Technical Report

Conceptual Design Evaluation for Full-Scale Particulate Organic Matter Removal from Klamath River Source Water Using Stormwater Treatment Technology

Prepared for

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March 2015

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Conceptual Design Evaluation for Full-Scale Particulate Organic Matter Removal from Klamath River Source Water Using Stormwater Treatment Technology

1. Introduction

On February 18, 2010, the United States, the States of California and Oregon, PacifiCorp, regional Native American 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., J.C. Boyle, Copco 1, Copco 2, and Iron Gate 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 for interim operation of the dams and mitigation activities prior to potential removal of the hydroelectric facilities. One such provision - titled Interim Measure 11: Interim Water Quality Improvements - emphasizes water quality improvement projects in the Klamath Basin during the interim period.

As part of Interim Measure 11, PacifiCorp contracted with Watercourse Engineering, Inc. (Watercourse) to assess the feasibility of using vortex separation technology to remove particulate organic matter from the Klamath River. A prototype continuous deflective separation (CDS) particle separator was specially constructed and tested for this study. CDS separators are gravity-driven separators consisting of a specifically-designed round vault and screen through which treated waters travel in a circular (vortex) fashion to effectively screen, separate, and trap suspended material. CDS separators are most commonly employed in municipal stormwater treatment systems to remove coarser particulates.

Several studies have identified stormwater treatment technologies as effective means of removing particulates and associated nutrients from surface water runoff that potentially promote algae growth in receiving waters (Patel *et al*. 2004; Reddy *et al*. 2006; Perry *et al*. 2009). However, no significant work has been completed to investigate the potential of using stormwater treatment technology to directly remove algae and organic matter from affected waters. The Klamath River is nutrient-enriched, due to large loads of nutrients and organic matter to the river from hypereutrophic Upper Klamath Lake (UKL) and other upstream sources (NAS 2004; Lindenberg *et al*. 2009). Algae and organic matter loads from UKL are seasonally dominated by the biomass of the blue-green algae species *Aphanizomenon flos-aquae* (APFA). Reductions of seasonal algae and organic matter loads emanating from UKL could provide substantial water quality improvements in the Klamath River, and especially in Keno Reservoir, which is just downstream of UKL and experiences seasonal anoxia due to the processing of organic matter loads from UKL (Sullivan *et al*. 2011; 2012; 2013). Further, water quality improvements from the reductions in particulate organic matter loading would potentially provide important benefits for endangered suckers found in Keno Reservoir (USFWS

2001) and may improve the water quality impairments in the reservoir that will require a seasonal juvenile and adult trap and haul program for anadromous fish (NMFS 2007). Additionally, reductions in organic matter loading could also lead to lower seasonal organic matter concentrations in the Klamath River downstream of Keno Dam.

Field experiments employing prototype hydrodynamic vortex separation technology conducted in 2012 and 2013 were used to determine the potential removal efficiency of phytoplankton and larger particulate matter from Klamath River water in the vicinity of Link River Dam. Details of the field work are presented in Watercourse (2013; 2014).

In this report, information from these field studies is used to develop conceptual designs of full-scale treatment facilities utilizing CDS technology to improve water quality downstream of Link River Dam. These representative layouts or options are theoretical and are intended to provide examples and approximate costs should the technology or elements of the technology be considered for application in the Klamath River to reduce organic matter and its attendant oxygen demand and nutrient concentrations in downstream reaches.

1.1. Approach

Conceptual-level design of full scale CDS-based treatment facilities used information from field experiments to identify capacities, removal rates, and optional configurations. Four options for facilities design were analyzed as described in this report, and represent a wide range of conditions. However, it may be desirable to consider additional layouts or configurations if further more-detailed planning of CDS-based treatment facilities is pursued. Conceptual-level estimates of costs were developed for the various components and the total net present value for each option was estimated based on a 20-year life-cycle cost analysis. This analysis provides a general range of costs for a facility, and allows for relative comparisons among the various options. The identification of key component costs (e.g., fish screens, pumping systems, etc.) provides insight into the estimated costs and trade-offs of removing various fractions of organic matter depending on system design, location, and overall flows through a system.

An initial step in the conceptual-level design and cost analysis was delineating various potential facilities layouts. Because large scale removal of organic matter from water using storm water technology has never been applied or proposed at this scale, there are inherent assumptions regarding design and cost that are subject to uncertainty. Therefore, the conceptual system layouts are proxies that represent key elements and costs are order-of-magnitude (ballpark) estimates for purposes of relative comparisons among the four options. Further, while there are specific locations and elements are identified herein, no assumptions are made regarding other factors not explicitly considered in this study that could affect feasibility, such as access, permitting, impacts on existing facilities, or land acquisition/right of way considerations. Instead, this report is intended to focus on the technical elements and feasibility of reducing organic matter loading through storm water technology and associated conceptual, or feasibility-level, cost estimates. Thus, the cost estimates presented for the various system layouts should not be considered construction cost estimates and are intended only to assist in determining whether further evaluation of the technology is warranted, and if so, which design alternative or alternatives may present the most promise for implementation.

