Klamath Hydroelectric Settlement Agreement:
Interim Water Quality Improvements
(Interim Measure 11)

Study Plan: Continued Development of the Water Quality Accounting Framework

Version: October 18, 2010

Introduction

On February 18, 2010, the United States, the States of California and Oregon, PacifiCorp, Tribes, and a number of other stakeholder groups signed the Klamath Hydroelectric Settlement Agreement (KHSA). The KHSA lays out the process for additional studies, environmental review, and a determination by the Secretary of the Interior regarding whether removal of four dams owned by PacifiCorp on the Klamath River (i.e., Iron Gate, J.C. Boyle, Copco 1, and Copco 2 dams) will advance restoration of the salmonid fisheries of the Klamath Basin, and is in the public interest (which includes effects on local communities and Tribes).

The KHSA includes provisions and detailed actions for the interim operation of the dams and mitigation activities prior to removal of the dams or the termination of KHSA. One of the measures – titled Interim Measure 11: Interim Water Quality Improvements – emphasizes nutrient reduction projects in the basin to enhance water quality in the Klamath River, while also addressing water quality, algal and public health issues in Project reservoirs and dissolved oxygen in J.C. Boyle reservoir. The purpose of Interim Measure 11 is to improve water quality in the Klamath River during the interim period leading up to potential dam removal.

Prior to the date of the Secretarial Determination, the measure calls for PacifiCorp to implement studies or pilot projects to address four categories of studies specified for Interim Measure 11:

- Development of a Water Quality Accounting Framework
- Constructed Treatment Wetlands Pilot Evaluation
- Assessment of In-Reservoir Water Quality Control Techniques
- Improvement of J.C. Boyle Reservoir Dissolved Oxygen

This study plan addresses the proposed activities under Interim Measure 11 over a 2-year time frame (that is, during years 2010 and 2011) to address the first of these four categories of studies. The Secretarial Determination is to be finalized in March 2012.

Purpose and Objectives

The Klamath River Total Maximum Daily Loads (TMDLs) and associated Implementation Plans for Oregon and California (ODEQ 2010, Regional Water Board 2010) recommend several potential implementation actions to address water quality impairments in the Klamath River. One of these actions is development of a "water quality improvement tracking and accounting program" for the Klamath Basin. PacifiCorp is working in cooperation with the Regional Water Board, Oregon Department of Environmental Quality (ODEQ), and U.S. Environmental Protection Agency (USEPA) Regions 9 and 10 to develop the Klamath basin water quality improvement tracking and accounting program.

The purpose of this Study is to continue development of a water quality improvement tracking and accounting program, and framework elements. The key concept behind the program is to facilitate opportunities for collaboration among Basin stakeholders to reduce nutrient loads, temperature loads, and loads of other constituents from upstream sources to reduce and offset water quality impairments in the Klamath River. This program will provide a record of individual actions and provide a potential basis for a market that facilitates a higher level of activity and collaboration than could be achieved by individual entities and dischargers alone.

Task and Work Elements

During 2009-10, Watercourse, under contract with PacifiCorp, developed information related to the scope of the water quality improvement tracking and accounting program (TAP). This information included: (1) a technical study and program development plan; and (2) a stakeholder information and participation plan. These documents assisted the Regional Water Board and ODEQ in drafting appropriate language for the program as described in the TMDLs and Implementation Plans for Oregon and California (ODEQ 2010, Regional Water Board 2010). Additional tasks include working cooperatively with the TAP Working Group[1] in guiding meetings with Environmental Incentives, developing general program documents, and specific deliverables. The inception and subsequent development has required considerable program management resources (i.e., education, additional meetings, development of a workshop, information documents). In addition to contributing to these group activities, Watercourse has completed a comprehensive stakeholder identification document, wherein information on over 50 stakeholders was assembled. Information included entity background, mission, policies and programs that address water quality, water quality regulatory consideration, and contact information. Watercourse also developed a document identifying water quality parameters amenable to include in the Klamath TAP. This document summarizes those constituents that are listed in the Klamath River mainstem and tributaries in Oregon and California, identifies the factors that affect these constituents in aquatic environments, and provides an initial ranking of these constituents as high, medium, or low potential for trading. Currently, Watercourse is

[1] The Klamath Basin Tracking and Accounting Program working group consists of representatives from Oregon Department of Environmental Quality; North Coast Regional Water Quality Control Board; U.S. Environmental Protection Agency, Regions IX and X; PacifiCorp, Environmental Incentives, and Watercourse Engineering, Inc. This working group is tasked with guiding the development of a water quality tracking and accounting program to improve water quality in the Klamath Basin.

working on a third document identifying available on credit calculating tools and identifying their potential for use in the Klamath TAP framework.

Working in cooperation with Oregon and California, ongoing work will focus on program definition, expanding stakeholder roles, program technical and policy elements, and ultimately program implementation.

The tasks and work elements that will be conducted over the next 2-year time frame (that is, during years 2010 and 2011) are described in the following sections.

Completion of Program Design

PacifiCorp and Watercourse will continue to participate in program design elements and general TAP working group activities. General support for program design that includes continued development of situational analysis tasks and feasibility assessment (2010), feasibility scope and design (2010-11), specific program design elements (2011), and program launch (2012). Dates provided in parenthesis are current targets.

Stakeholder Outreach

Stakeholder outreach is an integral part of the TAP working group activities. The working group shares the task of outreach among all parties, working towards a proactive and transparent process to communicate information to stakeholders. In this collaborative process, Watercourse will:

- Assist in implementing plans for stakeholder information and input.
- Assist in contacting stakeholders to inform them of TAP status.
- Assist in developing materials and planning meetings, as necessary.
- Participate in stakeholder meetings, as necessary.

Determine Constituents for Tracking and Trading

Watercourse is in the process of building upon the "Water Quality Constituents Amenable to Trading" document to extend the general background information to Klamath River basin specific information. This includes:

- Further definition of eutrophication pollutants (e.g., forms of nutrients included into the TAP). Certain constituents may be important to tracking or trading, but may be more challenging to track or trade. Inorganic forms of nutrients – those which are readily available for plant growth – may not be reflected in typical trading metrics, such as total nitrogen or total phosphorous (EPA, 2004). Further, the Klamath River basin is large and complex, leading to spatially and temporally varying water quality conditions. Reach specific conditions may vary considerably. Identifying such variability in space and time will provide critical information to the TAP working group and stakeholders regarding the opportunities for water quality improvement.
- An approximate understanding of subwatershed pollutant priorities and seasonal effects to inform the need for transport ratios and define critical periods. Understanding where

and when water quality conditions are impaired and the quantification of impairment is important in developing opportunities for credit development. Transport ratios to transfer water quality improvement credits from one location to another require such information to ensure appropriate representation of opportunities exist within the TAP. Such ratios may be constituent and site dependent.

- Spatial extent and fate of constituents in the Klamath River and tributaries. Constituents identified in the first phase of this work are not conservative and vary considerably in space and time among Klamath River mainstem reaches, as well as among tributaries. Certain constituents undergo transformations (e.g., nitrogen species), or exchange across the air-water interface (dissolved oxygen, pH (carbon dioxide), temperature (heat exchange). When trading or tracking such constituents, the spatial and temporal extent of impairment as well as the spatial and temporal extent of water quality benefits developed through prescriptive actions is important, i.e., the fate and transport mechanisms should be understood and accommodated as feasible. The wide range of conditions in the Klamath Basin presents challenges; however Watercourse is familiar with a wide range of existing and potential tools and approaches that will help provide direction for the TAP program.

Constituent Control and Credit Calculation Methodology

Watercourse is in the process of extending the work on credit calculation from existing tools to the development of site-specific tools or methods applicable to the Klamath River. This work will include:

- Identifying credit development opportunities at the sub-watershed and main-stem scale, including the likely need for pollutant delivery ratios and tributary or reach specific definitions of success. (The current need is not a set of numeric answers, but the definition if how and why opportunities should be included in the Program Design stage.) Development of credit is a pivotal element of the TAP program. Identifying opportunities and providing a general ranking (e.g., high to low) is a first step in determining the extent and potential size (or volume) of credit opportunities. This information will assist the working group in developing appropriate approaches, identify stakeholder opportunities, and refine program design to accommodate conditions that occur in the Klamath Basin.

