

4.2.2 Algal Filtration

4.2.2.1 Performance

The rationale for the ranking of the Algal Filtration project category relative to designated performance objectives includes:

- While nutrients would still be present in lake sediments and waters flowing through this type of system, the continued filtration of algal biomass from the water column is a direct approach to decreasing oxygen demand and nutrients in the system. Further, removal of toxin-producing cyanobacteria such as *Microcystis aeruginosa* reduces a potential source of cyanotoxins.
- Key uncertainties make the Algal Filtration project category less feasible than the other top-ranked project categories at this time. Specifically, it is unclear how effective targeted filtration would be given the extensive blooms and large biomass associated with algae in Upper Klamath Lake. Other unknowns include the specific location of filtration activity; disposition or disposal of filtered material; and the amount of filtered material needed to provide demonstrable water quality benefit. Potential adverse impacts include the potential release algal toxins to water column during harvesting and the possibility of impacts to federally-endangered suckers.
- This project type does not focus on a solution to the key issues, but rather is a “band-aid” fix that addresses symptoms. It seems that the algal biomass removal project has replaced this idea.
- Algae filtration scored high with breakout groups and as a pilot project concept in rankings of the 2012 Klamath River Water Quality Workshop (Stillwater et al. 2013). Before considering implementation, viability of algae filtration technology needs to be evaluated using a pilot project to better assess feasibility and resolve uncertainties. This would be done as part of the Algae Biomass Removal (Harvesting) at Link Dam project category as summarized above.

4.2.2.2 Operability

The rationale for the ranking of the Algal Filtration project category relative to designated operability objectives includes:

- Projects under this Algal Filtration category would be active operations likely involving barges with large filtering systems. The 2012 Klamath River Water Quality Workshop estimated that the cost of operation a single barge would be about $370,000 per year (Stillwater et al. 2013). It is likely that more than one barge would be necessary.
- Concerns raised during the review of this project category include: Possible release of microcystin resulting from *Microcystis aeruginosa* cells ruptured during harvest; how and where biomass would be disposed of; and the effect this project type may have on ESA-listed suckers in Upper Klamath Lake.
- Disposal of harvested algal biomass to the Lost River is not an acceptable option. To date, there is no certainty demonstrating that microcystin toxicity can be reduced to allow use of the captured material as feedstock. No viable/stable option has been identified to dispose of algal material.
- This Algal Filtration project category is one of seven categories with estimated intermediate-term lifetime or longevity. That is, the Algal Filtration project category is expected to have a duration on the order of 6 to 12 years, and are therefore not long-term or potentially permanent.

4.2.2.3 Economics

The rationale for the ranking of the Algal Filtration project category relative to designated cost objectives includes:

- The ACM for the Algal Filtration project category is estimated at $370,000, which ranks 2nd lowest of 12 candidate project categories. Total Algal Filtration construction cost is estimated at $300,000 (Stillwater et al. 2013). Total costs of operation and maintenance are estimated at $3,400,000 over 10 years (Stillwater et al. 2013).
- Although the costs are comparatively low, more study is needed to assess feasibility and resolve uncertainties before algae filtration could be implemented as a more broad-based water quality restoration measure.

4.2.3 Particulate Organic Matter Removal from Klamath River Source Water Using Stormwater Treatment Technology

4.2.3.1 Performance

The rationale for the ranking of the Particulate Organic Matter Removal project category relative to designated performance objectives includes:

- Stormwater treatment technologies can be effective means of removing particulates and associated nutrients from surface water runoff that potentially promote algae growth in receiving waters. Reductions of seasonal algae and organic matter loads emanating from Upper Klamath Lake could provide substantial water quality improvements in the Klamath River. This is especially the case in Keno Reservoir, which experiences seasonal anoxia due to the processing of organic matter loads from the lake.
- Water quality improvements from the reductions in particulate organic matter loading would potentially provide important benefits for endangered suckers found in Keno Reservoir. Reductions in organic matter loading could also lead to lower seasonal organic matter concentrations in the Klamath River downstream of Keno Dam.
- Key uncertainties make the Particulate Organic Matter Removal project category less feasible than the other top-ranked project categories at this time. Unknowns include: (1) the need for and type of fish

screens, which will depend on facility layout; (2) the location and property for facilities; and (3) sponsors and funding sources for facilities design, construction, and operation.

- The Particulate Organic Matter Removal project category potentially conflicts with the Algae Biomass Removal (Harvesting) at Link Dam project category because both of projects are aimed at removal of the same material and are conceptually located in the same physical space. They may be redundant in terms of their purpose and need; however, it is not expected that algae and nutrient loading in Upper Klamath Lake would so rapidly improve as to make one method unfeasible. If the location conflicts could be addressed, the projects may interact for greater overall benefit.
- Some IMIC members indicate that previous IM11 analysis has suggested this project was unlikely to succeed. The algal biomass removal project was seen as a replacement for this idea. Additionally, this project does not address directly address the key issue of nutrient enrichment, but rather mitigates symptoms.

4.2.3.2 Operability

The rationale for the ranking of the Particulate Organic Matter Removal project category relative to designated operability objectives includes:

- Projects under the Particulate Organic Matter Removal project category would be active operations involving with large particulate removal systems. There are concerns about how and where the particulate biomass will be disposed of, and what effect this project type may have on ESA-listed suckers or other fish.
- Disposal of harvested particulate biomass to the Lost River is not an acceptable option. Also, there is not enough certainty demonstrating that microcystin toxicity can be reduced to allow use of the captured particulate biomass as feedstock and no viable/stable option has yet been identified to dispose of particulate biomass.
- A Particulate Organic Matter Removal feasibility study has been conducted, and construction, operation, and maintenance requirements have been estimated (Watercourse 2014). However, because a suitable site, funds, and sponsorship for a Particulate Organic Matter Removal facility has not been identified, it is likely that implementation and operation could take a long time to occur. Additionally, lack of secured water rights to operate the facilities may be a barrier.
- This candidate project category is one of five categories with estimated long-term duration. That is, projects implemented under this category are expected to have a duration on the order of 20 years or more. However, unlike most of the other long-term project categories, the Particulate Organic Matter Removal project category would not be expected to be permanent, because it is a treatment for symptoms that ideally would be eradicated at some time in the future as other measures bring permanent water quality improvement.

4.2.3.3 Economics

The rationale for the ranking of the Particulate Organic Matter Removal project category relative to designated cost objectives includes:

- The ACM for the Particulate Organic Matter Removal project category is estimated at $1,000,000 to $4,000,000, which ranks 5th lowest of 12 candidate project categories. Total construction, operation, and maintenance costs are estimated at $20,000,000 to $80,000,000 over 20 years, depending on level of removal desired.
- The ACM costs are comparatively in the middle of the range among the candidate project categories. However, the algal biomass removal project is seen as a likely replacement for the Particulate Organic Matter Removal project technology.

4.2.4 Sediment Removal (Dredging) from Upper Klamath Lake or Keno Reservoir

4.2.4.1 Performance

Dredging would involve the physical removal of accumulated sediments from Upper Klamath Lake or Keno Reservoir to improve water quality by directly removing pollutants, nutrient-rich sediments, and decomposing organic plant matter. The rationale for the ranking of the Sediment Removal (Dredging) project category relative to designated performance objectives includes:

- Targeted dredging of a portion of Upper Klamath Lake (e.g., just south of Goose Bay) or Keno Reservoir containing relatively high concentrations of phosphorus could decrease the potential for internal loading of phosphorus to the lake and subsequent nuisance algal blooms.
- There are several concerns associated with the potential project category of Sediment Removal (dredging) in Upper Klamath Lake or Keno Reservoir. Many case studies indicate that dredging is not an effective way to reduce internal nutrient loading in eutrophic and hypereutrophic water bodies (Cooke et al. 2005; Søndergaard et al. 2007; Zamparas and Zacharias 2014). A key uncertainty is the unknown amount of phosphorus that must be removed from sediments to affect the whole lake (or reservoir) phosphorus equilibrium. Volume of material generated along with disposal of this material needs to be defined. The rate at which nutrient-rich material would settle out of lake water into the recently dredged areas would affect the lifespan of the project.
- There is the risk of accidental capture and mortality of endangered suckers in the Upper Klamath Lake along with temporarily impaired water quality from increased turbidity. Additionally, dredging would affect the benthic invertebrate community in Upper Klamath Lake, which likely contributes substantially to fish diet in the lake.
- Sediment dredging in Upper Klamath Lake scored in the bottom tier in terms of group support and as a full-scale project in the rankings for the 2012 Klamath River Water Quality Workshop (Stillwater et al. 2013).

4.2.4.2 Operability

The rationale for the ranking of the Sediment Removal (Dredging) project category relative to designated operability objectives includes:

- The Sediment Removal (Dredging) project category would be relatively straight-forward to design and implement technologically, but likely would be challenging to permit. There are concerns about how and where the dredged sediments would be disposed of, and what effect this project type may have on ESA-listed suckers or other fish.
- This candidate project category is one of seven categories with estimated intermediate-term lifetime or longevity. That is, projects implemented under this category are expected to have a duration on the order of more than 3 but less than 20 years, and are therefore not long-term or potentially permanent. Sediment Removal is not considered sustainable over the long-term, particularly if external phosphorus and sediment loads are not reduced.
- Because suitable sites, funds, and sponsorship for sediment removal projects have not been identified, it is likely that it could be a long time before Sediment Removal (dredging) would be implemented and function is achieved.

4.2.4.3 Economics

The rationale for the ranking of the Sediment Removal (Dredging) project category relative to designated cost objectives includes:

- The ACM for the Sediment Removal (Dredging) project category is estimated at $57 million for Upper Klamath Lake and $370,000 for Keno Reservoir. The ACM for sediment removal in Upper Klamath Lake ranks as the highest (most expensive) of 12 candidate project categories, while the ACM for sediment removal in Keno Reservoir ranks 2nd lowest of the 12 candidate project categories.
- The Sediment Removal (Dredging) for Upper Klamath Lake would require very substantial implementation costs, estimated at $460 million over 5 years (Stillwater et al. 2013). The implementation costs for Sediment Removal (Dredging) for Keno Reservoir are estimated at $1,470,000 over 5 years (Stillwater et al. 2013).