1.2. Report Organization

The report consists of seven sections. The first section provides an introduction to the project and general approach. Section 2 presents design consideration specific to organic matter load reduction. Efficiency of particulate organic material removal at different separator operations (termed “sump fraction”); net reductions for particulate carbon, nitrogen, and oxygen; and net reduction in biochemical oxygen demand associated with separator operations are quantified for design consideration. For additional information on CDS technology, prototype separator construction, field experiments, results and analysis, the reader is referred to Watercourse (2013; 2014). Section 3 describes four conceptual design options/layouts for a full-scale separator facility, and how each option was developed from pre-defined discrete system components (e.g., pumps, pipes, fish screens, etc.). Section 4 presents results of the life-cycle cost analysis and discusses the relative costs among the four options. Additionally, costs and load reductions are quantified as an additional metric to examine and compare the four options. Conclusions and recommendations are presented in Section 5, and Section 6 includes report references. Section 7 is an appendix that details the costs associated with each component of the various system options and layouts, as well as examples of the life-cycle cost calculations.

2. Design Considerations and Organic Matter Load Reduction

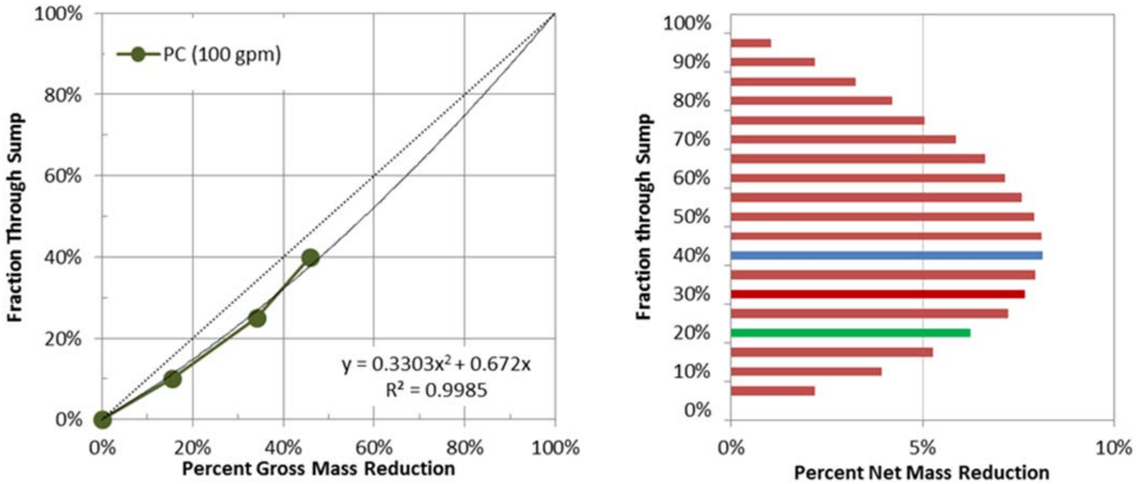
Conceptual-level designs were identified by direct field observations of separator performance based on a range of operations. Outlined below are the anticipated load reductions that could be achieved based on field work completed in 2012 and 2013 (Watercourse 2013, 2014). Reductions in particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), as well as ultimate biochemical oxygen demand (BOD_u) are presented. This information provides insight into the relative approximate cost of treatment to different removal levels, and the potential reductions that could be observed with a full scale organic matter separator facility using the CDS technology.

2.1. Load Reductions and Results Based on Field Observations

The organic matter separator field experiments in 2012 and 2013 focused on removing organic matter using the CDS stormwater technology identified above (Watercourse 2013; 2014). In these experiments, influent water was separated into two outflows – a “treated” outflow that would be returned to the river at Link River Dam with reduced organic matter, and a “sump” outflow that would include separated organic matter that would be delivered to the A-Canal.[1] The organic matter separator was tested for a range of sump outflows (also presented as a “sump fraction” of the total inflow), and an optimal

[1] Downstream impacts of increased “sump” water discharges into A-Canal have not been assessed within the context of this report, but could be evaluated if this technology is considered for future use.

sump fraction was identified. The most efficient sump fraction for particulate carbon removal in the 2013 experiment was determined to be approximately 40 percent of total inflow (Figure 1(a)) – meaning that 40 percent of the inflow would be diverted to the A-Canal for use in agricultural operations. However, an inspection of removal efficiencies for various sump fractions indicates that notable mass removal can still occur at sump fractions that have lower efficiencies (Figure 1(b)).



(a) (b)

Figure 1. Efficiency curve representing (a) the relationship between fraction of outflow through the sump and the percent gross mass reduction and (b) associated concentration reduction. Optimal reduction highlighted in blue at approximately 40 percent fraction of total flow through sump, reduction associated with a 20 percent sump fraction shown in green (2013 field data).