- Identifying and developing necessary credit calculation methodology and range of unit credit costs (including trading ratios), including the need for tributary specific goals, credits and delivery or transport ratios. Once credit opportunities are identified, credit calculation methodologies and associated range of unit credit costs can follow. In cooperation with the working group and others, appropriate methods will be developed. Site or reach specific goals will be explored to assist in credit and delivery or transport ratios (e.g., transferring credit from one location to another). Aspects of this work will depend on final program form and structure that should be developed in the latter part of 2010 or early 2011. Certain work can commence in the immediate future.

- Identifying and quantifying specific constituent control approaches and associated costs. This last item, identifying and quantifying specific constituent control approaches, will occur in 2011 following a planned workshop on water quality control approaches.

Program design refinement and implementation planning, program participation

PacifiCorp and Watercourse will continue to assist in program refinement and implementation, as well as overall program participation. It is envisioned that tasks previously carried out by Watercourse (such as meeting planning) will be completed by other entities. Nonetheless, participation in program refinement, implementation, and overall general participation is envisioned to occur throughout the process.

Data and Information Analysis and Reporting

Work to date has utilized a wide range of literature, reports, and discussions with other program participants and professionals with water quality trading or tracking experience. This information is collected through literature searches, interviews, meetings, and other methods. These resources provide some of the latest advances and findings in the dynamic field of water quality trading and tracking, and these resources will continue to be utilized. Information and analyses are reviewed by working group members and as such draft and final products, typically as technical memorandums, are products supporting the working group.

Future products will include reviewing technical tools, which will bring a different level of deliverables to the working group and stakeholders. Such technical tools will require documentation and possibly electronic (computer) files to be incorporated into the process. As with all participants in the process, a transparent and well documented process will be followed.

Two technical memoranda are proposed:

- Constituents for Tracking and Trading
- Constituent Control and Credit Calculation Methodology

Watercourse has produced an agenda for meetings over the last year. In the near future this may continue (to be replaced by another party in the future). The working group intends to share tasks. If Watercourse is tasked with another activity (e.g., meeting minutes), reporting will be consistent with that task.

Schedule

The schedule for the four principal activities identified above is shown below. Some of these tasks are still under discussion by the working group, and flexibility will be required as additional information is gained and additional stakeholders are incorporated into the process. As such, dates are subject to change.

Activity	Deliverable	Estimated Date
Stakeholder outreach	n/a	Ongoing
Constituents for tracking and trading	Technical Memoranda	October 2010 – May 2011
Constituent control and credit calculation methodology	Technical Memoranda	October 2010 – December 2011

Program refinement and implementation planning, program participation	n/a	Ongoing

References

ODEQ. 2010. Draft Upper Klamath and Lost River Subbasins Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP). Oregon Department of Environmental Quality (ODEQ). February 2010.

Regional Water Board. 2010. Final Staff Report for the Klamath River Total Maximum Daily Loads (TMDLs) and Action Plan Addressing Temperature, Dissolved Oxygen, Nutrient, and Microcystin Impairments in California, the Proposed Site Specific Dissolved Oxygen Objectives for the Klamath River in California, and the Klamath River and Lost River Implementation Plans. North Coast Regional Water Quality Control Board, Santa Rosa CA. March 2010.

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Klamath Hydroelectric Settlement Agreement:
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(Interim Measure 11)

Study Plan: Evaluation of Organic Matter Removal from Keno Reservoir and the Upper Klamath River

Version: October 18, 2010

Introduction

On February 18, 2010, the United States, the States of California and Oregon, PacifiCorp, Tribes, and a number of other stakeholder groups signed the Klamath Hydroelectric Settlement Agreement (KHSA). The KHSA lays out the process for additional studies, environmental review, and a determination by the Secretary of the Interior regarding whether removal of four dams owned by PacifiCorp on the Klamath River (i.e., Iron Gate, J.C. Boyle, Copco 1, and Copco 2 dams) will advance restoration of the salmonid fisheries of the Klamath Basin, and is in the public interest (which includes effects on local communities and Tribes).

The KHSA includes provisions and detailed actions for the interim operation of the dams and mitigation activities prior to removal of the dams or the termination of KHSA. One of the measures – titled Interim Measure 11: Interim Water Quality Improvements – emphasizes nutrient reduction projects in the basin to enhance water quality in the Klamath River, while also addressing water quality, algal and public health issues in Project reservoirs and dissolved oxygen in J.C. Boyle reservoir. The purpose of Interim Measure 11 is to improve water quality in the Klamath River during the interim period leading up to potential dam removal.

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- Development of a Water Quality Accounting Framework
- Constructed Treatment Wetlands Pilot Evaluation
- Assessment of In-Reservoir Water Quality Control Techniques
- Improvement of J.C. Boyle Reservoir Dissolved Oxygen

This study plan addresses one of the proposed activities under Interim Measure 11 over a 2-year time frame (that is, during years 2010 and 2011) to address the second and third of these four categories of studies. The Secretarial Determination is to be finalized in March 2012.

Purpose and Objectives

The Klamath River from Link River to Keno dam experiences degraded water quality conditions on a seasonal basis, causing unsuitable conditions for fish and other aquatic organisms. Although other elements contribute to impaired water quality (e.g., agricultural return flows, municipal and industrial discharge, and instream processes), Upper Klamath Lake has been and remains the principal driver of water quality in this reach due to large loads of nutrients and organic matter discharged from the lake.

Actions identified in the California and Oregon TMDL's (Regional Water Board, 2010; ODEQ, 2010) identify treatment wetlands, centralized treatment, and a water quality tracking and accounting program as potential approaches to improved water quality in the Klamath River. One approach for water quality improvements is the removal of phytoplankton and large particulate organic matter that has direct implications on water quality impairment in the Link River to Keno dam reach (as well as downstream reaches). This project would address directly similar issues to wetlands treatment and centralized treatment (removal of particulate matter), and provide information of value for the tracking and accounting program.

The approach proposed herein employs a well-developed technology to remove particulate material using hydrodynamic separation and/or screening facilities. Such facilities have multiple benefits beyond being widely tested, including:

- an ability to target positive, negative, or neutral buoyant particles,
- ability to select specific particle sizes,
- relatively low cost,
- modest maintenance,
- can be driven with low head requirements (e.g., a few feet), and
- can be implemented quickly.

This Study Plan describes a pilot project that would assess the efficacy of such facilities on removing particulate organic matter and phytoplankton through field as well as laboratory testing of waters from the Klamath River in the vicinity of Link River dam or Keno reservoir.

Background

Large loads of nutrients and organic matter discharged from Upper Klamath Lake into downstream reaches cause extensive, persistent anoxia and associated water quality impairment (Mrazik, 2006). This impairment has direct implications on fisheries (Gutermuth et al. 2000) and aquatic life. For example, ODFW (1996) surveys found virtually no fish life in the Klamath River below Lake Ewauna, although Piaskowski (2003) and Piaskowski and Simon (2005) found suckers (Lost River and shortnose) persisting in Link River and the upper portion of Lake Ewauna. The hypothesis is that very low dissolved oxygen conditions preclude the presence of these species in an environment that currently only supports a benthic community highly tolerant of pollution.

Short-term reduction of the large seasonal loads emanating from Upper Klamath Lake is probably not feasible due to the substantial internal loading that occurs in the lake (NAS, 2004), so short term actions are of interest. Deas and Vaughn (2006) and Mahugh et al (2008) identified a potential role for engineered wetlands adjacent to Keno reservoir to reduce organic matter. Other options that have been discussed include treatment of waters from Upper Klamath Lake (Regional Water Board, 2010), in-reservoir treatment (e.g., oxygenation or reaeration), and physical removal of algae and larger particulate organic matter. This Study Plan focuses on approaches for reductions of the large loads phytoplankton and particulate organic matter discharged from the lake. Such a reduction would directly reduce oxygen demanding substances from Keno Reservoir and the river, as well as their associated nutrient loads, and lead to direct water quality improvements in the near-term.