4.2.5 Oxygenation in Keno Reservoir

4.2.5.1 Performance

The rationale for the ranking of the Oxygenation in Keno Reservoir project category relative to designated performance objectives includes:

- Commercially-available oxygenation systems could deliver oxygen to Keno reservoir to substantially enhance decomposition of organic matter loads emanating from Upper Klamath Lake and improve dissolved oxygen conditions in Keno reservoir, and possibly further downstream in the Klamath River. In addition, the resulting water quality improvements in Keno reservoir could potentially provide important benefits for endangered suckers found in the reservoir and potentially facilitate anadromous fish passage through the reservoir in the future if downstream dams are removed or fish passage is otherwise established.
- There are several issues or uncertainties associated with the potential project category of Oxygenation in Keno Reservoir. Instream oxygenation systems would likely need fish screens because there would be potential for unintended capture of endangered suckers and other fish in the intakes necessary for these systems. The location and property for facilities as well as project sponsors and funding sources have not been defined.
- Oxygenation projects of this type address symptoms rather than the causes of water quality impairment. Oxygenation would help dissolved oxygen levels downstream of where they are located, but not water temperatures or nutrient loading.
- Oxygenation projects could be an action to provide for better fish migration conditions through Keno (including salmon reintroduction in the future). If cost of oxygenation technologies is reduced in the future, oxygenation could be worth reconsidering in forums outside of IM11.

4.2.5.2 Operability

The rationale for the ranking of the Oxygenation in Keno Reservoir project category relative to designated operability objectives includes:

- Dissolved oxygen enhancement techniques are likely to involve substantial amounts of design, engineering, and permitting. Construction, operation, and maintenance would also be relatively complex. Oxygenation systems used to enhance dissolved oxygen either inject pure oxygen directly into water typically using a diffuser, or into a side-stream contact chamber using a downflow contactor.
- This candidate project category is one of seven categories with estimated intermediate-term lifetime or longevity. That is, projects implemented under this category are expected to have a duration on the order of 6 to 12 years, and are therefore not long-term or potentially permanent.

4.2.5.3 Economics

The rationale for the ranking of the Oxygenation in Keno Reservoir project category relative to designated cost objectives includes:

- The ACM for the Oxygenation in Keno Reservoir project category is estimated at $5,400,000 to $10,000,000, which ranks 4th highest of 12 candidate project categories. The Oxygenation in Keno Reservoir project category would require very substantial implementation costs, estimated at $54,000,000 to $100,000,000 (CH2M and Watercourse 2016).

4.2.6 Coagulant Injection Treatment to Sequester and Inactivate Nutrients

4.2.6.1 Performance

The rationale for the ranking of the Coagulant Injection Treatment project category relative to designated performance objectives includes:

- One of the advantages of alum application is that phosphorus remains bound in a semisolid matrix (known as floc) even during seasonal periods of low dissolved oxygen in the sediments and/or water column when phosphorus would otherwise be released and support algae growth.
- Reductions in phosphorus loading in Keno Reservoir could interact in a beneficial way with reduced nutrient loading coming from Upper Klamath Lake. However, the main precaution associated with alum use is the presence of free aluminum at low pH (< 6.0), which can be toxic to aquatic life. To maintain the appropriate pH, alum treatments must be chemically buffered.
- There is uncertainty in the efficacy of alum treatment in Upper Klamath Basin waters (i.e., low alkalinity, high seasonal pH), including consideration of re-suspension potential for shallow areas of Upper Klamath Lake. Sedimentation rates in these water bodies would likely require frequent alum reapplications. In addition, there are no existing sponsors and funding sources for this type of project, and the location and property for shore-side staging and support facilities are unknown.
- The Coagulant Injection Treatment project category would address a symptom, rather than directly addressing the key issue of nutrient loading. Alum tends to be less effective if external phosphorus and sediment loads are not reduced. This approach scored in the bottom tier in terms of group support and as a full-scale project in the rankings for the 2012 Klamath River Water Quality Workshop (Stillwater et al. 2013).

4.2.6.2 Operability

The rationale for the ranking of the Coagulant Injection Treatment project category relative to designated operability objectives includes:

- Given the presence of ESA-listed species in Upper Klamath Lake and Keno Reservoir, permitting requirements would likely be challenging. The Tribes in the Klamath Basin generally object to use of chemicals in the Klamath River system. The Tribes have substantial concerns with some treatment chemicals becoming toxic at certain pH levels. Overall, the tribal concerns would likely preclude this project type.
- This candidate project category is one of seven categories with estimated intermediate-term lifetime or longevity. That is, projects implemented under this category are expected to have a duration on the order of more than 3 but less than 20 years, and are therefore not long-term or potentially permanent. The longevity of treatments varies, but typically about 10 years can be expected in lake systems with effectiveness waning over time as the floc layer sinks and new sediment with un-bound phosphorus settles and covers the floc layer.

4.2.6.3 Economics

The rationale for the ranking of the Coagulant Injection Treatment project category relative to designated cost objectives includes:

- The ACM for the Coagulant Injection Treatment project category is estimated at $18,000,000, which ranks 3rd highest of 12 candidate project categories. The Coagulant Injection Treatment project category would require very substantial implementation costs, including construction and mobilization costs estimated at $2,250,000, and operation and maintenance costs estimated at $177,750,000 over 8 years (Stillwater et al. 2013).

4.2.7 Combined Sediment Sequestration of Phosphorus and Oxygenation in Lake Ewauna/Keno Reservoir

4.2.7.1 Performance

The rationale for the ranking of the Combined Sediment Sequestration of Phosphorus and Oxygenation in Lake Ewauna/Keno Reservoir project category relative to designated performance objectives includes reasons as listed above under both the Oxygenation (Section 4.2.5) and Coagulant Injection Treatment (Section 4.2.6) project categories (considered in combination).

4.2.7.2 Operability

The rationale for the ranking of this project category relative to designated operability objectives includes reasons as listed above under both the Oxygenation (Section 4.2.5) and Coagulant Injection Treatment (Section 4.2.6) project categories (considered in combination).

4.2.7.3 Economics

The rationale for the ranking of the Combined Sediment Sequestration of Phosphorus and Oxygenation in Lake Ewauna/Keno Reservoir project category relative to designated cost objectives includes:

- The ACM for this project category is estimated at $4,343,590, which ranks 5th highest of 12 candidate project categories. This project category would require very substantial implementation costs, including construction and mobilization costs estimated at $5,191,772, and operation and maintenance costs estimated at $81,680,000 over 20 years (Stillwater et al. 2013).

5 Next Steps

5.1 Additional Information Gathering and Matrix Refinement

Additional information will be gathered in Phase 2 to allow more differentiation between the five of top-ranked project categories. Further discussion with the IMIC is occurring to identify and plan for additional information and assessment needed to allow the IMIC to make more specific determinations on the PLP. For example, as an activity in upcoming Phase 2 of the PLP process, the matrix of the top-ranked project categories will continue to be refined to provide more specific information. Refinements to the matrix will potentially include: (1) targeting of priority projects by geographical area or location; (2) refining costing information to better inform allocation of funds; (3) adding nutrient-removal efficiency information or metrics to allow additional comparisons of effectiveness of priority projects; and (4) providing more information on who-is-dong-what in the upper basin so as to consider where project categories may cumulatively benefit ongoing water quality work.

5.2 Second Workshop and Specific PLP Determination

As described previously (Section 1), the next steps in the process for development of the specific PLP will occur in Phase 2. The specific PLP will be determined in Phase 2 using both the Phase 1 results (as described in this report) and the additional data and information gathered in Phase 2. Initially it is expected that it will be necessary to explore further details on the top-ranked PLP project categories. It is envisioned that a second PLP Workshop will be conducted with interested IMIC members during Phase 2. During this second workshop, participants will: (1) review the detailed information on top-ranked projects and establish a ranking approach; (2) identify and determine the specific PLP; (3) discuss the approach to allocation of funding amounts; and (4) discuss the process and governance needs anticipated to implement the PLP. The process and governance considerations will include: authorization and contracting of priority projects; funding amounts for different priority projects; use of a fiscal agent for contracting of work and payment of funds; and responsibilities for oversight of project implementation, progress, and outcomes.

5.3 Expected Final PLP Report

A final PLP report will be prepared to conclude Phase 2. The report will be guided by the development of the ranking process discussed previously (Sections 5.1 and 5.2). At this time it is expected that the report will provide: (1) a discussion of the process and rationale for selection of the specific PLP; (2) details as developed during Phase 2 with regard to allocation of funding amounts for the PLP and the process and governance anticipated to implement the PLP; and (3) appropriate recommendations for follow-up Phase 3 activities (e.g., development of specific plans and designs of projects to be implemented from the PLP; obtaining regulatory approvals; and selection of contractors for implementation).

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Appendix A:
Matrix of Candidate Project Categories

Matrix of Candidate Project Categories

To facilitate IMIC's development of the PLP, PacifiCorp compiled a matrix of information relating to the candidate project categories. The matrix includes 12 candidate project categories that have been assessed, evaluated, or studied to-date, including summary findings regarding relative effectiveness and costs. This matrix provides a basis for the IMIC to assess the various candidate project categories and to ultimately develop the final PLP (anticipated in Phase 2).

The IMIC was provided a single matrix for all 12 candidate project categories that was used in the PLP workshop. Following the workshop and the desires of the workshop participants, PacifiCorp split the matrix into two parts as presented in this appendix. This first part provides a detailed matrix for the five Top-Ranked PLP Candidate Project Categories (as discussed in Section 4.1 of the preceding report). This second part provides additional matrix information for the other seven PLP candidate project categories that were rejected from further PLP consideration (as discussed in Section 4.2 of the preceding report). The five Top-Ranked PLP Candidate Project Categories were separated into a more detailed matrix to allow for the inclusion of additional information for the IMIC's use as the PLP is further developed and finalized.

Matrix Contents and Definitions

The attached matrix of candidate project categories includes the following information:

- **Name of Technique or Project.** The short name used to define each of the particular candidate project categories.
- **Location.** The physical spot on the ground where the candidate project categories would be placed (if known). Locations could be site-specific (e.g., at Link River dam) or more broadly implemented (e.g., in the Wood River basin).
- **Goals, Objectives, Assumed Capability.** Summary of the goals, objectives, and assumed capability of the candidate project category. The goals and objectives indicate what the candidate project category is intended to achieve in terms of water quality benefits. The assumed capability addresses anticipated effectiveness of the candidate project category in achieving the intended water quality benefits.
- **Design Features and Elements.** Summary of the anticipated conceptual layout, facilities, and operation of the candidate project category.
- **Potential Adverse Impacts and Uncertainties.** Summary of the potential adverse environmental impacts, if any, that might be associated with construction and operation of the candidate project category. Summary of the uncertainties of the candidate project category regarding its potential implementation and effectiveness.
- **Estimated Cost of Project.** Estimated costs of the candidate project category are itemized for potential pilot and full-scale application of the candidate project (if applicable). Each of these itemizations include design, construction, operation and maintenance, if data is available. Where sufficient cost information is available, an 'Annualized Cost Metric' (ACM) is estimated. The ACM is calculated as the sum total of all estimated costs for the project category (including for design, construction, operation and maintenance, if available) divided by the estimated duration of the project in years[5]. The ACM

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[5] In some cases, the total costs and project life-spans used in the ACM calculation are based on a number of years that differs from the estimated duration of the project category. For example, the costs for the Riparian Fencing and Grazing Management project category are estimated over 10 years (rather than 20 years as the long-term duration assumes). The main reason for difference is to maintain consistency with the source of cost information

provides an approximate cost per-year metric that can be used for cost comparisons across project categories. For calculation simplicity, the ACM values reported in the matrix were not adjusted for inflation.