While optimal separator performance may be the most desirable design goal, practical design and cost considerations pose constraints that may result in less efficient removal rates with lower sump fractions being economically optimal. Using hydrodynamic vortex separation technology may be an effective approach to reduce organic matter in the upper Klamath River, but management of the collected organic matter (sump fraction) is a particularly important constraint that is a direct function of the volume of water targeted for disposal/reuse. Specifically, the larger the sump fraction, the more water that must be managed with resultant higher costs.

Load reductions were estimated based on 2012 field results[2] for particulate carbon (PC)[3], particulate nitrogen (PN), and particulate phosphorus (PP) removal. Load reductions were based on an optimal sump fraction of 40 percent, as well as for sump fractions of 20 and 10 percent. For these sump fractions, the gross particulate reduction and net particulate reduction (removal), as well as the reduction in tons of PC, PN, and PP for June through September 2012 based on flows at Link River (USGS 11507500), were

[2] 2012 data were used because there were typical levels of algae present during this field experiment. The 2013 field experiment illustrated that the separator also removed algae at low concentrations, but overall percent mass reductions were smaller when very little algae was present.
[3] Particulate carbon is assumed to equal particulate organic carbon herein. Field samples analyzed for particulate inorganic carbon were non-detect.

estimated[4]. Gross mass reduction (GMR) is calculated as the total reduction of particulate mass between the inflow and outflow. Net mass reduction refers to that portion that the separator removes over and above the reduction associated with sump fraction.

For sump fractions of 40, 20, and 10 percent, net particulate load reductions[5] were 24.2, 20.6, and 14.6 percent, respectively. Load reductions for PC, PN, and PP over this range of sump fractions ranged from 234 to 389 tons, 48.4 to 80.2 tons, and 4.9 to 8.2 tons, respectively (Table 1). These values indicate that a full-scale removal system assumed to be operating for several months at flow rates typical of Link River below the Eastside Powerhouse in the algae growth period (e.g., 1,000 cfs) could remove a considerable mass of particulate organic matter.

Based on the 2012 field experiments, when the sump fraction was halved (from 40 to 20 percent), net particulate reduction decreased by 14.9 percent. However, the reduction in the sump fraction from 40 to 10 percent (a 75 percent reduction) decreased net particulate reduction by 40 percent. This non-linear relationship between sump ratio and reduction in net particulate matter is likely quite important from potential design and cost perspectives. For example, pumping and delivery of waters associated with system design are considerable potential costs, and the non-linear relationship suggests these potentially-considerable costs would differ on a per-unit removal basis depending on sump ratio.

Table 1. Sump fractions and associated gross particulate reduction; net particulate reduction; and PC, PN, and PC removed for June through September 2012 (based on 2012 experimental results).

Sump Fraction (%)	Gross Particulate Reduction (%)	Net Particulate Reduction (%)	PC Removed* (Ton)	PN Removed* (Ton)	PP Removed* (Ton)
10	25	14.6	234	48.4	4.9
20	41	20.6	331	68.2	6.9
40	64	24.2	389	80.2	8.2

*PC, PN, and PP removed are the totals for the June 1 through September 30 period.

While the organic matter separator removed particulate matter, the impact on total carbon (TC), total nitrogen (TN), and total phosphorus (TP) (where total forms equal particulate plus dissolved) was also calculated for various sump ratios. TC removal ranged from 5.4 to 8.9 percent, TN ranged from 4.8 to 8.0 percent, and TP ranged from 4.5 to 7.4 percent, with lower values for the 10 percent sump fraction and upper values for the 40 percent

[4] Daily average flows from Link River near Klamath Falls (USGS 11507500) do not precisely represent flows at Link River Dam. Return flows from PacifiCorp's West Side Powerhouse enter the river downstream of the USGS Gage. Nonetheless, the USGS flows are a sufficient proxy to illustrate the magnitude of load reductions for the purposes of this report.

[5] Total particulate matter includes particulate carbon, particulate phosphorus, and particulate nitrogen. It was assumed that for the short duration of the study, the stoichiometric ratios were stable. Measurements of particulate carbon have the least uncertainty associated and were used as the basis for estimating reductions in total particulate matter. Particulate matter is assumed to be comprised of approximately 35 percent particulate carbon.

sump fraction (Table 2). These findings indicate that while the organic matter separator only removes particulate matter, the reductions in TC, TN, and TP are still notable.

Table 2. Sump fractions and percent net reduction in total carbon, total nitrogen, and total phosphorus based on 2012 experimental results.

	Net Reduction		
Sump Fraction (%)	Total Carbon (%)	Total Nitrogen (%)	Total Phosphorus (%)
10	5.4	4.8	4.5
20	7.6	6.8	6.3
40	8.9	8.0	7.4

The original intent of this experiment was to reduce ultimate biochemical oxygen demand[6] (BOD_u) in downstream reaches, particularly Keno Reservoir. Keno Reservoir experiences extensive and persistent anoxia during summer periods, leading to a reduced assimilative capacity and an inhospitable environment for many aquatic species. Reducing oxygen demand to Keno Reservoir through a reduction in organic matter could improve downstream water quality conditions. Using PC (equivalent to particulate organic carbon), BOD_u reduction associated with the organic matter separator was calculated.