The activities conducted under this Study Plan include assessment of the potential use of hydrodynamic separation and/or screening to remove phytoplankton and larger particulate matter from the water. Hydrodynamic separation/screening emanates from stormwater removal technology, and has a wide range of successful applications for removing particles and chemicals from water. The large loads of organic matter from Upper Klamath Lake are dominated by the bloom-forming blue-green algae *Aphanizomenon flos aquae*, which have a relatively large particle size (Peterson Holm et al, 1983) and buoyant characteristics (Canter Lund and Lund, 1995). These characteristics, which create a competitive advantage for *Aphanizomenon* over other phytoplankton in the lake, allow for the use of a separation and/or filtration strategy to remove these algae from the water column.

There have been many studies identifying stormwater treatment as an effective way of removing particulate matter and associated nutrients that potentially promote algae growth (Perry et al, 2009; Reddy et al, 2006; Patel et al, 2004). However, no significant work has been completed on using stormwater removal facilities for the specific purpose of removing algae biomatter. The activities conducted under this Study Plan will assess several separation technologies (high flow separation, vortex separators, deflection separators, etc.) on algal and particulate organic matter removal. These approaches can treat down to particle sizes on the order of two millimeters, with high removal rates (e.g., 60 to 80 percent) for both buoyant and neutrally buoyant materials in stormwater applications (http://www.contech-cpi.com).

A critical attribute of these separation technologies (and associated devices) is that they are specifically designed to work on gravity flow with low head (on the order of a few feet), so there are no direct power requirements. The local stream gradient at Link River is sufficient to operate such devices (although in this assessment, water will be pumped through a segregated, on-shore treatment system as described further below). An important aspect of these devices is that they can accommodate flow rates of tens to over a hundred cubic feet per second (http://www.contech-cpi.com). In addition, these devices can be used in series (e.g., treatment "trains"), wherein combinations of settling, filtration and separation can be employed to target a range of materials or specific sized materials. In sum, these separation technologies (and associated devices) can provide the potential to treat the volumes of water required to have a direct, beneficial water quality effect in Keno reservoir and downstream reaches of the Klamath River.

Task and Work Elements

The tasks and work elements under this Study over the next two-year time frame (that is, during years 2010 and 2011) will be conducted as a two-phase project, consisting of both on-site pilot scale assessments and, presuming a successful pilot test a pre-design and cost estimate of installation and maintenance will be developed. The two phases are described in the following sections.

Phase I: Project Approach and Onsite Assessment

Phase I consists of fully defining the project approach, including a literature review of the range and types of technology available. Subsequently an on-site assessment will be completed. The onsite assessment will utilize a portable, pilot scale stormwater treatment system to explore removal efficiencies under field conditions. This on-site work is invaluable because the experiments are conducted under actual field temperatures and water quality conditions. Offsite, or laboratory, pilot scale assessment requires that water be collected and transported to a laboratory, wherein experiments are completed with a wider range of treatment devices with small volumes of water. This latter approach is not deemed adequate.

The pilot scale system will treat up to approximately 200 gpm (0.44 cfs), and consist of a tank, separator, trash pump, plumbing (hoses), and energy source (generator). The trash pump has minimal affect on particulate matter in the size range of interest, thus providing a representative particle size to the treatment system.

Particle size distribution will be measured with a LISST (Laser In-Situ Scattering and Transmissometry (Sequoia Scientific, 2005)) to quickly and accurately define field conditions regarding particle size and, if feasible, settling characteristics. Further, physical, chemical, and biological samples will be collected to ascertain removal efficiencies of treatment approaches, including:

Physical
- Temperature, dissolved oxygen (probe)
- Particle size distribution (LISST-ST in the field)
- Total suspended solids (analytical laboratory)
- Volatile suspended solids (analytical laboratory)
- Turbidity (field instrument)

Chemical
- Particulate organic carbon (analytical laboratory)
- Carbonaceous Biochemical Oxygen Demand (analytical laboratory)

Biological
- Algal species and biovolume (analytical laboratory)
- Chlorophyll *a* and pheophytin (analytical laboratory)

Sampling will be completed on the influent stream and effluent stream to identify the efficacy of the treatment technology. Sample size will ideally be a minimum of 10 samples per treatment technology or individual experiment; however, not every constituent may be collected for analysis at every sampling event. Multiple technologies or approaches may be employed. Certain technologies are more costly than others, thus testing a range of devices will be beneficial. If certain devices cannot be tested due to pilot scale issues (e.g., too small), recommendations will be made regarding future testing.

Phase II: Design and Cost

Upon completion of Phase I, Watercourse will work with one or more contractors that develop such treatment systems to develop a theoretical full-scale treatment system. This will be a 10 percent, or pre-design level analysis to identify approximate costs (capital and operations and maintenance) associated with the estimated treatment level. Limitations, constraints, or other considerations will be identified for the application of hydrodynamic separators in the project area.

Quality Control

Water quality sampling will be collected consistent with PacifiCorp's Quality Assurance Program Plan and Standard Operating Procedures (SOP).

Data and Information Analysis and Reporting

All data from the experiment will be compiled and assessed. Removal efficiencies will be assessed using appropriate statistical measures (e.g., t-test, ANOVA, or any of several other statistical tests). Removal efficiencies will be identified by particle size and treatment technology. The reduction in organic matter load will be estimated, and form the basis (i.e., scaled up) to approximate a full scale treatment prescription.

Costs will be identified for a range of treatment approaches, as appropriate, and levels of treatment at full scale will be approximated. These data will be useful to resource managers and decision makers regarding the overall feasibility of particulate organic matter removal in the project area.

Phase I and Phase II findings and information will be presented in a final project.

Schedule

Activity	Date
Phase I: Planning, design, and mobilization	Fall 2010 – June 2011
Phase I: Field Work	June – August 2011
Phase I: Data processing and write-up	August – October 2011
Phase II: Theoretical Design	September-November 2011
Phase II: Economic Analysis	November-December 2011

Activity	**Date**
Reporting	February 2012

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Klamath Hydroelectric Settlement Agreement:
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Study Plan: Evaluation of Treatment Provided by Wetlands

Version: October 18, 2010

Introduction

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Prior to the date of the Secretarial Determination, the measure calls for PacifiCorp to implement studies or pilot projects to address four categories of studies specified for Interim Measure 11:

- Development of a Water Quality Accounting Framework
- Constructed Treatment Wetlands Pilot Evaluation
- Assessment of In-Reservoir Water Quality Control Techniques
- Improvement of J.C. Boyle Reservoir Dissolved Oxygen

This study plan addresses the proposed activities under Interim Measure 11 over a two-year time frame (that is, during years 2010 and 2011) for the second of these four categories of studies. The Secretarial Determination is to be finalized in March 2012.

Purpose and Objectives

Constructed treatment wetlands have been identified as a potentially viable means of improving water quality conditions in the upper Klamath River (Lyon et al. 2008, Deas and

Vaughn 2006). Target water quality improvements include reduced total suspended solids, organic matter (biochemical oxygen demand), nutrients and local water temperature improvements. In the context of this study "treatment wetlands" include wetlands constructed in upland areas, restoration of jurisdictional wetlands that have lost part of their wetland function such as farmed wetlands and prior converted wetlands, and enhancement of existing wetlands to uplift wetland function through replacement of invasive species with native plants and improved hydrology. All of these wetlands scenarios can increase the wetland ecosystem functions throughout the watershed and discharge cleaner and cooler water that contributes to meeting the water quality targets in all areas of the Klamath River watershed.

The purpose of this Study is to complete important activities for anticipated treatment wetlands in the upper Klamath River basin. These planning activities will include the following tasks: (1) prepare initial estimates of treatment wetland sizes and effectiveness at watershed-scale; (2) describe the state-of-the-art and current similar applications of treatment wetland technologies; (3) prepare a summary "white paper" of the above tasks for the Water Quality Workshop on treatment wetlands in the Klamath Basin; (4) plan for further pilot tests of constructed wetland pre-treatment techniques; and (5) investigate potential partnerships, land acquisition opportunities, and water rights requirements.