- **Duration.** The estimated lifetime or longevity of the candidate project category reported in months or years, if available. Otherwise, duration is qualitatively referred to as 'short-term', 'intermediate term', or 'long-term'. For use in this matrix, short-term is a duration of 3 years or less; for example, pilot projects fall into this duration category. Long-term is a duration of 20 years or more (and including potentially permanent); for example, wetlands restoration falls into this duration category. Intermediate is any duration in-between (more than 3 and less than 20 years); for example, potential use of oxygenation facilities fall into this duration category.
- **Collaboration, Synergy, or Conflict.** If pertinent to a priority project category, information is provided on relevant practitioners in the area to allow consideration of possible collaboration, synergies, or conflicts. When there is the potential for additive benefits between two project categories, they are said to have synergistic benefits. For example, a demonstration wetland facility (DWF) would have potential synergies with diffuse source treatment wetlands (DSTWs) or natural wetlands restoration, because a DWF could provide research opportunities for assessing effectiveness of DSTWs or restored natural wetlands. When the benefit of one project category is not possible if another project category is undertaken, then the two would be said to conflict. An example of a conflict could be where two wetland projects, say a DSTW and a restored natural wetland are targeted at the same physical location. Another example could be the conflict between algae biomass removal which targets the same material as particulate organic matter removal making them potentially redundant in terms of their purpose and need.
- **Information Sources.** Key reference sources that describe or support the summary statements in the matrix for a given project category.

Matrix of Top-Ranked Project Categories

The top-ranked PLP candidate project categories (in no particular order) include:

- Diffuse Source (Decentralized) Treatment Wetlands
- Natural Wetlands Restoration
- Riparian Fencing and Grazing Management
- Irrigation Efficiency and Water Management Projects
- Algae Biomass Removal (Harvesting) at Link Dam

The matrix for these project categories is provided on the following pages.

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which is sometimes different than the duration used in the matrix. Extension of costs for life-spans beyond those in the source material did not seem appropriate.

Diffuse Source (Decentralized) Treatment Wetlands (DSTWs)	
Location	For DSTWs, the Wood River and Sprague River watersheds are identified as priority locations because of current land use practices and a perceived capacity for additional wetland rehabilitation. DSTWs are small (about 10 acres or less each) flow-through or terminal wetlands located along creeks and canals or in low-lying areas in fields within the Wood River and Sprague River valleys.
Goals, Objectives, Assumed Capability	A network of DSTWs would decrease external loading of phosphorus and nitrogen to Upper Klamath and Agency lakes and may help decrease nuisance algal blooms in these waterbodies. The goals for DSTWs are generally the same as for other types of wetlands, but the functionality occurs in relatively smaller pockets and has the advantage of onsite treatment and habitat. Constructed treatment wetlands have been shown to be effective at removing a range of pollutants from incoming waters, including total suspended solids, phosphorus, nitrogen, metals, organic compounds, and bacteria and pathogens (Mitsch and Gosselink 2000; Kadlec and Wallace 2009). These systems can also provide high quality wildlife habitat. Stillwater et al. (2013) used a generalized geographic information system (GIS) analysis to estimate that DSTWs, typically sized at 5-6 acres each, could theoretically represent a maximum potential cumulative area of 600 acres in the Wood River Valley. Stillwater et al. (2013) estimate that the majority of DSTW acreage (540 acres) would be mid-field systems scattered throughout the valley, with the remainder (60 acres) consisting of creek/canal-side DSTWs. For the valley as a whole, 31,500 acres or 98 percent of the existing land use would remain the same under this theoretical DSTW area scenario (Stillwater et al. 2013). Stillwater et al. (2013) estimates that this maximum potential cumulative area of 600 acres of DSTWs would provide about a 5-20 percent cumulative annual reduction of phosphorus and 5-15 percent cumulative annual reduction of nitrogen for the Wood River Valley, depending on the relative amounts of flow-through and terminal DSTWs (see Figure 3.11 in Stillwater et al. 2013). The corresponding cumulative flow reduction from the adjacent waterways would be just over 3 percent, based on estimated evapotranspiration losses (see calculations in Appendix B in Stillwater et al. 2013).
Design Features and Elements	Wetland-located water treatment can occur throughout a watershed, rather than at the bottom or just prior to discharge into a large receiving water body. Design and implementation of networks of small-scale DSTWs can achieve the benefits of wetland ecosystem functioning in multiple locations throughout a watershed. DSTWs are designed to accommodate an estimated amount of stormwater runoff from the landscape or a particular hydraulic residence time given adjacent agricultural canal flow. Specific design elements allow DSTWs to function at smaller scales such as natural low points in pastures and agricultural fields or areas directly adjacent to small drainage ditches. Unlike larger-scale habitat and treatment wetlands, DSTWs can be located on a fraction of an existing parcel and result in less permanent loss of land.
Potential Adverse Impacts & Uncertainties	Potential adverse impacts: Potential for unintended consequences (i.e., invasive species, mosquitos, nutrient export, creation of sate or federally jurisdictional wetlands). Uncertainties: To generate the necessary nutrient reduction, many DSTWs would be necessary. It would seem uncertain at this time if willing sponsors and landowners are available. Other uncertainties are associated with the number of required features and reliability of effectiveness.

Diffuse Source (Decentralized) Treatment Wetlands (DSTWs)	
Estimated Cost of Project	Pilot Study: $230,000 to $270,000 (pg. 50 of Stillwater et al. 2013) Construction: $663,000 per 50 units (pg. 15 of Appendix A of Stillwater et al. 2013) O&M (timeframe): $130,000 a year for 10 years for 50 units (pg. 15 of Appendix A of Stillwater et al. 2013) ACM: $223,300
Duration	Long term
Collaboration, Synergy, or Conflict	USFWS, Trout Unlimited, Klamath Tribes, and Stillwater Sciences are collaborating on several pilot DSTWs. DEQ (Mike Hiatt) and the Regional Board (Clayton Creager) are planning to discuss with Natural Resource Conservation Services their interest in encouraging DSTWs as an approved practice. DSTWs would have potential synergies with other wetland restoration-related project categories (e.g., Natural Wetlands, DWF as described below) because resulting watershed-level nutrient removal using wetlands systems would be additive.
Information Sources	Kadlec, R.H. and S. Wallace. 2009. Treatment Wetlands. 2nd edition. CRC Press. Boca Raton, FL. Mitsch, W. and J. Gosselink. 2000. Wetlands. Third Edition. John Wiley & Sons, Inc., New York. Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, and NSI/Biohabitats. 2013. Water Quality Improvement Techniques for the Upper Klamath Basin: A Technical Workshop and Project Conceptual Designs. Prepared for California State Coastal Conservancy, Oakland, California.

Riparian Fencing and Grazing Management	
Location	The Sprague River, Williamson River, and Wood River valleys are identified as priority locations because of current land use practices and a perceived capacity for additional riparian rehabilitation. Generally, riparian fencing and grazing management should be focused in valley-bottom areas where grazing is concentrated. This primarily includes the Sprague River main stem, Williamson River downstream of Kirk Reef, and Sevenmile Creek, but also includes areas such as restored wetlands and springs in the Wood River valley.
Goals, Objectives, Assumed Capability	The overall objective is to manage and restore riparian corridors along streams that flow into Upper Klamath Lake to reduce sediment loads (and sediment-bound nutrients) in the streams. Because of relatively high phosphorus content of soils in the Upper Klamath Basin and the fact that both the Upper Klamath Lake Drainage and Klamath River TMDLs point to external phosphorus loading from the basin above Upper Klamath Lake as a driver of water quality throughout the system, minimizing sediment load associated with land use (i.e., sediment loads above background) is a potential priority. Walker et al. (2015) closely correlated sediment load and total phosphorus in the Upper Klamath Basin. A number of studies indicate that Riparian Fencing and Grazing Management can be very effective at managing sediment loads in surface runoff. For instance, Wenger (1999; page 20) states that "…riparian buffers should be viewed as an essential component of a comprehensive, performance-based approach to sediment reduction." Additionally, riparian fencing and grazing management were the central focus of the Upper Klamath Basin Comprehensive Agreement (April 18, 2014; see in Information Sources below) which was created from review of scientific literature. Diebel et al. (2008) found that riparian management targeting areas of nutrient input could use riparian buffers to retain and remove substantial percentages of sediment and nutrients from runoff. Wenger (1999) and Buffler et al. (2005) provide extensive literature reviews that demonstrate that the ability of a riparian buffers to remove total suspended solids, phosphorus, and nitrogen from runoff as a function of the buffer's width. These riparian systems can also provide high quality wildlife habitat.
Design Features and Elements	For planning and assessment purposes, features and elements can be approximated based on Riparian Program specifics in the Upper Klamath Basin Comprehensive Agreement (April 18, 2014; see in Information Sources below). These specifics indicate that Riparian Fencing and Grazing Management will be implemented through agreements entered into with willing landowners. Minimum width of protected riparian areas will be approximately the lesser of about 50 feet or a reasonably consistent contour 2 feet above the elevation of the adjacent stream water surface, constrained by an absolute minimum of about 30 feet. The maximum needed width of protected riparian areas will be about 100 to 130 feet (this includes area in fields adjacent to the riparian area such that the combined width of the two areas is 100 to 130 feet, unless the landowner agrees to a greater width). Within these limits, a baseline width of 75 to 90 feet can be used as a starting point for delineation for planning and assessment purposes. Wenger (1999) and Buffler et al. (2005) provide extensive literature reviews with specific information about sediment and nutrient removal. Wenger (1999) reports average total suspended solids reductions of 81 percent for a 15-ft buffer and 91 percent for a 30-ft buffer. Peterjohn and Correll (1984) found that a 160-ft riparian