Table 3. Net particulate reduction and average BOD_u reduction.

Sump Ratio (%)	Net Particulate Reduction (%)	Average BOD_u Reduction[1] (Pounds of BOD_u/day)	Equivalent Population (#)
10	14.6	14,043	70,213
20	20.6	19,813	99,067
40	24.2	23,276	116,380

[1]Assumes 1.0 mol of C is equivalent to 3.66 mol of BODu (Deas 2000, Chapra 1997, Environmental Laboratory 1995) and one person produces 0.2 pound per day of BOD (WEF 2009, City of San Jose 2009).

These results indicate that net particulate organic matter removal is both achievable at levels in excess of 20 percent and that these removal rates lead to notable reductions in particulate and total nutrients and BOD_u (Table 1, Table 2 and Table 3). Given these levels of treatment (sump fractions) and removal rates, rough estimates of potential removal by full scale organic matter removal facilities were developed. These rough estimates were applied in the conceptual-level design analysis as described below, and are intended for initial planning purpose only. More detailed analysis would be required if any of these concepts or associated elements were to be pursued further.

3. Conceptual Design

Conceptual-level design of full-scale separator facilities included identifying the assumed project facilities and locations. These conceptual designs provide initial and preliminary

[6] BOD is amount of dissolved oxygen needed by aerobic microbes to oxidize organic material over a specific time period. The reaction is temperature dependent. BOD ultimate (BODu) represents the dissolved oxygen required as time $\rightarrow\infty$.

information on potential scale-up of separator facilities. This level of initial and preliminary assessment is typically termed pre-design analysis and is intended as a high-level exploration of possible performance conditions and associated ballpark costs. Facility design considerations for each of the four options, including their assumed system features, are outlined below.

3.1. Separator Facility Design Considerations

Design considerations for potential organic separator facilities focus on the timing and location of operation, capacity, and facility elements. For this study, we assumed that 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. We further assumed that the location of a facility would be at the southern end of Upper Klamath Lake, near the outflow at Link River Dam. Specific locations assessed include the Eastside Forebay at Link River Dam and A-Canal intake and fish screen. 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. Finally, for the levels of treatment identified herein, it was assumed that these sump outflows would only modestly increase current loads of particulate matter in A-Canal.

To assess implementation of various facility designs, four basic conceptual design elements were identified, several which include multiple components. These individual design elements were used to "build" discrete options. In this manner, the approximate costs of the individual elements were estimated and subsequently summed to estimate the total approximate cost of a particular option. The basic conceptual design elements include:

- <u>Separator Facility</u>: A separator facility consisting of multiple continuous deflection systems (CDS) units was assumed for example conceptual layout purposes. These could be pre-fabricated units (e.g., up to 50 cfs) or custom units (e.g., up to several hundred cfs). As such, a separator facility with a capacity of up to 1,000 cfs was assumed. Components of the separator facility include CDS units and stilling basins.
- <u>Fish Screen</u>: A fish screen was assumed for options where no fish collection/transport facility was proposed or where an existing fish screen was unavailable.
- <u>Conveyance</u>: Pipelines and associated infrastructure were required to convey the waters from a separator facility to a discharge location, including piping, tunnels, and discharge facilities.
- <u>Pumping</u>: For most options, it was assumed that the fraction of water routed through the sump required pumping to the discharge location near A-Canal (upstream or downstream of the fish screen). For options with a pumping

component, the fraction of flow through the sump was a design consideration. Pumping of sump or treated waters without fish are termed water pumps and capacity would be achieved with pumps in parallel (individual unit size was approximately 100 cfs), rather than a single large pump. If no fish screen was proposed (including existing fish screens), a fish collection/transport facility (fish-friendly pumps) was assumed that would be similar to the existing U.S. Bureau of Reclamation fish collection/transport facility at A-Canal (Reclamation 2005). As with water pumps, above, it was assumed these facilities would probably consist of parallel fish transfer pumps (individual unit size was approximately 32 cfs), rather than a single large pump. For options with a fish collection/transport facility, the fraction of flow through the sump was a design consideration. Control facilities and electricity costs for pumping are also included under this element.

Based on these four design elements and associated components, four example layout options were identified, all in the A-Canal and Link River Dam area, and include:

- Option 1: Eastside Forebay Facility with Fish Screen,
- Option 2: Eastside Forebay Facility Without Fish Screen,
- Option 3: A-Canal Facility (no fish screen)
    - 3.1 Separator flow of 550 cfs
    - 3.2 Separator flow of 250 cfs
- Option 4: Eastside Forebay Facility with Fish Screen, no pumping.

The layout and various elements for each option are described in detail below.

3.1.1. Additional Considerations

Some of the facility conceptual design considerations incorporate existing Reclamation facilities, including their A-Canal screen and fish collection/transport facility. All conceptual facility designs assume discharge of concentrated organic matter to A-Canal, while maintaining the water delivery rates and volumes. Reclamation is not a contributor to this report and any assumptions herein regarding the aforementioned facilities are for illustrative purposes only and without the benefit of consultation with, or endorsement of, Reclamation.