Task and Work Elements

The tasks and work elements that will be conducted under this Study over the next 2-year time frame (that is, during years 2010 and 2011) are described in the following sections.

Estimation of Treatment Wetland Area and Effectiveness at Watershed-Scale

Restoration and construction of wetlands have been identified as an important strategy for reducing the large loads of nutrients and organic matter in the Klamath River. For example, the Regional Water Board (2010) TMDL allocations for the Klamath River will require reductions in the current nutrient loads in the river (as measured at Stateline) of about 90 percent for total phosphorus and 70 percent for total nitrogen. The Regional Water Board (2010) mentions wetland treatment systems and other "nutrient reduction technologies" as potential actions to address these substantial reductions the TMDL will require.

When considering the potential use of treatment wetlands to reduce nutrient loads in the Klamath River (along with organic matter and total suspended solids), an important "side board" is to first determine the approximate magnitude of wetland acres that would be needed to achieve load reduction requirements or objectives. This determination would "bound the problem" and help in guiding further activities (as described below) to assess locations, configurations, water rights requirements, and types of treatment wetlands (including associated ancillary treatment techniques) that would need to be implemented to achieve desired nutrient reductions.

Lyon et al. (2008) developed similar initial estimates of wetland size requirements to support the assessment of potential constructed wetlands on locations adjacent to the Klamath River in the vicinity of the Klamath Hydroelectric Project. Under this Study Plan, similar treatment wetland design tools will be used to provide estimates of wetland size requirements, but assuming a larger (expanded) watershed scale. These estimates will

include the range of possible size requirements for constructed wetland systems to achieve nutrient load reductions at various assumed levels (including levels required in the TMDL). Additional estimates will then be made of the potential changes in size requirements that could result from the implementation of additional pre-treatment techniques, assuming possible limitations on available land and/or the need to achieve particularly low concentrations in the discharge from wetlands.

Identification of the "Nutrient Treatment Toolbox": State-of-the-Art and Current Similar Applications of Treatment Wetland Technologies

Ancillary Treatment Technologies

Once the range in required size or "footprint" of wetlands (assuming no pretreatment) has been estimated (in the previous task), the need for and extent of ancillary treatment technologies can be evaluated in the context of possible space availability constraints, as well as nutrient reduction objectives. In cases of high influent loads, the addition of pretreatment of the inflow to the wetland is often considered (EPA 1999) to augment removal rates. Therefore, it is assumed that the effectiveness of a constructed treatment wetland can be enhanced if water entering at the wetland inflow is pretreated to reduce total suspended solids, organic matter, or nutrients prior to entering wetland cells.

This evaluation would consist primarily of a literature review supplemented by interviews with leading researchers on pretreatment methods options. Such options would include, but not necessarily be limited to, hydrodynamic separation and/or filtration facilities, dosing of alum or other polymer, and periphyton "biofilms" on artificial benthic mesh. Options will also include a range of more conventional wastewater treatment systems from controlled biological and chemical nutrient removal in concrete tanks to earthen basins with coagulation, sedimentation, and sand filtration.

Detailed summaries of each option will be developed. A matrix will be also be developed that ranks options by primary purpose, level of effectiveness, and relative advantages and disadvantages for consideration in potential application to the Klamath Basin (such as, potential ease of implementation, potential for nutrient reduction, and approximate costs to implement).

Wetlands Configuration and Operations Options

In addition to pre-treatment technologies, wetland effectiveness can also be enhanced by optimizing treatment wetland configurations and operations. The literature review and expert interviews as conducted above also will be used to gather, summarize, and evaluate information on wetland configuration and operations options. Wetland configurations and operations will address elements such as, but not necessarily limited to, water depths, flow path lengths, numbers and types of cells within the wetland, general differences in plant and soil materials and features, flow controls, and maintenance requirements. Given the diffuse nature of non-point source pollution in the Klamath Basin, treatment wetlands types and configurations will be considered to include both wetlands specifically constructed for treatment, as well as existing wetlands that can be restored or enhanced to provide the desired treatment.

Important Analogies Offered by Actual Examples Elsewhere

The literature review and expert interviews as conducted above also will be used to gather, summarize, and evaluate information on examples of actual treatment wetlands used elsewhere to address similar requirements and objectives. For example, such examples elsewhere could include (but not necessarily be limited to):

- Everglades Treatment Wetlands, Florida
- Lake Okeechobee Treatment Wetlands, Florida
- Mississippi-Ohio-Missouri River Basin wetlands restoration
- Wetlands Nutrient "Farming" Initiative, Illinois
- Prado Wetlands Restoration, California
- Lake Elsinore Wetlands Nutrient Removal Project, California
- Lake Tahoe Phosphorus Loading Reduction, California
- Orange County Nitrogen and Selenium Master Plan, California
- Neuse River Basin Wetlands Restoration Program, North Carolina
- Clayton County Water Authority Wetlands, Georgia
- Clean Water Services Natural Treatment System Wetlands, Oregon
- RUSA Natural Treatment System for Phosphorus Removal, Oregon
- City of Boise Wetlands for Phosphorus Removal, Idaho

These other examples will serve as important potential analogies to the Klamath Basin situation. As analogies, the implementation experiences and level-of-effectiveness of these other projects will provide valuable insights for use in evaluation and planning for potential treatment wetlands in the Klamath Basin.

Detailed summaries of each example will be developed. The detailed summaries will also describe the implementation experiences and level-of-effectiveness of these other projects, as well as the situational similarities relative to potential application to the Klamath Basin (such as basin scale, background water quality conditions, level of nutrient reduction desired and achieved, and approximate costs of implementation and operations).

Preparation of Summary for Water Quality Workshop on Constructed Treatment Wetlands in the Klamath Basin

Interim Measure 10 of the KHSA includes a plan to convene a basin-wide technical conference on water quality conditions in the Klamath River basin (Water Quality Conference). The intent of the Water Quality Conference is to focus on nutrient reduction in the basin, including constructed wetlands and other treatment technologies. The results obtained from the first two tasks of this Study as described above will provide valuable information for the Water Quality Conference. To assist in communicating the results of these tasks, a summary white paper will be prepared. The summary will provide Study

background, descriptions of information obtained, and results of assessments as described in the above tasks. This summary will be valuable in helping to inform discussions among subject matter experts at the Water Quality Conference.

Planning for Pilot Tests of Specific Treatment Wetland Techniques

Results of the above tasks are expected to identify logical next steps to more specifically ascertain the types, sizes, configurations, and locations of treatment wetlands. It is anticipated that bench, pilot, and demonstration-scale studies will be required to support final evaluation and design of constructed treatment wetland options. This task will identify and provide a scoping-level assessment and ranking of such studies. This task also will identify the relative merits and value of conducting such studies and how such studies would be conducted. The actual implementation of laboratory, bench, and pilot studies will be the subject of follow-on Study Plans as appropriate.

The studies to be considered may include (but are not necessarily limited to):

- Wetland mesocosms or "tote" tests to assess configuration variables. Wetland mesocosms in one cubic meter totes can be used to cost effectively test a wide range of configuration variables (such as hydro-period, water depth, and plant species) in small but representative wetland cells. These tests can be conducted on-site with Klamath River water to further assess applicability to the Klamath River system.

- Wetland mesocosms or "tote" tests to assess pretreatments. Wetland mesocosms or "tote" tests can be used to conduct trials set up to evaluate phosphorus removal using alum or other coagulant addition to river water or irrigation drainage water to test pretreatment removal mechanisms prior to discharge to a wetlands. These tests could also test use of peat and of clay soils for enhancing phosphorus removal prior to river discharge.

- Field studies of periphyton "biofilms". Field studies of periphyton "biofilms" on artificial benthic mesh for denitrification and for phosphorus uptake. Traditionally, wetlands research has focused on sediments as the primary site for denitrification, but recent research has shown that significant denitrification rates can be achieved in constructed wetlands with periphyton "biofilms" attached to natural or artificial substrata, including benthic polyethylene mesh (Ishida et al. 2008). The placement of artificial benthic mesh serves as a uniform substratum for high biomass periphyton communities that support high denitrification rates. Also, commercial technologies are now available that factor in periphyton biomass harvesting as a means of phosphorus removal.