Riparian Fencing and Grazing Management	
	buffer in an agricultural catchment in the Mid-Atlantic Coastal Plain trapped 94 percent of suspended sediment that entered, with 90 percent trapped in the first 60 ft. Wenger (1999) and Buffler et al. (2005) report that a riparian buffer strip of 30-60 ft will, in most cases, retain the major part of the nutrients carried by surface runoff. In the short term, riparian buffers retain the majority of total phosphorus that enters, and retention increases with riparian buffer width. Wenger (1999) reports that after 26 ft, grassed buffers retained 66 percent of phosphate in surface runoff, while after 52 ft, 95 percent was retained. The long-term effectiveness of riparian buffers in retaining available phosphate is questionable. Whereas nitrate can be denitrified and released into the atmosphere, phosphorus is either taken up by vegetation, adsorbed onto soil or organic matter, precipitated with metals, or released into the stream or groundwater (Wenger 1999). It is possible for a buffer to become saturated with phosphorus when all soil binding sites are filled; in this situation, any additional phosphorus inputs will then be offset by export of soluble phosphate (Wenger 1999). Soils become saturated at different rates, depending on factors such as cation exchange capacity and redox potential. Harvesting vegetation may be the only reasonable management technique that permanently removes phosphorus from the system. However, such harvesting can destabilize the riparian area and lead to erosion, and should be restricted to areas well away from the stream bank (Wenger 1999). Welsch (1991) recommends 15 ft, although data provided in Welsch (1991) indicates that 25-50 ft would provide a greater margin of safety. The Nutrient Tracking Tool (NTT) model is being developed by the NRCS for use in the Upper Klamath Basin. While the calibration studies have not yet been completed, the NTT model can provide a reasonable estimate of nutrient reduction benefits from a wide range of riparian fencing and grazing management practices. The NRCS NTT team can be contacted for more information at (541) 883-6932.
Potential Adverse Impacts & Uncertainties	Potential adverse impacts: Potential for unintended consequences (i.e., stream channel substrate and shape changes; creation of state or federally jurisdictional wetlands), and loss or reductions in use of agricultural lands. Uncertainties: To generate the necessary nutrient reduction, many miles of riparian protection and enhancement would be necessary. It would seem uncertain at this time if sufficient willing sponsors and landowners are available. Other uncertainties are associated with the magnitude and reliability of effectiveness.
Estimated Cost of Project	Construction and O&M: (timeframe): $35,606,000 over 10 years (total estimated implementation costs for Sprague, Williamson, and Wood River subbasins, including main stems and tributaries) ACM: $3,560,600 The above costs are based on Barry et al. (2010), who estimated implementation costs in the above subbasins over a 10-year period for riparian corridor management agreements; 318 miles of fencing construction and offstream watering; 548 miles of maintenance of existing fences and managing of riparian corridor plants. Trout Unlimited’s costing guidelines, which contain adjustments to account for culverts and other project contingencies, include: • $3.50 per lineal ft for fencing • Add $5,000 per mile for additional work (culverts, tree removal, etc.)

Riparian Fencing and Grazing Management	
	• Add $10,000 for off-stream watering system (no well drilling) • Add $12,000 for any well drilling for stock water wells
Duration	Long term
Collaboration, Synergy, or Conflict	Protection and restoration of riparian buffers is functionally the same as wetland restoration and enhancement. In other words, as related to nutrient removal, riparian buffers are in the same functional category as Natural Wetlands Restoration and in many cases DSTWs. Regarding potential collaboration, Trout Unlimited and USFWS currently are implementing this type of project in the Upper Klamath Basin. In the future, the Klamath Tribes are planning to undertake similar projects in collaboration with USFWS, Klamath Watershed Partnership (KWP), and Trout Unlimited as part of a program of implementation originally described in the Comprehensive Agreement, but likely implemented in conjunction with the Upper Klamath Basin Watershed Action Plan, which is under development by the Klamath Tribes, The Nature Conservancy (TNC), USFWS, Trout Unlimited, ODEQ, Klamath Watershed Partnership (KWP), and the Regional Board (M. Skinner, pers. comm.). The NRCS National Water Quality Initiative is also considering activities in this project category.
Information Sources	Barry, M., L. Dunsmoor, S. Peterson, D. Watson, and S. Mattenberger. 2010. Projected Restoration Actions and Associated Costs Under the Klamath Basin Restoration Agreement for the Upper Klamath River Basin Above Keno, Oregon. Jointly prepared by U. S. Fish and Wildlife Service, Klamath Tribes, Klamath Basin Rangeland Trust, and Ranch and Range Consulting. July 30, 2010. Buffler, S., C. Johnson, J. Nicholson, and N. Mesner. 2005. Synthesis of Design Guidelines and Experimental Data for Water Quality Function in Agricultural Landscapes in the Intermountain West. USDA Forest Service/UNL Faculty Publications. Paper 13. http://digitalcommons.unl.edu/usdafsfacpub/13 Diebel, M., J. Maxted, P. Nowak, M. Vander Zanden. 2008. Landscape planning for agricultural nonpoint source pollution reduction. I: A geographical allocation framework. Environmental Management 42:789-802. Kallestad, J. and M. Swanson. 2009. Riparian Buffers for Western Washington Agriculture. Tilth Producers Farm Walk Series. Washington State University, Pullman WA. August 3, 2009. Michie, R. 2010. Cost Estimate to Restore Riparian Forest Buffers and Improve Stream Habitat in the Willamette Basin, Oregon. Prepared by Oregon Department of Environmental Quality, Watershed Management Section, Portland, OR. March 2010. Peterjohn, W. T. and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology 65(5): 1466-1475. The Freshwater Trust (TFT). 2015. Recommendations for Process Improvements: Phosphorus Crediting in the Klamath Basin. Submitted to PacifiCorp by The Freshwater Trust. March 2015. Upper Klamath Basin Comprehensive Agreement. April 18, 2014. http://klamathtribes.org/wp-content/uploads/2014/08/2014-4-18-UPPER-KLAMATH-BASIN-COMPREHENSIVE-AGREEMENT.pdf

Riparian Fencing and Grazing Management	
	Walker, J., J. Kann, W. Walker. 2015. Spatial and temporal nutrient loading dynamics in the Sprague River Basin, Oregon. Prepared for The Klamath Tribes Natural Resources Department. Wenger, S. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia. Welsch, D. J. 1991. Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources. Radnor, PA: USDA Forest Service.

Natural Wetlands Restoration	
Location	Larger (10s to 1,000s of acres) fringe wetlands areas on the margins of Upper Klamath Lake, Agency Lake, Keno reservoir, and Klamath Straits Drain.
Goals, Objectives, Assumed Capability	The key goal of wetlands restoration is to facilitate improvement in water quality in Upper Klamath Lake, Agency Lake, Keno reservoir, Klamath Straits Drain, and ultimately the Klamath River by nutrient removal from surface waters through wetland ecosystem processes (Wong et al. 2011; CH2M Hill 2012; Stillwater et al. 2013; Sullivan et al. 2014). The primary means of envisioned wetland restoration is to reconnect delta areas with Upper Klamath Lake, Agency Lake, Keno reservoir, and Klamath Straits Drain. These reconnections would restore wetland areas and improve water quality by reducing the external loadings of phosphorus and nitrogen to Upper Klamath Lake, Agency Lake, Keno reservoir, and Klamath Straits Drain. Wetlands restoration also could provide habitat for the endangered shortnose and Lost River suckers if located in Upper Klamath Lake. TNC implemented the foremost example of this reconnection approach to wetland restoration (beginning in 1996) in the Williamson River Delta. This delta was once a vast expanse of floodplain and lake-fringe wetland habitat that formed where the Williamson River entered Upper Klamath Lake. In the mid-20th Century, the delta was separated from the river and lake by levees and converted to agricultural production. Agricultural practices on the delta included pumping water from the property into the lake to drain the fields before planting. This pumped water contributed about 21-25 tons of phosphorus per year to Upper Klamath Lake (Snyder and Morace 1997), which contributed to the lake's severe enrichment issues, including extensive algae blooms. These actions also eliminated important marsh habitat historically used by the endangered Lost River and shortnose suckers. In the initial stage of TNC's Williamson River Delta wetland restoration, there was concern that breaching levees and reconnecting former agricultural fields could release a large amount of stored phosphorus into Upper Klamath Lake, further degrading water quality. Conservation benefits from restoration, particularly an increase in habitat for suckers, were expected to offset the initial export of phosphorus, so the decision was made to breach the levees and monitor the results. Levees were breached on the west side of the Delta in 2007, inundating approximately 3,500 acres, and on the east side of the Delta in 2008, inundating approximately 2,000 acres (Aldous et al. 2005, 2007). Subsequent monitoring indicated that far less phosphorus was released into the lakes and wetlands following restoration than modeling and experiments had predicted (Wong et al. 2010; Stevens and Tullos 2011; Hayden and Hendrixson 2013). Ultimately, a well-designed wetland restoration should be expected to provide a net reduction in nutrient export to the lakes and river. Constructed treatment wetlands have been shown to be effective at removing a range of pollutants from incoming waters, including total suspended solids, phosphorus, nitrogen, metals, organic compounds, and bacteria and pathogens (CH2M Hill 2012; Stillwater et al. 2013; Sullivan et al. 2014).
Design Features and Elements	Wetland projects can be small-scale (1 acre to 10s of acres), large-scale (100s to 1,000s of acres) or in-between, depending on resource management needs and site constraints. Projects can be located anywhere degraded naturally-occurring wetlands already exist. This could be in downstream portions of a watershed to capture pollutants before they leave the system and are discharged into a receiving waterbody, or they can be scattered throughout a watershed to provide on-site treatment and habitat.

Natural Wetlands Restoration	
	For wetland restoration that involves reconnecting former agricultural fields, it is possible that releases would initially release stored phosphorus into the adjoining lake or reservoir, resulting in temporary degrading of water quality. However, TNC's Williamson River Delta wetland restoration monitoring has indicated that such releases had far less phosphorus than modeling and experiments had predicted (Wong et al. 2010; Stevens and Tullos 2011; Hayden and Hendrixson 2013). Over time, the capacity of wetlands to reduce nutrient loads to downstream water bodies can be uncertain (Fisher and Acreman 2004). Whether wetlands serve as a source or sink for nutrients depends on a number of different factors including hydrologic and geomorphic conditions, seasonal patterns of uptake and release, and ecosystem succession (Mitsch and Gosselink 2000). It is well-established that interception and removal of nutrients and particulates (including algae) can be accomplished using constructed wetlands (Kadlec and Wallace 2009). Properly-designed treatment wetlands have been shown to be highly effective at removing a range of pollutants from incoming waters, including total suspended solids, phosphorus, nitrogen, metals, organic compounds, and bacteria and pathogens (CH2M Hill 2012; Stillwater et al. 2013; Sullivan et al. 2014). For example, the removal of nutrients and particulates require that the average residence time of water in the wetland – referred to as "hydraulic residence time" or "hydraulic retention time" – is of sufficient duration (on the order of several days) for wetland-related mechanisms and processes to occur. Normally, hydraulic retention time of about 2 days is needed to remove approximately 80 to 90 percent of total suspended solids typically found in lake and river waters (Kadlec and Wallace 2009). CH2M Hill (2012) includes a summary of nitrogen and phosphorus removal data in wetlands receiving flow from river diversions and other large wetland systems. This summary indicates removal efficiencies of 20 to 75 percent for total phosphorus, 40 to 65 percent for total nitrogen, and 50 to 90 percent for nitrate-nitrogen. General design criteria for wetland rehabilitation (Kadlec and Wallace 2009; CH2M Hill 2012) typically address the following features or attributes: • Water inundation or saturation for some portion of the growing season • Topography and configuration that support a slow-moving, tortuous flow path for water • Varied depth to support a variety of vegetation types and habitats • Inlet and outlet structures, if hydrology is to be managed
Potential Adverse Impacts & Uncertainties	Potential adverse impacts: Potential for invasive species (aquatic/terrestrial) management problems and bioaccumulation potential (e.g., mercury); initial release of stored phosphorus into the adjoining waterbody from wetland restoration projects that involve levee breaching. Uncertainties: location and property for wetlands restoration; sponsors and funding sources; magnitude and reliability of effectiveness; extent of routine maintenance and how maintenance relates to function over time (i.e., does an unmaintained wetland decrease in efficiency over time?).
Estimated Cost of Project	Pilot Study: $150,000 to $275,000 (5 to 10-acre plot along Keno Reservoir; pg. 63 of Stillwater et al. 2013)