The assumed discharge of additional organic matter to A-Canal could have impacts on downstream Lost River reaches. The Lost River experiences water quality impairments (ODEQ 2010) and increasing organic matter loads may further impact water quality. Ideally, an organic matter removal project would represent an interim measure to provide short-term relief to downstream Klamath River reaches until longer term measures to reduce organic matter from Upper Klamath Lake are implemented and are achieving results. Such timelines also may be consistent with TMDL implementation activities on the Lost River. If so, organic matter removal could be providing downstream benefits to

Klamath River reaches for many years prior to other water quality improvement projects being considered in the Lost River Basin.

Finally, scaling up the system from the prototype field test unit to a full-sized system may result in a change in performance. However, Watercourse worked closely with the manufacturer to develop a prototype field test unit that would minimize such issues. Further, refinements were made to the original prototype system to correspond more closely to full-scale units (e.g., design and implementation of a new insert for the 2013 field season). As a result, performance associated with scale issues is assumed to be minimal. Additional testing and collaboration with the manufacturer would be required if more-detailed design and construction of such facilities was considered.

3.2. Facility Configurations

All configurations included a separator facility and a system to convey water to a discharge point. Elements that varied among the four options included fish screens, collection/transport facilities, and pumping. The conceptual elements for the options outlined above are summarized in Table 4, and are presented in more detail below. These conceptual layouts do not constitute design recommendations, but rather are examples for informational and illustrative purposes only.

Table 4. Design option elements for a separator facility in the Link River Dam area of Upper Klamath Lake, and discharge location.

Option	Separator Facility Location	Link River Fish Screen	Pumping	Conveyance	Sump Discharge Location*
1	Eastside	Yes	Water	Pipeline	A-Canal
2	Eastside	No	Water & Fish	Pipeline	Upstream of A-Canal Fish Screen
3	A-Canal	No	Water	Pipeline	A-Canal
4	Eastside	Yes	n/a	Tunnel	A-Canal

*This refers to the sump discharge location relative to the A-Canal fish screen. “Upstream” denotes that the discharge point is upstream of the A-Canal fish screen, all other options discharge downstream of the A-Canal fish screen.

3.2.1. Option 1: Eastside Forebay Facility with Fish Screen, Discharge Downstream of A-Canal Fish Screen

The first conceptual layout option assumed a full-scale separator facility that takes advantage of the elevation difference between the East Side Powerhouse forebay water surface and the elevation of Link River adjacent to the forebay. This elevation difference is 10 to 15 feet and is sufficient to support adequate gravity flow through the separator units. A fish screen would be required and located at the entrance to the forebay. The sump waste stream would be conveyed to the A-Canal diversion and discharged downstream of the existing Reclamation fish screen and fish collection/transport facility at A-Canal (Figure 2). Pumps are required to transport the water from the separator facility to the A-Canal diversion. A pipeline, located below grade along the existing gravel roadway and parking area, would be used to convey the water from the sump to the A-Canal diversion channel. There would be an approximate 20 to 25 foot elevation drop between the separator sump discharge location at the Eastside Powerhouse forebay and the sump discharge location at A-Canal. The treated outflow was assumed to be released to Link River below Link River Dam.

Figure 2. Schematic of conceptual layout Option 1 (not to scale).

Option 2: Eastside Forebay Facility Without Fish Screen, Discharge Upstream of A-Canal Fish Screen

The second conceptual layout option is similar to Option 1, except instead of installing fish screens, it is assumed a fish collection/transport facility would be used to convey the sump fraction through a fish-friendly water conveyance system (Figure 3). Fish would potentially enter the separators and exit through the sump. The sump waste stream is assumed to be conveyed to the A-Canal diversion immediately above the A-Canal fish screens. The fish in the discharge stream are assumed to be screened at the U.S. Bureau of Reclamation A-Canal facility, while the waste stream would go into the A-Canal diversion channel. As a future planning step, the potential effects of separator on larvae/juvenile fish would need to be determined; such effects are not considered herein. It is uncertain whether such a system could be permitted given current requirements for fish screens on water diversions. The need for a fish screen would require further assessment and relevant regulatory agency approvals. The treated outflow is assumed to be released to Link River below Link River Dam.