- Tests of applicable soils conditions. Evaluate the potential for native soils and peat in the watershed to remove nutrients as water is percolated through them in artificial groundwater recharge wetlands and wet meadows that contribute increased groundwater discharge to the river.

- Bench tests of settling agents. Bench tests could be valuable for assessing dosing of settling agents (e.g., polymers) specific to Klamath River water samples for phosphorus (and potentially TSS, TN, and organic matter) removal. One approach to reducing phosphorus is careful dosing of settling agents in influent waters. Settling agents are a

well-established treatment approach, including in wetlands, for reducing phosphorus through sorption phenomena, ionic exchange and other physico-chemical processes.

- Bench tests of treatment package plants. Bench scale testing could be valuable for assessing pretreatment of Klamath River water samples using a small-scale wastewater treatment package plant (such as for denitrification). Commercially-available package plants use various technologies (e.g., synthetic media trickling filters) for aerobic treatment and nitrification. Filtered effluent from the package plant would be discharged to the wetland for further treatment.

Identification of Partnerships, Investigation of Land Acquisition, and Water Rights Requirements

Further evaluation and design of constructed treatment wetland options for the Klamath Basin also will depend on other practicality factors, such as stakeholder partnerships, land availability, and water rights requirements. In this Study task, these particular factors will be further examined to assess potential opportunities and constraints. Work elements under this task will include:

- Possibility to work cooperatively with the U.S. Bureau of Reclamation (Reclamation) on construction of a pilot treatment wetland adjacent to Keno Reservoir near Klamath Falls. Reclamation has funded the construction portion of a pilot project (Proposal No. 08SF200023: $484,707), and there is the possibility that PacifiCorp could cooperatively support the pilot project through funding a property purchase, providing pilot study criteria and designs, or other means.
- Investigate other potential partnerships with large-scale land owners and stakeholders in the upper Klamath Basin (such as, the Nature Conservancy, irrigation districts, Tribes, Natural Resources Conservation Service). Identify specific wetland restoration and construction opportunities and incentives as suggested by these stakeholders.
- Identify potential land acquisition options and transfer to third party options. Assess costs of potential land acquisition options and transfer. This information would guide PacifiCorp decision-making regarding PacifiCorp's role in a potential treatment wetlands project.
- Identify potential water rights and other permitting requirements related to water use by treatment wetlands and routing of waters through constructed treatment wetlands. Assess implications of these requirements on feasibility, design, operation, and maintenance of constructed treatment wetlands. Coordinate this effort with similar assessments currently being conducted by Reclamation.

Schedule

Activity	Date
Estimation of treatment wetland size and effectiveness	November 2010 – January 2011
Wetland treatment technologies and analogies	November 2010 – February 2011

Activity	Date
Summary paper for Water Quality Conference	March 2011
Planning for pilot test of specific techniques	March – May 2011
Assessment of partnerships, land acquisition, and water rights	November 2010 – September 2011
Final report	November 2011

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Klamath Hydroelectric Settlement Agreement:
Interim Water Quality Improvements
(Interim Measure 11)

Study Plan: Pilot Testing of Environmentally-Safe Algaecide on Copco Reservoir Water

Version: October 18, 2010

Introduction

On February 18, 2010, the United States, the States of California and Oregon, PacifiCorp, Tribes, and a number of other stakeholder groups signed the Klamath Hydroelectric Settlement Agreement (KHSA). The KHSA lays out the process for additional studies, environmental review, and a determination by the Secretary of the Interior regarding whether removal of four dams owned by PacifiCorp on the Klamath River (i.e., Iron Gate, J.C. Boyle, Copco 1, and Copco 2 dams) will advance restoration of the salmonid fisheries of the Klamath Basin, and is in the public interest (which includes effects on local communities and Tribes).

The KHSA includes provisions and detailed actions for the interim operation of the dams and mitigation activities prior to removal of the dams or the termination of KHSA. One of the measures – titled Interim Measure 11: Interim Water Quality Improvements – emphasizes nutrient reduction projects in the basin to enhance water quality in the Klamath River, while also addressing water quality, algal and public health issues in Project reservoirs and dissolved oxygen in J.C. Boyle reservoir. The purpose of Interim Measure 11 is to improve water quality in the Klamath River during the interim period leading up to potential dam removal.

Prior to the date of the Secretarial Determination, the measure calls for PacifiCorp to implement studies or pilot projects to address four categories of studies specified for Interim Measure 11:

- Development of a Water Quality Accounting Framework
- Constructed Treatment Wetlands Pilot Evaluation
- Assessment of In-Reservoir Water Quality Control Techniques
- Improvement of J.C. Boyle Reservoir Dissolved Oxygen

This study plan addresses one of the proposed activities under Interim Measure 11 over a 2-year time frame (that is, during years 2010 and 2011) to address the third of these four categories of studies. The Secretarial Determination is to be finalized in March 2012.

Purpose and Objectives

In 2008 and 2009, PacifiCorp initiated effectiveness testing of environmentally-safe sodium carbonate peroxyhydrate (SCP) algaecide based on controlled bench tests using water taken from Copco and Iron Gate reservoirs. SCP (e.g., Greenclean Pro) is approved for use as an algaecide by the U.S. Environmental Protection Agency (EPA), and is also approved under NSF/ANSI Standard 60 (drinking water treatment chemicals). On February 27, 2006, the California Department of Pesticide Regulation (DPR) registered SCP for aquatic application as an algaecide used to control blue-green algae (see Water Quality Order No. 2004-0009-DWQ NPDES No. CAG990005 National Pollutant Discharge Elimination System Permit for the Discharge of Aquatic Pesticides for Aquatic Weed Control in Waters of the United States, as amended by adoption of State Water Resources Control Board [State Water Board] Resolution No. 2006-0039). By-products of SCP include oxygen and water.

The purpose of activities proposed under this Study Plan is to conduct selective localized treatments of the environmentally-safe SCP (e.g., Greenclean Pro) using water from Copco reservoir in isolated containers. Based on previous tests wherein algaecides were applied to discrete volumes of water collected from Copco reservoir, results indicated that SCP applications may be effective in reducing the algae standing crop and, at certain application rates, reducing microcystin concentrations in water from the reservoirs. This work under this Study Plan will extend the experiment to focus on pilot treatment application of algaecides with the principal active ingredient of SCP (e.g., Greenclean Pro) to reduce algal concentrations <u>and</u> microcystin levels.

Byproducts of SCP algaecides are water and oxygen, with the physical algae potentially contributing an oxygen demand and microcystin to the water column. Because cyanotoxins are stored intracellularly, algaecides can lead to releases of toxin to surrounding waters (Kenefick et al., 1993). Jones and Orr (1994) and Touchette et al. (2005) present studies demonstrating microcystins are released when *Microcystis aeruginosa* blooms were treated with algaecides including copper sulfate or SCP. This release can be quite rapid (e.g., hours), depending on the algaecide application quantity (Jones and Orr, 1994).

Discussions with SCP manufacturers, as well as limited testing in 2009, indicate that both application quantity and repeated applications may reduce microcystin concentrations released from blue-green algae (either naturally or through application of the algaecide). Antoniou et al. (2005) identify that while conventional water treatment processes can result in increased levels of soluble toxin associated with microcystin, chemical oxidation treatment technology using titanium dioxide (an oxidant with similar purposes as hydrogen peroxide, the active chemical in SCP) to enhance photocatalytic oxidation shows promise in reducing microcystin concentrations. Benjamin et al. (2000) indicate that such oxidation can be enhanced with hydrogen peroxide, and that although less effective, hydrogen peroxide alone can provide treatment to reduce microcystin concentrations. Given these findings, the work under this Study Plan will explore the use of SCP treatment to reduce algal concentrations <u>and</u> microcystin levels during a blue-green algae bloom period in Copco reservoir.