Natural Wetlands Restoration

Construction: For restoration of wetlands in the upper Klamath Basin, Stillwater et al. (2013) estimated construction costs of $17,000,000 for 1,600 acres, or about $10,600 per acre (pg. 19 of Stillwater et al. 2013, pg. 13 of Appendix A of Stillwater et al. 2013)

O&M (timeframe): Stillwater et al. (2013) estimated O&M costs of $21,000,000 over 50 years for 1,600 acres, or about $13,250 per acre over 50 years (pg. 19 of Stillwater et al. 2013; pg. 13 of Appendix A of Stillwater et al. 2013)

ACM: $765,500

In considering the above cost estimates, it is noteworthy that costs for wetland creation and restoration projects can be highly variable, depending on project size, complexity, and site-specific conditions. In terms of project complexity, wetland creation and restoration projects can range widely from a simple passive levee breach or reconnection system to a more-engineered wetland system involving basin construction, grading, planting, and water control structures. Costs for wetland creation and restoration projects reported above by Stillwater et al. (2013) and additional sources below (Zentner et al. 2003; King and Bohlen 1995) do not include estimated costs for land acquisition.

Zentner et al. (2003) reported costs for wetland creation and restoration projects in Northern California. Costs are construction costs only, reported on a per-acre basis in 2002 dollars. Zentner et al. (2003) divided wetland projects into three types: (1) salt marsh restoration through breeching of diked baylands; (2) creation or restoration of perennial freshwater marshes, which are inundated all or most of the year, and dominated by open water, cattails (*Typha* spp.), and tules (*Scirpus* spp.); and (3) creation or restoration of seasonal wetlands, which are inundated seasonally (typically 3 to 6 months) and dominated by common wetland plants such as rushes (*Eleocharis* spp., *Juncus* spp.) and sedges (*Carex* spp.).

For relatively simple dike breeching projects (i.e., breeching only without other construction actions), Zentner et al. (2003) reported project costs of $6,000 to $14,000 per acre (about $7,900 to $18,500 per acre in inflation-adjusted 2017 dollars). For more complex dike breeching projects (i.e., breeching with additional grading and planting actions), Zentner et al. (2003) reported project costs of $59,000 to $140,000 per acre (about $77,900 to $185,000 per acre in inflation-adjusted 2017 dollars).

For perennial marsh restoration projects, Zentner et al. (2003) reported project costs of $21,400 to $33,300 per acre (about $27,700 to $43,500 per acre in inflation-adjusted 2017 dollars). For seasonal marsh/wet meadow restoration projects, Zentner et al. (2003) reported project costs of $12,000 to $42,000 per acre (about $15,800 to $55,400 per acre in inflation-adjusted 2017 dollars).

King and Bohlen (1995) examined cost estimates for approximately 1,000 historical wetland creation, restoration, and enhancement projects carried out in 44 states over 25 years from 1970 to 1995. King and Bohlen (1995) report that, for wetland creation and restoration projects other than those that involved converted agricultural land, average project costs ranged from just under $20,000 to over $75,000 per acre (about $32,000 to $120,000 per acre in inflation-adjusted 2017 dollars). Conversions of agricultural land to wetland proved substantially less costly, usually around $1,000 per acre (around $1,600 per acre in 2017 dollars).

Per acre costs of wetland creation and restoration projects decline with project size (King and Bohlen 1995). Small projects (under 0.5 acre) accounted for a disproportionate share of very high-cost projects. This is because of relatively high

Natural Wetlands Restoration	
	fixed costs associated with these projects and the standardizing of costs at the level of 1 acre (e.g., a 0.25-acre project costing $15,000 implies costs of $60,000 per acre). Per acre project costs were only weakly related to the type of wetland being constructed (King and Bohlen 1995). Site specific and project specific factors had a much larger effect on per-acre project costs. Construction costs, as opposed to pre-construction or post-construction costs, usually were the largest component of overall project costs (King and Bohlen 1995). However, monitoring and follow-up costs were highly variable, and led to unusually high project costs in some cases.
Duration	Long term
Collaboration, Synergy, or Conflict	Potential synergies with other wetland restoration actions (e.g., DSTWs, Riparian Fencing, DWF) because resulting nutrient removal would be additive. Regarding potential collaboration, the TNC Williamson River Delta project has a large number of collaborators, but in particular the USFWS, which views the large lake fringe wetlands as key to their sucker recovery strategy.
Information Sources	Aldous, A. R., C. B. Craft, C. J. Stevens, M. J. Barry, and L. B. Bach. 2007. Soil phosphorus release from a restoration wetland, Upper Klamath Lake, Oregon. Wetlands 27:1025–1035. Aldous, A., P. McCormick, C. Ferguson, S. Graham, and C. Craft. 2005. Hydrologic regime controls soil phosphorus fluxes in restoration and undisturbed wetlands. Restoration Ecology 13: 341-347. CH2M Hill. 2012. Approaches to water quality treatment by wetlands in the Upper Klamath Basin. Prepared by CH2M HILL, Portland, Oregon for PacifiCorp Energy, Portland, Oregon. Fisher, J. and M. Acreman. 2004. Wetland nutrient removal: a review of the evidence. Hydrology and Earth System Sciences 8:673–685. Hayden, N.J. and H.A. Hendrixson. 2013. Water quality conditions on the Williamson River Delta, Oregon: Five years post-restoration. 2012 annual report. The Nature Conservancy, Portland, OR. Kadlec, R.H. and S. Wallace. 2009. Treatment Wetlands. 2nd edition. CRC Press. Boca Raton, FL. King, D. and C. Bohlen. 1995. The Cost of Wetland Creation and Restoration. Final Report, Contract No. DE-AC22-92MT92006. Prepared for the U.S. Department of Energy. Prepared by the University of Maryland. DOE/MT/92006-9. Mitsch, W. and J. Gosselink. 2000. Wetlands. Third Edition. John Wiley & Sons, Inc., New York. Snyder, D.T. and J.L. Morace. 1997. Nitrogen and phosphorus loading from drained wetlands adjacent to Upper Klamath and Agency Lakes, Oregon. US Geological Survey, Water-Resources Investigations Report 97–4059. Stevens, C.J. and D.D. Tullos. 2011. Effects of temperature and site characteristics on phosphorus dynamics in four restored wetlands: implications for wetland hydrologic management and restoration. Ecological Restoration 29: 279-291. Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, and NSI/Biohabitats. 2013. Water Quality Improvement Techniques for the Upper Klamath Basin: A Technical Workshop

Natural Wetlands Restoration	
	and Project Conceptual Designs. Prepared for California State Coastal Conservancy, Oakland, California. Sullivan, A.B., Sogutlugil, I.E., Deas, M.L., and Rounds, S.A., 2014, Water-quality modeling of Klamath Straits Drain recirculation, a Klamath River wetland, and 2011 conditions for the Link River to Keno Dam reach of the Klamath River, Oregon: U.S. Geological Survey Open-File Report 2014–1185, 75 p. Wong, S.W., M.J. Barry, A.R. Aldous, N.R. Rudd, H.A. Hendrixson, and C.M. Doehring. 2011. Nutrient release from a recently flooded delta wetland: comparison of field measurements to laboratory results. Wetlands. 31:433-443. Zentner, J., J. Glaspy, and D. Schenk. 2003. Wetland and Riparian Woodland Restoration Costs. Ecological Restoration, Vol. 21, No. 3, pp. 166-173.

Agricultural Irrigation Efficiency and Water Quality Improvement Projects	
Location	Irrigated agricultural areas within subbasins of the Upper Klamath Basin include the Sprague River, Williamson River, Upper Klamath Lake, Lost River, Upper Klamath East, and Butte Creek. Specific areas or locations that are logical to be targeted for these projects include: • Klamath Project and Lost River, Horsefly, and Langell Valley Irrigation Districts • Klamath Irrigation District • Tule Lake Irrigation District • North Ditch off of the North Fork Sprague • Upper end of Middle Sprague • Lake Ewauna/Keno Reservoir – mainstem Klamath River Reclamation's Klamath Project Area includes 188,000 of the 502,000 acres of private irrigated land in the basin upstream of Iron Gate dam. This includes lands leased from the various wildlife refuges that are supplied with water by Reclamation. The majority of the private irrigated land in the basin, about 314,000 acres, is located outside Reclamation's Klamath Project Area. NCRS (2006) subbasin assessments indicate an opportunity to conserve water and improve water quality on 130,000 acres of irrigated lands within Reclamation's Klamath Project Area. Outside Reclamation's Project Area there is an opportunity for water conservation on approximately 220,000 irrigated acres.
Goals, Objectives, Assumed Capability	The overall objective is to manage irrigation and associated return flows along streams that flow into Upper Klamath Lake or the Klamath River in order to reduce sediment loads (and sediment-bound nutrients) and irrigation tailwater discharges to the streams and rivers in the upper Klamath Basin. Given the relatively high phosphorus content of soils in the Upper Klamath Basin and the fact that both the Upper Klamath Lake Drainage and Klamath River TMDLs point to external phosphorus loading from the basin above Upper Klamath Lake as a driver of water quality throughout the system, minimizing return flow associated with irrigation is a potential priority. Any method that captures sediment or retains soil on agricultural lands would reduce phosphorus loads. For example, converting from flood or furrow irrigation to drip, sprinkler, or gated pipe irrigation conserves water and keeps more phosphorus in the field. Likewise, fields that are leveled to a gentle slope irrigate more uniformly and do not suffer as much irrigation-induced erosion as fields with greater slope. Reclamation assessments indicate that if all potential conservation practices are implemented on all irrigated lands, on-farm water use efficiency could reduce water use (and hence potential runoff) by up to 25 percent in the Upper Klamath Basin, with a concomitant reduction in nutrient and sediment loadings to adjacent waterways (Reclamation 2012, 2016). An additional potential two to five percent reduction in water use could be achieved by increasing management in upland range and forestland areas.
Design Features and Elements	Irrigation Efficiency and Water Management Projects include the reduction of irrigation return flow by using wetlands/ponds and pump-back systems; upgrading irrigation systems to reduce irrigation-induced erosion, sedimentation to streams, and increase the efficiency of irrigated water applications to reduce runoff; and lining or piping delivery systems to reducing water loss and sediment delivery to rivers and streams. Examples of specific projects include canal lining, water storage improvements, water conveyance and pumping improvements, on-farm delivery and best practices, on-farm individual storage ponds/tanks, or land idling.