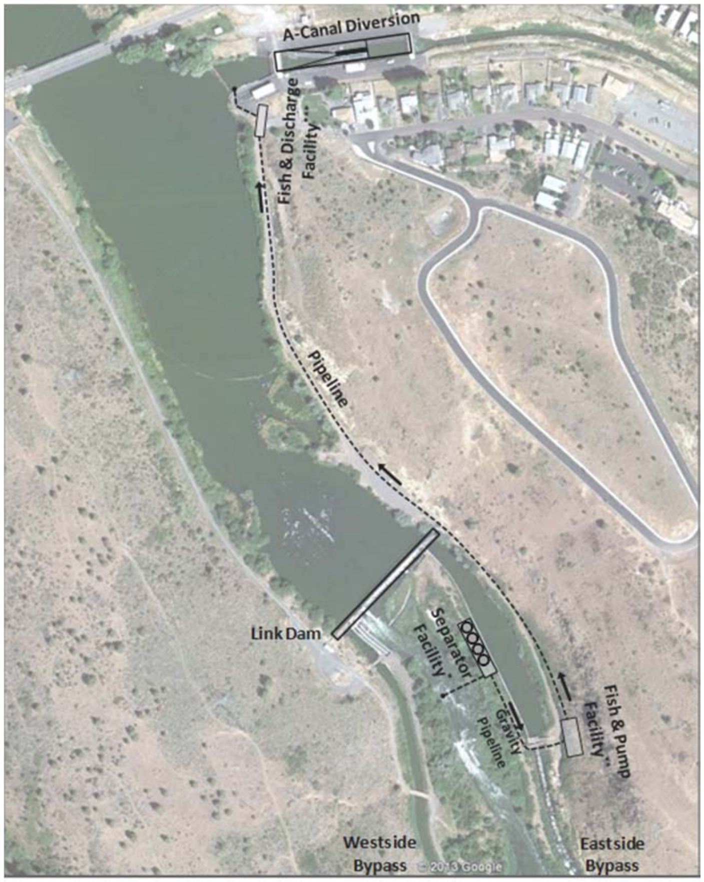


Figure 3. Schematic of conceptual layout Option 2 (not to scale).

3.2.2. Option 3: A-Canal Facility (no fish screen) with Discharge below Eastside Forebay

A third conceptual layout option would be to place a separator facility downstream of the A-Canal fish screen (Figure 4). The inflow would be drawn from A-Canal, but the separator outflow would be sent to the discharge below Link River Dam (either into Link River or to the Eastside Powerhouse). The sump waste stream would be released to A-Canal. This option would not involve the construction of a new fish screening facility, because it would be located behind the existing Reclamation fish screen at A-Canal. However, the overall capacity of the system would be limited because A-Canal would also be conveying waters to the Reclamation's Klamath Project. While this option is an all-gravity system, only a fraction of the water currently released at Link River Dam would be treated. Two flow rates of treatment are assumed for this analysis based on historical delivery and canal capacity: 550 cfs and 250 cfs. These two assessments are termed Option 3.1 and 3.2, respectively. These treatment flow rates are notably less than the 1,000 cfs assumed for Options 1, 2, and 4. Additional constraints are possible space limitations downstream of A-Canal where CDS units would be placed. These potential space limitations would need to be evaluated if there was future interest in this option.

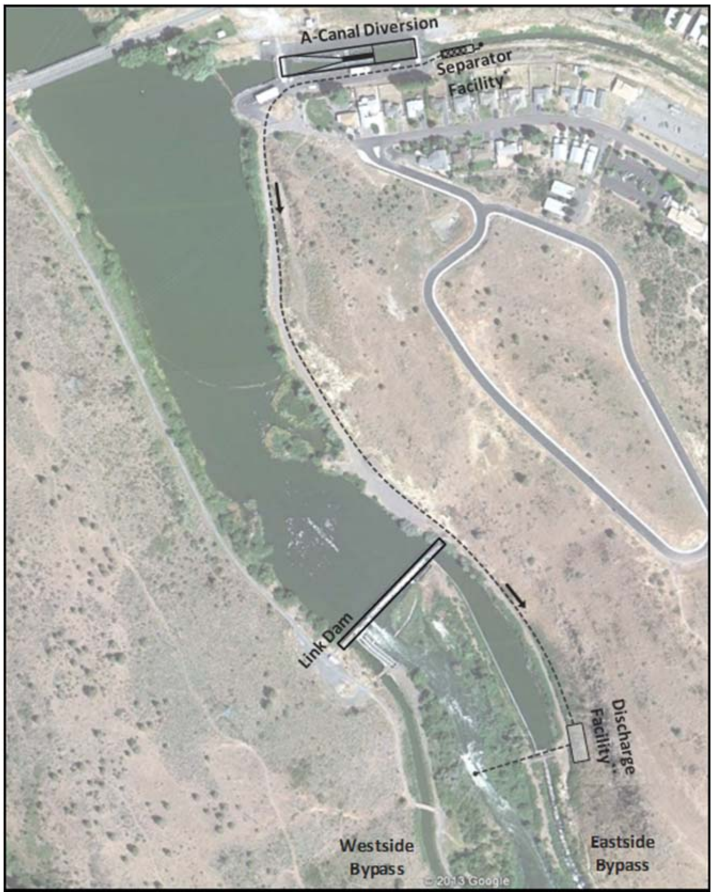


Figure 4. Schematic of implementation Option 3 (not to scale).

3.2.3. Option 4: Eastside Forebay Facility with Fish Screen, Discharge to A-Canal via Tunnel

The fourth option assumes a tunnel would be constructed that would convey the sump waste stream to a nearby discharge location on the A-Canal (Figure 5). The separator facility would operate behind a new fish screen within the Eastside forebay, while the post-separator treated outflow would be released into Link River. There would be no pumping under this option.