Task and Work Elements

The tasks and work elements that will be conducted under this Study over the next two-year time frame (that is, during years 2010 and 2011) are described in the following sections.

- Planning: a literature review will be developed for the topic of the microcystin toxin treatment approaches. From these findings, the testing and sampling plan will be adapted to refine pilot program design.
- Testing: Testing will be conducted in isolated containers outside of the reservoir using 200 liter polypropylene, translucent barrels. This testing will allow effectiveness and implementation information to be gathered (in addition to that obtained in the previous tests), and will provide important details on potential full-scale applications to reservoir areas. Water temperatures and light conditions in the containers likely will differ from the reservoir environment, but these limitations are acceptable at this exploratory level. Because of the quick response time of SCP applications, the impacts of initial treatment (for algal standing crop reduction) and follow-up treatment to assess reduction in overall toxin concentrations will take place over a short period (e.g., hours).
- Sampling: Sampling will include algal species, microcystin, chlorophyll a (and pheophytin). Sampling will be integrated at over a 1 meter depth, and a total of 3 to 5 samples per container will be collected.
- Reporting: The information developed from the above tasks and work elements will be compiled in a brief technical memorandum. The conclusions and recommendations of the report will serve as a guide for potential future SCP applications in the reservoirs. If results of this pilot testing are successful, selective application of such environmentally safe-algaecides may be considered to reduce conditions for potential exposure, particularly in higher-use areas (e.g., boat ramps, docks, etc.).

Quality Control

Water quality sampling will be collected consistent with PacifiCorp's Quality Assurance Program Plan and Standard Operating Procedures (SOP).

Data and Information Analysis and Reporting

Project data will be assessed through graphical and statistical measures. Time series plots of concentrations (Figure 1). In past experiments there has been sufficient scatter in the microcystin results that triplicate tests will be completed. Algal species, chlorophyll a (and pheophytin), and microcystin will be sampled at the beginning, selected intermediate times, and end of the experiment. Water temperature will be monitored in all containers, and dissolved oxygen and pH readings will be taken at specific intervals to track any changes in conditions.

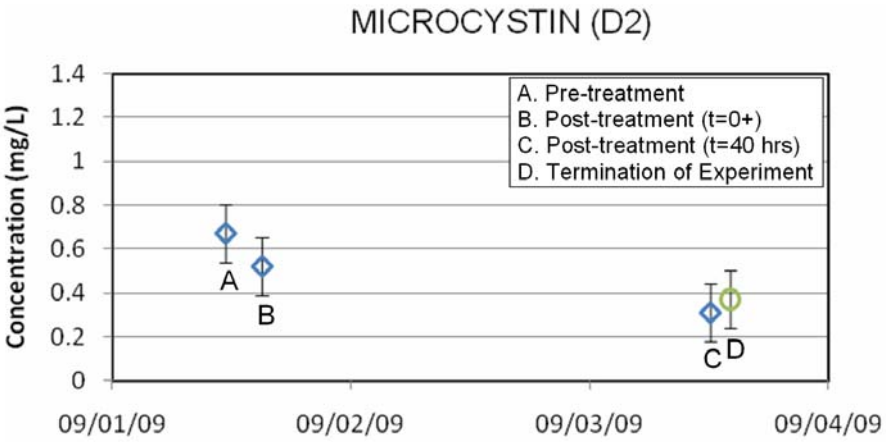

Figure 1. Example graph of microcystin concentrations through time during one of the previous tests of an SPC (Greenclean Pro) application. Testing conducted by Watercourse Engineering, Inc.

Trials will be conducted to test for the effects of different application rates and reapplication treatments. These tests will provide a means to compare average concentrations between one trial to another. Handling and treating large containers of water is a resource intensive task: 4 or 5 trials (each in triplicate) are planned to be processed simultaneously. During the final setup of tests, modifications to the proposed work may occur.

The literature review, field methods and data, and analyses will be presented in a technical report.

Schedule

Activity	Date
Planning, materials acquisition, and mobilization	November 2010 – June 2011
Field work	July – September 2011
Data processing and write-up	September – December 2011

References

Antoniou, M.G., A.A. de la Cruz, D.D. Dionysiou. 2005. Application of immobilized titanium dioxide photocatalysis for the treatment of microcystin–LR. Poster: International Symposium on Cyanobacterial Harmful Algal Blooms (ISOC-HAB). September 6-10, Durham, North Carolina.

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Klamath Hydroelectric Settlement Agreement:
Interim Water Quality Improvements
(Interim Measure 11)

Study Plan: Testing of Intake Cover for Water Quality Control at Iron Gate Reservoir

Version: October 18, 2010

Introduction

On February 18, 2010, the United States, the States of California and Oregon, PacifiCorp, Tribes, and a number of other stakeholder groups signed the Klamath Hydroelectric Settlement Agreement (KHSA). The KHSA lays out the process for additional studies, environmental review, and a determination by the Secretary of the Interior regarding whether removal of four dams owned by PacifiCorp on the Klamath River (i.e., Iron Gate, J.C. Boyle, Copco 1, and Copco 2 dams) will advance restoration of the salmonid fisheries of the Klamath Basin, and is in the public interest (which includes effects on local communities and Tribes).

The KHSA includes provisions and detailed actions for the interim operation of the dams and mitigation activities prior to removal of the dams or the termination of KHSA. One of the measures – titled Interim Measure 11: Interim Water Quality Improvements – emphasizes nutrient reduction projects in the basin to enhance water quality in the Klamath River, while also addressing water quality, algal and public health issues in Project reservoirs and dissolved oxygen in J.C. Boyle reservoir. The purpose of Interim Measure 11 is to improve water quality in the Klamath River during the interim period leading up to potential dam removal.

Prior to the date of the Secretarial Determination, the measure calls for PacifiCorp to implement studies or pilot projects to address four categories of studies specified for Interim Measure 11:

- Development of a Water Quality Accounting Framework
- Constructed Treatment Wetlands Pilot Evaluation
- Assessment of In-Reservoir Water Quality Control Techniques
- Improvement of J.C. Boyle Reservoir Dissolved Oxygen

This study plan addresses one of the proposed activities under Interim Measure 11 over a 2-year time frame (that is, during years 2010 and 2011) to address the third of these four categories of studies. The Secretarial Determination is to be finalized in March 2012.

Purpose and Objectives

This activity involves the evaluation of a cover or barrier in the vicinity of the Iron Gate dam intake for water quality control. The concept behind the intake cover or barrier is to control the depth at which water is withdrawn from the reservoir into the intake, and thereby potentially enhance water quality downstream of Iron Gate dam by excluding or reducing the potential entrainment of biomass from blooms of cyanobacteria (blue-green algae) and potential associated algal toxins (i.e., microcystin) . Microcystin is included in the *Action Plan for the Klamath River Total Maximum Daily Loads Addressing Temperature, Dissolved Oxygen, Nutrient, and Microcystin Impairments in the Klamath River in California and the Lost River Implementation Plan* adopted by the California Regional Water Quality Control Board North Coast Region (Regional Water Board) in March 2010 (Regional Water Board 2010).

Previously, PacifiCorp installed and evaluated a floating barrier curtain across the entire width of Iron Gate reservoir (approximately 1,100 feet) at the current log boom location, which is about 1,800 feet upstream of the dam to determine the efficacy of reducing algal entrainment (Asaeda et al, 1996). Detailed velocity measurements (using an acoustic Doppler current profiler [ADCP]) surrounding the curtain in Iron Gate reservoir were obtained in 2009. Findings from the ADCP measurements suggested that curtain deployment at the log boom is too far from the outlet tower to have the desired effect of limiting surface entrainment into the outlet tower and/or may require a curtain of greater depth.

Based on this previous work, the purpose of this Study is to assess placing a cover directly on the outlet tower trash rack in lieu of curtain placement. The outlet tower at Iron Gate Dam is screened with a trash rack from the surface to the invert of the structure (approximately 30 plus feet deep), and surface waters and associated algae are readily entrained (Figure 1). This cover potentially would have a direct impact on reducing surface water entrainment and would overcome the problem of placing a curtain upstream at an appropriate distance and depth.