Agricultural Irrigation Efficiency and Water Quality Improvement Projects	
	These irrigation efficiency and water management efforts would contribute to improved water quality in adjacent canals and streams by preventing excessive soil leaching and runoff into local water sources. Water conservation practices that reduce tailwater runoff from irrigated fields can provide extensive improvements in water quality (Shock and Welch 2011; Reclamation 2016). Improved irrigation practices to manage soil water includes more precise irrigation timing and managed deficit irrigation strategies to reduce agricultural water use and conserve water, but they require excellent control of the timing and amounts of the applied water. Techniques to improve irrigation efficiency also include installing more efficient irrigation systems. Sprinkler and drip irrigation systems are more efficient than furrow irrigation. By using polyacrylamide (PAM) or straw mulch, the sediment that normally would be washed away in runoff, instead settles to the bottom of the furrow or ditch, preventing excess phosphorus loss (Iida and Shock 2008). Sedimentation basins with pump-back systems pump water to the top of the field or to the next field thereby collecting and reusing runoff (Shock and Welch 2011). Vegetation filter strips can be implemented as barriers to slow and filter runoff water containing sediment. As water runs through the filter strip, the sediment settles and is trapped in the strip (Shock et al. 2013). Data and information is not currently available on the specific nutrient removal or reduction efficiencies by potential Irrigation Efficiency and Water Management Projects. In the Lost River Valley, there are current efforts to monitor the main points of diversion and some of the large tail water return locations (M. Hiatt, DEQ, pers. comm.). This is ahead of large scale piping efforts that are potentially moving forward in this area. Piping and irrigation strategies help to reduce irrigation water contact with soils and other nutrient containing organic material (Ciotti 2005; Ciotti et al. 2010). Through irrigation efficiency projects, the potential for tail water return will be greatly reduced. This reduction will in turn help reduce or eliminate the suspected loading stemming from these discharges. The environmental benefits relate directly to reduced nutrient and temperature loading through reduction of irrigation return flows and indirectly through reduced water demand which could potentially allow for more water in the streams and less need to divert water from Upper Klamath Lake.
Potential Adverse Impacts & Uncertainties	Potential adverse impacts: Potential for some tradeoff effects including, for example, improved water use efficiency from agricultural lands due to piping supply systems, while generally considered a positive effect, could result in less groundwater recharge and therefore reductions in local surface water runoff or groundwater discharge to streams. Uncertainties: It is uncertain at this time as to how much and when Irrigation Efficiency and Water Management Projects would occur in the basin, depending on landowner incentives and funding availability to undertake the projects. Other uncertainties are associated with the magnitude and reliability of effectiveness that actually result from these projects in affecting the necessary nutrient reduction.
Estimated Cost of Project	Construction: $200,000,000 O&M (timeframe): $27,000,000 over 20 years ACM: $37,000,000 The above costs are based on NRCS (2004), who estimated costs of implementing improved irrigation and water conservation practices in the Upper Klamath Basin. The estimated costs are evaluated as applied on 350,000 acres of private farm and range

Agricultural Irrigation Efficiency and Water Quality Improvement Projects	
	lands in the basin over an assumed period of 20 years. These estimated costs pertain specifically to implementation costs, and therefore do not account for potential resulting economic benefits of these actions to other resources, such as enhanced water availability and benefits to fish and wildlife habitat. It should be noted that costs for each project are highly depended on flow rates, installation difficulty, and other site-specific concerns (e.g., road crossings, creek crossings, elevation changes, etc.). Two other pertinent cost information includes: • In consultation with Reclamation and reviewing current and past piping projects funded through their WaterSmart program, the cost for 7,200 ft of pipe is $397,232.50 or $55.17 per foot. This is inclusive of labor and equipment cost. • Current estimates from Trout Unlimited for the North Ditch off of the North Fork Sprague is approximately $1,000,000 per mile or $189.39 per foot.
Duration	Long term
Collaboration, Synergy, or Conflict	Irrigation Efficiency and Water Management Projects will address some of the same non-point sources of sediment and nutrient loads (and therefore provide synergy with) as natural wetland restoration, DSTWs, and riparian buffers. Reduced runoff could reduce the nutrient loading that these other treatment systems are intended to manage, further increasing the overall reduction as many of these different projects come on line. However, it is possible that reduced runoff from agricultural uses could reduce the water supply to wetlands and DSTWs that the vegetation in these systems depend on to capture sediments and reduce nutrient loading. Regarding potential collaboration, potential agency partners include DEQ, North Coast Regional Water Quality Control Board, Reclamation, and NRCS. In addition to the water conservation benefits that are of significant interest to Reclamation and NRCS, the water quality agencies see this as a potentially important strategy for reducing discharge of phosphorus related to agricultural activities. Trout Unlimited is currently exploring options for some piping projects in the Sprague River area.
Information Sources	Ciotti, D., S. Griffith, J. Kann, and J. Baham. 2010. Nutrient and sediment transport on flood irrigated pasture in the Klamath Basin, Oregon. Rangeland Ecology & Management 63: 308-316. Ciotti, D. 2005. Water Quality of Runoff from Flood Irrigated Pasture in the Klamath Basin, Oregon. Thesis. Oregon State University. http://hdl.handle.net/1957/20575 Diebel, M., J. Maxted, P. Nowak, and M. Vander Zanden. 2008. Landscape planning for agricultural nonpoint source pollution reduction. I: A geographical allocation framework. Environmental Management 42:789-802. Iida, C.L. and C.C. Shock. 2008. Make Polyacrylamide Work for You! Oregon State University Extension Service. EM 8958-E. Natural Resources Conservation Service (NRCS). 2006. Conservation Resource Brief. Klamath River Basin. Number 0607. February 2006. Shock, C.C. and T. Welch. 2011. Tailwater Recovery Using Sedimentation Ponds and Pumpback Systems. Oregon State University, Department of Crop and Soil Science Ext/CrS 134.

Agricultural Irrigation Efficiency and Water Quality Improvement Projects	
	Shock, C.C., B.M. Shock, and T. Welch. 2013. Strategies for Efficient Irrigation Water Use. Sustainable Agriculture Techniques. Oregon State University Extension Service. EM 8783. Revised March 2013. U.S. Bureau of Reclamation (Reclamation). 2012. Klamath Project Yield and Water Quality Improvement Options. Appraisal Study: Summary. Klamath Project. Prepared by the U.S. Bureau of Reclamation, Mid-Pacific Region. October 2012. U.S. Bureau of Reclamation (Reclamation). 2016. Klamath Project Water Quality and Use – Initial Demonstration Assessment Upper Klamath Basin, Oregon. Prepared by the U.S. Bureau of Reclamation, Technical Service Center, Denver, Colorado. Klamath Basin Area Office Klamath Falls, Oregon. June 2016. Walker, J., J. Kann, and W. Walker. 2015. Spatial and temporal nutrient loading dynamics in the Sprague River Basin, Oregon. Prepared for the Klamath Tribes Natural Resources Department. Natural Resources Conservation Service (NRCS). 2004. Upper Klamath Basin: Opportunities for Conserving and Sustaining Natural Resources on Private Lands. Klamath Basin Rapid Subbasin Assessments. Natural Resources Conservation Service. United States Department of Agriculture. July 2004. Newton, D. and M. Perle. 2006. Irrigation District Water Efficiency Cost Analysis and Prioritization. Prepared for the U.S. Bureau of Reclamation and the Deschutes Water Alliance under Water 2025 Grant. Prepared by Newton Consultants, Inc., Redmond, OR. August 2006.

Algae Biomass Removal (Harvesting) at Link Dam	
Location	Pilot: The pilot would be located between the A-Canal and Link dam. Full-Scale: To be determined, but likely near Link River Dam
Goals, Objectives, Assumed Capability	The removal of organic matter loads (from the harvesting of algae) emanating from Upper Klamath Lake could provide substantial water quality improvements in the Klamath River and Keno reservoir. Water quality improvements would come in the form of reductions in organic matter that are sufficient to decrease nutrients and biochemical oxygen demand to levels that demonstrably improve dissolved oxygen and lessen enrichment downstream. Algae harvest and removal at Link dam would not itself resolve the dissolved oxygen or downstream nutrient-loading problems, but could provide some incremental improvement. One of the goals of a pilot project would be to look at the amount of biomass removal that is feasible, address disposal uncertainties, and fish screening requirements.
Design Features and Elements	Several design elements are common to algal filtration options: • Specified filter size for capturing multiple species of algae • Barriers to prevent accidental capture of endangered aquatic species or debris during filtration • Dewatering of algal biomass • Storage and transportation of biomass, followed by utilization and/or disposal <u>Pilot</u>: The harvester would be a series of rotating cylindrical drums, arranged in a line and attached on the eastern shoreline upstream of Link River dam. Dewatering units would be located on the eastern shoreline. The preliminary design for the pilot would include screens occupying approximately 48 feet of the channel's 170 foot total width while a full scale system would span a greater percent of the channel width. Drying would not take place on-site; the material would have to be trucked to an offsite location for drying and/or disposal. <u>Full-Scale</u>: A full-scale facility would likely be subsequently larger, occupying more of the channel width, more upland area, filtering more water, and removing more material. The location and design would be completed after a pilot project is successful and the decision is made to continue this line of investigation.
Potential Adverse Impacts & Uncertainties	Potential adverse impacts: Algae may release algal toxins into the water column during harvesting. Because water is pulled through screens that remove the algae, algae harvesting has the potential to entrain endangered suckers and other fish in Upper Klamath Lake. Uncertainties: To date, the disposition or disposal needs for filtered material has not been defined. The amount of filtered material needed to provide demonstrable water quality benefit has also not been defined. Although progress has been made recently, final fish screening requirements and feasibility of operation remain to be clarified. The persistence of algal toxins in harvested biomass is unknown, potentially affecting re-use options and operational costs.
Estimated Cost of Project	Pilot Study: $1,250,000 over 4 months (New Earth 2016) Construction and O&M (timeframe): The cost for a larger system would scale better than linearly (i.e., a system with twice the capacity would cost less than twice as much), because some system components such as dewatering are relatively independent of scale.