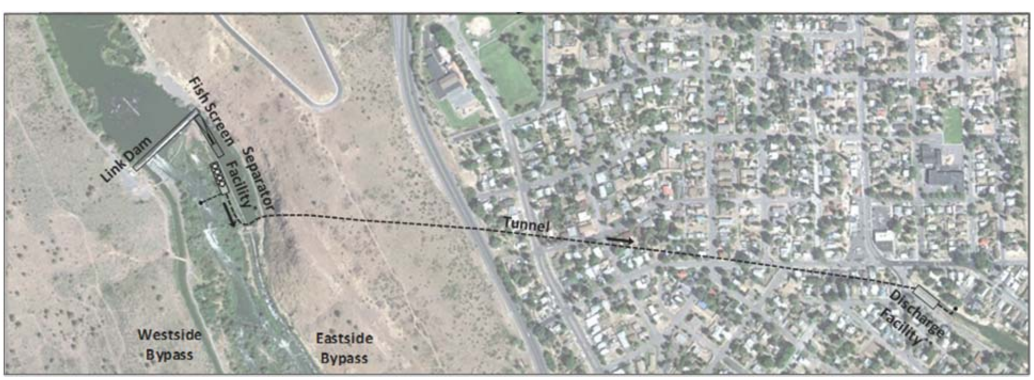


Figure 5. Schematic of implementation Option 4 (not to scale).

4. Cost Analysis

The cost analysis required developing design, capital, operations and maintenance (O&M), and electricity costs for the components and elements comprising each of the four options. For example, a separator facility would include the CDS units and appurtenant features, and a stilling basin to collect and pump the sump flows. Pumping would include pumps, associated infrastructure, a control facility, and associated power needs. Pumped water might be conveyed in a pipe (with associated material and trenching costs), and that water would need to be discharged in a manner that would preclude erosion. Also, a fish screen may be a necessary component of any option to ensure that entrainment does not occur–although Option 2 omits a fish screen. For each element identified previously, specific components were identified (Table 5). Each element and associated components and their costs are detailed in Appendix X.

Table 5. Organic matter separator project elements, associated components, and the options to which they apply.

Element[1]	Component[1]	Purpose	Options
Separator Facility	CDS Units	Remove algae and other particulate organic matter from the water.	All
	Stilling Basins	Reduce local CDS outflow velocities prior to transport to the discharge locations.	All
Fish Screen	Fish Screen	Prevent entrainment of fish into CDS units.	1, 4
Conveyance	Piping	Convey water from CDS units to discharge locations.	All
	Tunnel	Option 4 proposes a tunnel to convey water from the CDS units to A-Canal downstream of the underground section through the city of Klamath Falls.	4
	Discharge Facility	To prevent scour or damage to the bank at the discharge location.	All
Pumping	Pumps	Convey water from the CDS units to the discharge location.	All
	Fish Friendly Pumps	Fish Collection/Transport Facility to transport water and fish from CDS units at Eastside forebay to A-Canal.	2
	Control Facility	A housing unit to contain the pump controls and monitoring equipment.	All
	Power Requirements	Electrical cost of powering the pumps (per year).	All

[1]Not all elements are needed for all options.

Based on available cost information, Table 6 summarizes approximate cost estimates for each component assuming operations at 10, 20, and 40 percent sump fraction system were developed. An example is shown for Option 1 in Table 6, and similar tables are shown for the other options in Appendix A. These capital costs, along with assumptions on annual operating and maintenance (O&M) costs, with a factor of safety applied, were used to develop net present values for each of the options assuming a 20-year life span. Annual O&M costs were assumed to be 2 percent of capital costs (adjusted for inflation each year). A factor of safety of 35 percent was applied to all costs except electricity which was maintained at a constant $0.12 kW-hr. A 3.5 percent discount rate and 2 percent inflation rate was assumed for all analyses. No equipment salvage value at the end of the project life was assigned.

Table 6. Estimated approximate costs of organic matter removal project components for 10, 20, and 40 percent sump fraction: Option 1.

Element[1]	Component	Purpose	Options	Estimated Cost Based on Sump Fraction		
				10%	20%	40%
Separator Unit	CDS Units[2]	Remove algae and other particulate organic matter from the water.	All	$6,600,000	$6,600,000	$6,600,000
	Stilling Basins[3]	Reduce local CDS outflow velocities prior to transport to the discharge locations.	All	$220,000	$220,000	$220,000
Fish Screen	Fish Screen[4]	Prevent entrainment of fish into CDS units.	1, 4	$19,000,000	$19,000,000	$19,000,000
Conveyance	Piping[5]	Convey water from CDS units to discharge locations.	All	$1,790,000	$2,190,000	$3,290,000
	Tunnel	Option 4 proposes a tunnel to convey water from the CDS units to A-Canal downstream of the underground section through the city of Klamath Falls.	4	n/a	m/a	n/a
	Discharge Facility[6]	To prevent scour or damage to the bank at the discharge location.	All	$21,000	$21,000	$21,000
	Fish Passage Facility[7]	Improvements and modifications to downstream fish passage facilities at Link River Dam.	1, 2, 4	$500,000	$500,000	$500,000
Pumping	Pumps[8]	Convey water from the CDS units to the discharge location.	All	$210,000	$410,000	$810,000
	Fish Friendly Pumps[9]	Fish Collection/Transport Facility to transport water and fish from CDS units at Eastside forebay to A-Canal.	2	n/a	n/a	n/a
	Control Facility[10]	A housing unit to contain the pump controls and monitoring equipment.	All	$560,000	$560,000	$560,000
	Power Require-ments[11]	Electrical cost of powering the pumps (per year).	All	$216,000	$432,000	$865,000
Other	O&M[12]	Annual operation and maintenance costs	All	$1,035,000	$1,057,000	$1,112,000