This approach intends to incorporate elements similar to selective withdrawal, which has been used in other locations to limit algae intake. For example, raw water supply reservoirs have used selective withdrawal to manage taste and odor problems in drinking water facilities (Izaguirre and Devall, 1995). In this proposed application, a cover over the intake tower screen would be placed to reduce entrainment of near surface waters.

Figure 1. Iron Gate Dam outlet tower

Task and Work Elements

The tasks and work elements that will be conducted under this Study over the next two-year time frame (that is, during years 2010 and 2011) are described in the following sections.

Further Field Assessment of Potential Cover Feasibility

The tasks and work elements associated with continued evaluation of a barrier or cover in Iron Gate reservoir at the intake tower and will include the following:

- Conduct additional field observations of velocity profiles at the outlet tower at several distances upstream from the tower at different times of year (particularly critical summer and fall periods. In addition to in-lake field observations, physical measurements of the outlet tower and associated facilities will be completed.
- Incorporate water quality sampling coincident with the velocity profile observations to characterize water quality and phytoplankton conditions throughout the water column. Sampling downstream of the dam will occur concurrent with in-reservoir sampling to characterize both in-pool and below-dam water quality conditions. Upstream profiles will include conditions in the immediate vicinity of the outlet tower, and possible at the log-boom. Near-field sampling is intended to capture outlet tower water quality conditions. Log-boom (far field) sampling will allow interpretation of outlet tower conditions to the long term record at the log boom. Log-boom profiles will be sampled in the vicinity of the outlet tower to characterize conditions near the outlet. Downstream samples will be collected immediately below the powerhouse to minimize uncertainty in travel time to more distant locations downstream. Local meteorological conditions (e.g., wind) will be monitored.

- A technical memorandum will be prepared to present findings and recommendations for cover prototype design and monitoring.

Cover Prototype Testing and Monitoring – Phase II

If the data and analyses developed during Phase I suggest that a shallow intake screen cover is potentially feasible in reducing downstream algal concentrations, a temporary prototype cover will be designed, constructed, and tested in Phase II. During this Phase II work, it is envisioned that placement of the cover would initially occur over a limited time (days) and be monitored closely to assure an appropriate range of conditions (e.g., flows, wind, algal bloom presence) is captured.

Tasks in Phase II include:

- Design and construct a prototype cover for the outlet tower. Direct measurement of outlet tower and inventory of working spaces and facilities present (e.g., crane) will be completed. Appropriate materials for construction and methods of mobilizing cover and field testing will be determined.
- Conduct effectiveness monitoring. Collect velocity profiles to define velocity profiles under with and without cover conditions.
- Collect water quality samples in-pool and below-dam to ascertain differences in water quality under with and without cover conditions. Complete measurements at different times of day and over multiple days (at critical times of year) to compare performance. Sampling will be consistent with locations identified above. Local meteorological conditions (e.g., wind) will be monitored. Water quality constituents include physical measurements (e.g., temperature, dissolved oxygen, pH, EC), water quality grab samples (e.g., DOC, TOC, VSS, TSS, microcystin), phytoplankton species, chlorophyll a, and other as appropriate.
- A technical memorandum will be prepared to present findings and recommendations. The conclusions and recommendations of the memorandum will serve as a guide for potential future adjustments to and continued use of this technique should it show promise. Facilities and operational considerations will be included in this assessment, i.e., a cover could be manipulated (e.g., raised, lowered, or removed) in response to water quality conditions in Iron Gate reservoir.

Quality Control

Water quality sampling will be collected consistent with PacifiCorp's Quality Assurance Program Plan and Standard Operating Procedures (SOP). An SOP will be developed for use of the ADCP.

Data and Information Analysis and Reporting

Field data collected (water quality, phytoplankton, and ADCP measurements will be organized along with other information (e.g., release rates from Iron Gate reservoir, facilities dimensions, etc). Flow data will be analyzed to identify the contribution of waters from

various depths, and combined with water quality and phytoplankton data, provide insight on entrainment zone of the intake tower. Using upstream and downstream samples, the withdrawal (or entrainment) zone can be estimated. This information will be useful in identifying the potential efficacy of an intake cover and lend insight into design if restricting the intake zone potentially reduces downstream phytoplankton concentrations.

A technical memorandum will be prepared to present findings and recommendations. The conclusions and recommendations of the memorandum will serve as a guide for potential future adjustments to and continued use of this technique should it appear promising.

Schedule

Activity	Date
Predesign and field preparation	October 2010 – June 2011
Field observations and design	June – August 2011
Testing, Monitoring and Evaluation	August – September 2011
Technical memorandum	December 2011

References

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Klamath Hydroelectric Settlement Agreement:
Interim Water Quality Improvements
(Interim Measure 11)

Study Plan: Evaluation of J.C. Boyle Reservoir Dissolved Oxygen Improvement

Version: October 18, 2010

Introduction

On February 18, 2010, the United States, the States of California and Oregon, PacifiCorp, Tribes, and a number of other stakeholder groups signed the Klamath Hydroelectric Settlement Agreement (KHSA). The KHSA lays out the process for additional studies, environmental review, and a determination by the Secretary of the Interior regarding whether removal of four dams owned by PacifiCorp on the Klamath River (i.e., Iron Gate, J.C. Boyle, Copco 1, and Copco 2 dams) will advance restoration of the salmonid fisheries of the Klamath Basin, and is in the public interest (which includes effects on local communities and Tribes).

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Prior to the date of the Secretarial Determination, the measure calls for PacifiCorp to implement studies or pilot projects to address four categories of studies specified for Interim Measure 11:

- Development of a Water Quality Accounting Framework
- Constructed Treatment Wetlands Pilot Evaluation
- Assessment of In-Reservoir Water Quality Control Techniques
- Improvement of J.C. Boyle Reservoir Dissolved Oxygen

This study plan addresses the proposed activities under Interim Measure 11 over a 2-year time frame (that is, during years 2010 and 2011) to address the third and fourth of these four categories of studies. The Secretarial Determination is to be finalized in March 2012.

Purpose and Objectives

J.C. Boyle reservoir is a narrow, approximately 3.5 mile-long impoundment of 420 surface acres located on the Klamath River from RM 224.7 to RM 228.2 downstream of Upper Klamath Lake (UKL) in Klamath County, Oregon. J.C. Boyle reservoir is classified as eutrophic (nutrient-enriched) due to the large inflow loads of nutrients and organic matter from upstream sources, notably UKL. Because of these large loads, J.C. Boyle reservoir experiences reduced dissolved oxygen (DO) concentrations at certain times of the year. J.C. Boyle is generally well-mixed, but temporary stratification can occur during summer, particularly where the reservoir is deepest near the dam. During such temporary stratification, lower DO concentrations can develop in this deeper area.

The purpose of this Study is to conduct planning for, and testing of technologies for improving DO conditions in J.C. Boyle reservoir. For example, air injection, mechanical mixing, or oxygenation are techniques with the potential to improve DO conditions by maintaining reservoir mixing and increasing oxygen contact with the water in the reservoir. As part of planning efforts, this study will also conduct monitoring of DO in J.C. Boyle reservoir. Most of the existing DO data for the reservoirs consists of grab samples that represent snapshots in time. Continuous probe sampling of DO will be conducted in J.C. Boyle reservoir throughout the summer to better assess the temporal and spatial extent of DO conditions in the reservoir to inform the planning and testing of DO enhancement techniques.

Approaches to DO Enhancement in J.C. Boyle Reservoir

PacifiCorp previously prepared Reservoir Management Plans (RMPs) to evaluate the effectiveness and feasibility of various technologies and measures to improve water quality conditions in J.C. Boyle reservoir (PacifiCorp 2008a), as well as in Copco and Iron Gate reservoirs (PacifiCorp 2008b). The J.C. Boyle reservoir RMP identified several potential techniques for DO enhancement in lakes and reservoirs as described by Cooke et al. (2005), Thornton et al. (1990), and Cooke and Kennedy (1989). Of these techniques, three targeted at improving DO were further evaluated in the RMP development process: (1) water column circulation, (2) epilimnion methods, and (3) hypolimnetic methods.