Algae Biomass Removal (Harvesting) at Link Dam	
	ACM: Not available (pending development of cost information).
Duration	Pilot: Short term Full project: Intermediate term
Collaboration, Synergy, or Conflict	Initially it seems likely that interactions between Algal Filtration in Upper Klamath Lake and Algae Biomass Removal at Link Dam would be beneficial. It seems unlikely that either method could remove enough material to make the other method unfeasible. In the longer-term, if water quality were to dramatically improve and algae blooms less frequent and smaller, then perhaps these two methods would conflict. It's expected that conflict would probably be outside the life-span of either project. Regarding potential collaboration, the Link River Algae Removal Demonstration Project facilities would be designed, constructed, and operated by the New Algae Company (NAC) of Klamath Falls, Oregon. NAC provides outstanding local expertise and capabilities in the harvesting of algae. NAC began harvesting algae in the Klamath Falls area in 1982 and currently conducts algae harvesting operations in Upper Klamath Lake during the summer months.
Information Sources	CH2M. 2016. Interim Measure 11, Activity 7 – Assessment of Potential Algae Harvesting and Removal Techniques at Link River Dam. Prepared by CH2M, Portland, Oregon for PacifiCorp Energy, Portland, Oregon. New Earth. 2016. Proposal for Interim Measure 11 Study Algal Biomass Harvesting at Outlet of Upper Klamath Lake: Conceptual Design, Permitting, and Preparation for Pilot Study Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, and NSI/Biohabitats. 2013. Water Quality Improvement Techniques for the Upper Klamath Basin: A Technical Workshop and Project Conceptual Designs. Prepared for California State Coastal Conservancy, Oakland, California.

Matrix of Rejected Project Categories

The PLP candidate project categories that were not carried forward for detailed ranking include:

- Demonstration Wetland Facility (DWF)
- Algal Filtration
- Particulate Organic Matter Removal from Klamath River Source Water Using Stormwater Treatment Technology
- Sediment Removal (Dredging) from Upper Klamath Lake
- Oxygenation in Keno Reservoir
- Coagulant Injection Treatment to Sequester and Inactivate Nutrients
- Combined Sediment Sequestration of Phosphorus and Oxygenation in Lake Ewauna/Keno Reservoir

The matrix for these project categories is provided on the following pages.

Name of Project or Technique	Location	Goals, Objectives, Assumed Capability	Design Features and Elements	Potential Adverse Impacts & Uncertainties	Estimated Cost of Project	Duration	Synergy/Conflict	Information Sources
Demonstration Wetland Facility (DWF)	TBD Initial discussions with the IMIC regarding a conceptual DWF location focused on potential sites: (1) near Upper Klamath Lake, specifically adjacent to lake receiving streams including the Williamson, Wood, or Sprague rivers; (2) on lands adjacent to Keno reservoir; (3) on PacifiCorp-owned lands adjacent to the Klamath River upstream of Copco reservoir; and (4) Reclamation-owned lands adjacent to A-Canal.	The DWF would provide opportunity to demonstrate approaches to and effectiveness of constructed wetlands for treatment of water quality, particularly for reductions in nutrients and organic matter in runoff to waters in the upper Klamath Basin. Constructed treatment wetlands have been shown to be effective at removing a range of pollutants from incoming waters, including total suspended solids, phosphorus, nitrogen, metals, organic compounds, and bacteria and pathogens. The DWF would allow important research on: (1) ranges of feasible nutrient removal performance, including conditions with interactions with groundwater influence; (2) consumptive use of water in treatment wetlands, which may thereby limit application, given water rights constraints; and (3) vegetative community effects on treatment performance and soil rebuilding.	The DWF would include various wetland cells that would be used to test and evaluate specific design and operations criteria that maximize water treatment. The DWF would include several lined and unlined cells (of about 0.3 to 0.6 acres in size) that vary in depth and plant composition. These cells would be sized, controlled, and operated based on treatment efficiency and hydraulic residence time objectives. These systems can also provide wildlife habitat opportunities. The DWF likely would have ancillary facilities for supporting research activities and storing equipment.	Potential adverse impacts: Could result in permanent loss of existing wetlands or other upland land uses (e.g., agriculture) depending on location. Uncertainties: location and property for the DWF; sponsors and funding sources for the DWF.	**Pilot Study:** None proposed **Construction**: Total DWF construction cost estimated at $2,275,000 (CH2M HILL 2014) **O&M (timeframe)**: Total costs of operation, maintenance, monitoring and reporting estimated at $470,000 annually (or per-year of research activity; CH2M HILL 2014). **ACM**: $697,500	Estimated Project life = 10 years	Potential synergies with diffuse source treatment wetlands (DSTWs) or natural wetlands restoration, because a DWF could provide research opportunities for assessing effectiveness of DSTWs or restored natural wetlands. Possibly other synergies with other nutrient removal techniques.	CH2M HILL. 2012. Approaches to Water Quality Treatment by Wetlands in the Upper Klamath Basin. Prepared for PacifiCorp Energy, Portland, OR. Prepared by CH2M HILL, Inc., Portland, OR. August 2012. CH2M HILL. 2014. Demonstration Wetland Facility Preliminary Research and Implementation Plan, Klamath River, Oregon. Prepared for PacifiCorp Energy, Portland, OR. Prepared by CH2M HILL, Inc., Portland, OR. October 2014.
Algal Filtration	Within Upper Klamath Lake	Algal decomposition releases a pulse of nutrients which can fuel subsequent blooms. Removal of algal cells from water bodies before they die and decompose would reduce the potential for this undesirable oxygen demand and decrease the concentration of nitrogen and phosphorus in the water column. Filtration physically removes algal biomass from the water column, for example, by capturing live cells on screens that are pulled through the water column. While nutrients can still be present in lake sediments and waters flowing into the system, the continued filtration of algal biomass from the water column is a direct approach to decreasing oxygen demand and nutrients in the system. Further, removal of toxin-producing cyanobacteria such as *Microcystis aeruginosa* reduces a potential source of cyanotoxins.	Several design elements are common to algal filtration options: • Targeting of areas with concentrated algal blooms (i.e., "hot spots") • Specified filter size for capturing multiple species of algae • Barriers to prevent accidental capture of endangered aquatic species or debris during filtration • Mitigation of algal toxin release during filtration • Dewatering of algal biomass • Storage and transportation of biomass, followed by utilization and/or disposal	Potential adverse impacts: May release algal toxins to water column during harvesting. Possibility of impacts to federally-endangered suckers. Uncertainties: Specific location of filtration activity; disposition or disposal of filtered material; amount of filtered material needed to provide demonstrable water quality benefit.	**Pilot Study:** None proposed **Construction**: $300,000 (pg. 40 of Appendix A of Stillwater et al. 2013) **O&M (timeframe)**: $3,400,000 over 10 years (p. 40 of Appendix A of Stillwater et al. 2013) **ACM:** $370,000	Intermediate term	Initially it seems likely that interactions between Algal Filtration in Upper Klamath Lake and Algae Biomass Removal at Link Dam would be beneficial. It seems unlikely that either method could remove enough material to make the other method unfeasible. In the longer-term, if water quality were to dramatically improve and algae blooms less frequent and smaller, then perhaps these two methods would conflict. This conflict would appear probably be outside the life-span of either project.	Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, and NSI/Biohabitats. 2013. Water Quality Improvement Techniques for the Upper Klamath Basin: A Technical Workshop and Project Conceptual Designs. Prepared for California State Coastal Conservancy, Oakland, California.
Particulate Organic Matter Removal from Klamath River Source Water Using	Southern end of Upper Klamath Lake, near the outflow at Link River Dam. Specific locations assessed include the	Stormwater treatment technologies can be effective means of removing particulates and associated nutrients from surface water runoff that potentially promote algae growth in receiving waters. Reductions of	The basic conceptual design elements include: • Separator Facility consisting of multiple continuous deflection systems.	Potential adverse impacts: Potential for unintended capture of endangered suckers. Decrease in water quality in A Canal.	**Pilot Study:** Already complete **Construction and O&M (timeframe)**: $20,000,000 to $80,000,000 (depending on level of	20 years	Particulate organic matter removal potentially conflicts with an algae biomass removal project located at Link dam (above), because both of projects are aimed at	Watercourse Engineering, Inc. (Watercourse). 2015. Conceptual Design Evaluation for Full-Scale Particulate Organic Matter Removal from Klamath River Source Water Using Stormwater Treatment Technology,

Name of Project or Technique	Location	Goals, Objectives, Assumed Capability	Design Features and Elements	Potential Adverse Impacts & Uncertainties	Estimated Cost of Project	Duration	Synergy/Conflict	Information Sources
Stormwater Treatment Technology	Eastside Forebay at Link dam and A-Canal intake and fish screen.	seasonal algae and organic matter loads emanating from Upper Klamath Lake could provide substantial water quality improvements in the Klamath River. This is especially the case in Keno Reservoir, which is just downstream of Upper Klamath Lake and experiences seasonal anoxia due to the processing of organic matter loads from UKL. Water quality improvements from the reductions in particulate organic matter loading would potentially provide important benefits for endangered suckers found in Keno Reservoir. Reductions in organic matter loading could also lead to lower seasonal organic matter concentrations in the Klamath River downstream of Keno Dam.	• Fish Screen: A fish screen was assumed necessary for options where no fish collection/transport facility was proposed or where an existing fish screen was unavailable. • Conveyance: Pipelines and associated infrastructure to convey the waters from a separator facility to a discharge location, including piping, tunnels, and discharge facilities. • Pumping: A fraction of water routed through the sump required pumping to the discharge location near A-Canal (upstream or downstream of the fish screen). Operational Considerations: Organic matter removal would coincide with the seasonal increase in primary production at Upper Klamath Lake and the associated outflow of large loads of algae, approximately June through September. Separator facility capacity is assumed to be up to 1,000 cfs, which is consistent with the average flow at Link River below Eastside Powerhouse that occurs in the June through September period. While a fraction of waters diverted to A-Canal and released at Link River Dam would pass through the organic matter separator facility, the total diversions to the A-Canal and flow releases from Link River Dam would be unaltered. Sump outflows would only modestly increase current loads of particulate matter in A-Canal.	Uncertainties: The need for and type of fish screens depends on facility layout. The location and property for facilities as wells as sponsors and funding sources are all unknown.	removal desired; over 20 years) **ACM:** $1,000,000 to $4,000,000		removal of the same material and are conceptually located in the same physical space. They may be redundant in terms of their purpose and need; however, it is not expected that algae and nutrient loading in Upper Klamath Lake would so rapidly improve as to make one method unfeasible. If the location conflicts could be addressed, the projects may interact for greater overall benefit.	2013. Prepared for PacifiCorp Energy, Portland OR. March. Watercourse Engineering, Inc. (Watercourse). 2014. Evaluation of Particulate Organic Matter Removal from Klamath River Source Water Using Stormwater Treatment Technology, 2013. Prepared for PacifiCorp Energy, Portland OR. June. Watercourse Engineering, Inc. (Watercourse). 2013. Evaluation of Particulate Organic Matter Removal from Klamath River Source Water Using Stormwater Treatment Technology, 2012. Prepared for PacifiCorp Energy, Portland OR. April.
Sediment Removal (Dredging) from Upper Klamath Lake	A portion of Upper Klamath Lake just south of Goose Bay containing relatively high concentrations of phosphorus	Dredging is the physical removal of accumulated sediments from lakes or other waterbodies in order to improve water quality, recreation, and navigation, or support other uses. Dredging can improve water quality by directly removing pollutants, nutrient-rich sediments and decomposing organic plant matter. An entire lake bottom can be dredged or specific zones can be targeted where dredging may be most beneficial, such as areas with the thickest sediment layer or greatest concentration of pollutants. Targeted dredging of a portion of Upper Klamath Lake just south of Goose Bay containing relatively high	There are two primary methods used for lake dredging: mechanical dredging and hydraulic (i.e., suction) dredging. Mechanical dredging can be either “dry” or “wet” and involves earthmoving equipment and/or grab buckets to scoop sediment and transport it to a disposal site. Hydraulic dredging is a “wet” method and is the preferred method for dredging lake sediments, because it is faster than mechanical dredging, creates less turbidity in the surrounding water and can effectively remove loose, watery sediments. Once the area to be dredged has been identified, the appropriate dredging	Potential adverse impacts: There is the risk of accidental capture or mortality of endangered suckers along with temporarily impaired water quality from increased turbidity. Uncertainties: The amount of phosphorus that must be removed from sediments to affect the whole lake phosphorus equilibrium is currently unknown. Volume of material generated along with disposal of these spoils needs to be defined. The rate at which nutrient rich material would	**Pilot Study:** $940,000 to $1,400,000 (pg. 72 of Stillwater et al. 2013) **Construction and O&M (timeframe)**: $460,000,000 over 5 years at Upper Klamath Lake (pg. 26 of Stillwater et al. 2013; pg. 42 of Appendix A of Stillwater et al. 2013) **Construction and O&M (timeframe)**: $1,470,000 over 5 years at Keno Reservoir (pg. 42 of Appendix A of Stillwater et al. 2013).	Intermediate term	Because dredging provides removal of sediment nutrients, it would be synergistic with other projects that also result in removal of nutrients from the water column (e.g., particulate removal; algae filtration and harvest; coagulant injection).	Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, and NSI/Biohabitats. 2013. Water Quality Improvement Techniques for the Upper Klamath Basin: A Technical Workshop and Project Conceptual Designs. Prepared for California State Coastal Conservancy, Oakland, California.

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		concentrations of phosphorus could decrease the potential for internal loading of phosphorus to the lake and subsequent nuisance algal blooms.	methodology, the fate of the dredged material (i.e., re-use or disposal), and transportation requirements would be considered. Hydraulic dredging requires dewatering of the sediment and water mixture (slurry), often accomplished by piping the slurry to a settling basin. Sediments settle from the water column in the settling basin, so design of this feature requires determination of the sediment settling rate. In some cases excess water from the sediment slurry can be removed prior to being transported to the settling basin, which significantly decreases the amount of land area required for settling. An alternative to settling basins is geotextile tubes. The slurry is pumped through the tubes, allowing the filtered water to drain through the tubes' openings and the sediment to dry within. Geotextile tubes require a lined dewatering area, similar to settling basins.	settle out into the recently dredged area would affect the lifespan of the project.	**ACM:** $57,000,000 (Upper Klamath Lake) ; $360,000 (Keno reservoir)			
Oxygenation in Keno Reservoir	Lake Ewauna and Keno Impoundment	Oxygenation refers to oxygen transfer to (and dissolution in) the water using pure oxygen. Commercially-available oxygenation systems could deliver oxygen to Keno reservoir to substantially enhance dissolved oxygen (DO) conditions and attain water quality objectives. This could be accomplished by strategically-located oxygenation input plants along the 20-mile Keno reservoir. The addition of oxygen and resulting enhanced decomposition of organic matter loads emanating from Upper Klamath Lake could provide substantial water quality improvements in Keno reservoir, and possibly further downstream in the Klamath River. In addition, the resulting water quality improvements in Keno reservoir could potentially provide important benefits for endangered suckers found in the reservoir and potentially facilitate anadromous fish passage through the reservoir in the future if downstream dams are removed or fish passage is otherwise established.	DO enhancement techniques include both aeration systems (using air) and oxygenation (using concentrated or pure oxygen) systems. Oxygenation technologies used to enhance DO either inject pure oxygen directly into water typically using a diffuser, or into a side-stream contact chamber using a downflow contactor. An effective oxygenation system in Keno Reservoir could include one or both oxygenation systems. Oxygen transfer efficiency favors the potential use of side-stream oxygenation technology in Keno reservoir. Sparged oxygen transfer would be significantly constrained by the reservoir's relatively shallow depth of water. In addition, sparged oxygen cannot provide DO greater than saturation. In contrast, side-stream oxygenation will supersaturate the discharged water with DO at levels from 12 to 18 mg/L (125 percent to over 250 percent) near the diffuser. In addition to much greater oxygen transfer efficiency, side-stream oxygenation technology will perform better in a high-BOD environment such as Keno reservoir.	Potential adverse impacts: Potential for unintended capture of endangered suckers in the intakes necessary for side-stream systems. Permanent change of upland land-use and some minor permanent impacts to waters of the U.S. Uncertainties: Side-stream systems would likely need fish screens. The location and property for facilities as well as project sponsors and funding sources have not been defined.	**Pilot Study:** None proposed **Construction**: $54,000,000 to $100,000,000 (Keno reservoir) (pg. 20 of CH2M & WCE 2016) **ACM**: $5,400,000 to 10,000,000	Intermediate term	Unlikely to conflict with other measures because low DO levels in Keno Reservoir are likely an ongoing problem throughout the life-span of this project. Reductions in nutrient loading from other projects may reduce the amount of oxygen needed to meet water quality goals, a synergistic beneficial effect.	Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, and NSI/Biohabitats. 2013. Water Quality Improvement Techniques for the Upper Klamath Basin: A Technical Workshop and Project Conceptual Designs. Prepared for California State Coastal Conservancy, Oakland, California. CH2M and Watercourse Engineering, Inc. 2016. Interim Measure 11, Activity 4 – Conceptual Feasibility Study of Oxygenation Systems at Keno Reservoir. Prepared by CH2ML and Watercourse, Portland, Oregon for PacifiCorp Energy, Portland, Oregon.

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Coagulant Injection Treatment to Sequester and Inactivate Nutrients	Lake Ewauna and Keno reservoir	There is widespread consensus among lake scientists that alum is effective at sequestering and inactivating phosphorus and is safe to use. Alum is a chemical compound containing aluminum and sulfate that when added to water forms a semisolid matrix commonly referred to as floc. Alum floc is made up of aluminum hydroxide, which is heavier than water and sinks through the water column, collecting phosphorus as it settles. The settled material sinks into the existing sediments where the phosphorus remains bound over time. This process does not form a sediment cap and is not a biological barrier; benthic organisms live amongst the floc particles as they would other sediments. One of the advantages of alum application is that phosphorus remains bound in the floc even during seasonal periods of low dissolved oxygen in the sediments and/or water column when phosphorus would otherwise be released and support algae growth.	Alum micro-floc and oxygen would be injected into Lake Ewauna to reduce oxygen demand and sequester or inactivate phosphorus in the sediments and water column. There are several design considerations that are important: • Size of water body to treat • Alum dose required (typically 50-100 grams of alum per square meter of lake surface area) • Application strategy • Logistical constraints posed by alum volume required and proximity to supply • Availability and location of application staging area	Potential adverse impacts: The main precaution associated with alum use is the presence of free aluminum at low pH (< 6.0), which can be toxic to aquatic life. To maintain the appropriate pH, alum treatments must be chemically buffered. Uncertainties: The location and property for shore-side staging and support facilities needs to be identified. There are no existing sponsors and funding sources. The uncertainty in the efficacy of alum treatment in Upper Klamath Basin waters (i.e., low alkalinity, high seasonal pH), including consideration of re-suspension potential for shallow areas of Upper Klamath Lake	**Pilot Study:** Not available. **Construction:** Mobilization costs of $2,250,000 at Upper Klamath Lake (pg. 44 of Appendix A of Stillwater et al. 2013) **O&M (timeframe)**: $177,750,000 over 8 years at UKL (pg. 44 of Appendix A of Stillwater et al. 2013) **ACM:** $18,000,000	Intermediate term The longevity of treatments varies, but typically about 10 years can be expected in lake systems with effectiveness waning over time as the alum floc layer sinks and new sediment with un-bound phosphorus settles and covers the alum layer.	Reductions in phosphorus loading in Keno Reservoir could interact in a beneficial way with reduced nutrient loading coming from Upper Klamath Lake described from other projects.	Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, and NSI/Biohabitats. 2013. Water Quality Improvement Techniques for the Upper Klamath Basin: A Technical Workshop and Project Conceptual Designs. Prepared for California State Coastal Conservancy, Oakland, California. CH2M. 2015. Interim Measure 11 Study of Nutrient Reduction Methods: Jar Test Results and Summary Report. Prepared by CH2M, Portland, Oregon for PacifiCorp Energy, Portland, Oregon.
Combined Sediment Sequestration of Phosphorus and Oxygenation in Lake Ewauna/Keno Reservoir	Lake Ewauna/Keno reservoir	(combination of goals stated in the sections describing sediment sequestration and oxygenation)	(combination of design features stated in the sections describing sediment sequestration and oxygenation)	(combination of potential impacts stated in the sections describing sediment sequestration and oxygenation)	**Pilot Study:** Not available **Construction:** $5,191,772 (Keno Reservoir) (pg. 44 of Appendix A of Stillwater et al. 2013) **O&M (timeframe):** $81,680,000 over 20 years (Keno Reservoir) (pg. 44 of Appendix A of Stillwater et al. 2013) **ACM:** $4,343,590	Intermediate term		Stillwater Sciences, Jones & Trimiew Design, Atkins, Tetra Tech, Riverbend Sciences, Aquatic Ecosystem Sciences, and NSI/Biohabitats. 2013. Water Quality Improvement Techniques for the Upper Klamath Basin: A Technical Workshop and Project Conceptual Designs. Prepared for California State Coastal Conservancy, Oakland, California. CH2M and Watercourse Engineering, Inc. (Watercourse). 2016. Interim Measure 11, Activity 4 – Conceptual Feasibility Study of Oxygenation Systems at Keno Reservoir. Prepared by CH2M and Watercourse, Portland, Oregon for PacifiCorp Energy, Portland, Oregon.