As noted above, J.C. Boyle reservoir does not strongly stratify during summer, but only experiences gradual and transient vertical gradients of water temperature and DO. Therefore, specific epilimnion and hypolimnetic methods lack applicability to J.C. Boyle reservoir, leaving water column circulation as the most appropriate approach for potential application to J.C. Boyle reservoir.

The two most common techniques for water column circulation are: (a) air injection; and (b) mechanical mixing. Air injection (diffuser) systems utilize a compressor on shore that delivers air through diffusers placed near the bottom of the lake. The rising air bubbles cause water in the bottom water layer to also rise, entraining water and transporting it into the surface water layer. Mechanical mixing is accomplished using axial flow pumps to set up a circulation pattern. A flotation platform and frame support an electric motor, gearbox, drive shaft, and large propeller (6 to 15 foot diameter). The propeller is suspended just a few feet below the water surface. Its rotation "pushes" water from the reservoir surface

downward, setting up a vertical circulation pattern. Deeper water is circulated to the reservoir surface, where oxygenation from the atmosphere can then occur.

Oxygenation systems are similar to aeration systems (as described above) except that pure oxygen rather than air is used. To date, most applications of oxygenation systems in reservoirs have been used address oxygen deficits in the hypolimnion of large stratified reservoirs. In these cases, gaseous oxygen is passed to underwater diffusers and fine oxygen bubbles rise, releasing oxygen to the water as they do so. However, as noted above, a hypolimnetic oxygenation system lacks applicability to J.C. Boyle reservoir because it does not strongly stratify.

Recently, a specific oxygenation method with potential application to J.C. Boyle reservoir has come to PacifiCorp's attention – the Supersaturated Dissolved Oxygen (SDOX) system. The SDOX system uses oxygen gas that is pre-dissolved into a stream of water inside of a pressurized saturation tank to achieve supersaturated concentrations. The oxygenated water is then released from the saturation tank and mixed with the larger body of water being treated. The SDOX system has shown promising results in other river and reservoir systems for improving DO conditions.

In the following sections of this Study Plan, tasks and work elements are described for further assessing application and implementation of air injection, mechanical mixing, or oxygenation for improving DO conditions in J.C. Boyle reservoir.

Task and Work Elements

The tasks and work elements that will be conducted under this Study over the next 2-year time frame (that is, during years 2010 and 2011) are described in the following sections.

Assessment of Air Injection (or Aeration) for DO Improvement in J.C. Boyle Reservoir

In 2009, Horne et al. (2009) preformed a feasibility assessment of potentially implementing an air injection (diffuser) system in J.C. Boyle reservoir to enhance dissolved oxygen (DO). Horne et al. (2009) performed calculations of oxygen demands and requirements, and estimated system sizing and layouts for an air injection (diffuser) system in J.C. Boyle reservoir.

Horne et al. (2009) determined that the most appropriate system for J.C. Boyle reservoir would be an air injection (diffuser) system located in, and focused on DO enhancement in the deeper, lower portion of the reservoir. A focus on DO enhancement in the deeper, lower portion of the reservoir would be most appropriate because a system in the upper part of the reservoir would lack efficiency and effectiveness for two key reasons: (1) the high inflow load of biological oxygen demand (BOD) to the upper end of the reservoir could not be overcome by an air injection (diffuser) system; and (2) the upstream part of the reservoir is too shallow, so that the mixing and air plume effects from a system would be small. In addition, the length of diffuser pipe for a system in the upper part of the reservoir would be long, presenting difficulties of balancing the airflow over long lengths of pipe (although the use of individually regulated diffusers may overcome this drawback).

Horne et al. (2009) developed a preliminary conceptual design of an air injection (diffuser) system in the deeper, lower portion of J.C. Boyle reservoir that would include diffuser arrays, serviced by a 22 kW (~ 30 hp) air compressor. The estimated cost of installation of the conceptual air injection (diffuser) system as described in this report is $300,000 to $500,000. Operation and maintenance (O&M) costs are estimated at $40,000 to $60,000 annually, assuming a 4 to 5 month operations period (during the late spring, summer, and early fall time frame when DO is lowest and BOD is highest in the reservoir and its inflow).

No additional work is planned to be conducted under this Study Plan to further assess application and implementation of air injection in J.C. Boyle reservoir. The work by Horne et al. (2009) will serve as the base-of-information for potential air injection use in J.C. Boyle reservoir to be considered along with information obtained on mechanical mixing and oxygenation as described below.

Assessment of Mechanical Mixing for DO Improvement in J.C. Boyle Reservoir

Mechanical mixing in J.C. Boyle reservoir for enhancing DO will be further assessed by conducting the following work elements:

- Information will be gathered on commercially-available higher-energy mixers/circulators for potential application in J.C. Boyle reservoir. Emphasis will be placed on mixers/circulators that have a successful record of use in other lakes and reservoirs (e.g., ITT Flygt, KSB). Available information (including research literature) on use and effectiveness of these higher-energy mixer/circulators will be reviewed and summarized. Additional DO monitoring data, as described below, will be assessed to determine the applicability of the technology to address observed conditions in J.C. Boyle reservoir. Manufacturers will be contacted for information and specifications on available mixers/circulators, and the required equipment and power to support them in field applications.
- The existing CE-QUAL-W2 model for J.C. Boyle reservoir (developed by Watercourse Engineering) will be used to explore the potential effects on DO of increased mixing energy introduced into J.C. Boyle reservoir. Model results will be used to assess the increase in mixing energy at potential circulator deployment locations.

Further Assessment of Oxygenation for DO Improvement in J.C. Boyle Reservoir

Oxygenation at J.C. Boyle reservoir for enhancing DO will be further assessed by conducting the following work elements:

- Information will be gathered on the commercially-available Supersaturated Dissolved Oxygen (SDOX) system for dissolved oxygen delivery to J.C. Boyle reservoir. Emphasis will be placed on SDOX systems that have a successful record of use in other lakes and reservoirs (e.g., BlueInGreen). Available information (including research literature) on use and effectiveness of these SDOX systems will be reviewed and summarized. Additional DO monitoring data, as described below, will be assessed to determine the applicability of the technology to address observed conditions in J.C. Boyle reservoir. Manufacturers will be contacted for information and specifications on SDOX systems, and the required equipment and power to support them in field applications.

- The existing CE-QUAL-W2 model for J.C. Boyle reservoir (developed by Watercourse Engineering) will be used to explore the potential effects on DO of increased DO delivery from the SDOX system to J.C. Boyle reservoir.

Monitoring of DO Conditions in J.C. Boyle Reservoir

Monitoring of DO will be conducted in J.C. Boyle reservoir under this Study to better define the temporal and spatial extent of DO conditions in the reservoir. Most of the existing DO data for the reservoirs are grab samples and are just snapshots in time.

Two continuously-monitoring probes will be deployed to measure DO and water temperature in J.C. Boyle reservoir throughout the summers of 2010 and 2011. The probes will be deployed at depths of 3 and 7 meters near the reservoir log boom (upstream of the dam). The probes will record DO concentration (mg/l and percent saturation) and water temperature (^{o}C) at hourly intervals. The probes will also record pH and conductivity at hourly intervals.

Feasibility Assessment of DO Improvement Techniques

Based upon the assessment information developed for mechanical mixing and oxygenation as techniques for DO improvement in J.C. Boyle reservoir, and relying upon the existing information on air injection developed by Horne et al. (2009), a feasibility assessment will be conducted to determine the most appropriate means to improve DO in J.C. Boyle reservoir. This analysis will rely upon the additional DO monitoring data obtained, which will inform the assessments of the applicable technologies given local site conditions and constraints. The feasibility assessment will be used to inform the selection of water quality improvement projects under Interim Measure 11 in the event of an affirmative Secretarial Determination.

Schedule

Activity	Date
Gather pertinent information as described above	November 2010 – May 2011
Continue modeling to assess potential effects of DO improvement methods	January – March 2011
DO Monitoring	Summer 2010 and 2011
Final Feasibility Study Report	October – November 2011

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