[1]Not all elements are needed for all options. Capital costs presented herein represent a conservative cost estimate of infrastructure elements (pumps, CDS, units, fish screens, etc.) based on current information. Some costs include rough estimates for associated labor, but specific, local labor costs were not included. Final costs for each element may be higher or lower than estimated, but overall project costs are expected to be slightly higher when site preparation, permitting, and other associated costs are included. More comprehensive cost details presented in Appendix.
[2]Cost is based on 30 pre-cast units, constructed by Contech (*pers. comm*. John Pedrick). Basic installation costs are included, but for difficult locations, installation costs would increase. Cost do not include associated safety infrastructure that may be needed (e.g., overhead walkways, fencing, etc.).
[3]Includes the estimated cost for trenching, dewatering, hauling, lining, and fencing. Does not include costs for site preparation, leveling/grading, permitting, etc. Basin sizing was based on the maximum storage volume needed to hold 10 seconds of outflow from the CDS units (treated and sump combined). A 14-ft deep square basin was assumed. The concrete lining was assumed to be 12-inches thick with appropriate reinforcement.
[4]Costs are based on the cost of installing the fish screen and associated elements at A-Canal in 2003 (adjusted to 2014 dollars (ratio of 1.293)) (Reclamation, 2005). Note that Options 3.1 and 3.2 use the existing A-Canal fish screen. The cost of the existing A-Canal fish screen is not included in the estimated cost for Options 3.1 or 3.2 because the fish screen has already been constructed.
[5]Piping costs are estimated based on the costs of HDPE, metal (CMP), and concrete (RCP) pipe from the Department of Public Works, City of Rockville, MD (adjusted to 2014 dollars) (Rockville, 2010). Piping costs are $1.3 million dollars. Included herein are trenching costs of $875,000 based on the trenching associated with the A-Canal fish screen, where a 36" pipe extended from A-Canal to Eastside forebay. Total cost estimated at $2.175 million dollars.
[6]Riprap costs are based on estimated cubic yard costs (RSMeans 2013) and A-Canal fish screen project (Reclamation, 2005).
[7]Improvements to the East Side forebay intake gates and other facilities at Link River Dam are estimated to be approximately $500,000. Additional design considerations to address downstream fish passage impacts may result in other unknown costs, but are not included in this analysis.
[8]Based on the cost of a 200 cfs pumping facility. Sump flows range from 100 cfs to 350 cfs, indicating that one or two large pumping facilities may be required.
[9]Cost of fish friendly screw pumps are based on 2011 cost estimates published by Reclamation for the Tracy Pumping Plant project. The cost was $5,000,000 (in 2011 dollars) for 4, 28-inch (40 cfs) Wemco Hidrostal pumps (Reclamation, 2011).
[10]Control Facility/building cost is based on the cost of the control building installed for the A-Canal fish screen project.
[11]Pumping costs based on rate of $0.12/kWh and size of the pumps. Electrical costs shown are only for the first year; subsequent year costs are adjusted for inflation.
[12]Annual O&M costs are assumed to be approximately 2 percent of the capital cost of the project, adjusted by the safety factor. The O&M costs shown are only for the first year of the project; subsequent year costs are adjusted for inflation.
* Unless otherwise noted, costs are based on construction information from RS Means (2013, 2014)

The net present value for each of the options for 10, 20, and 40 percent sump fractions are shown in Table 7. Lower sump fractions translate to lower overall costs, but would also translate to lower removal rates, particularly for Options 3.1 and 3.2, where only a fraction of the 1,000 cfs river flow is treated. Overall, Options 1 and 4 are the most expensive. Fish screens form a large portion of the higher costs of both options 1 and 4. Option 2 assumes no fish screen, but includes fish friendly pumps which are an expensive component. Option 3.1 is estimated to be more expensive than 3.2 due to the larger volumes of water and pumping costs (550 cfs treated versus 250 cfs treated). Options 3.1 and 3.2 also do not include a fish screen, which makes them relatively less expensive than Options 1 and 4.

Table 7. Net present value for the five design alternatives, with three different sump fractions.

Option	Net Present Value ($Million)		
Sump Fraction →	**10%**	**20%**	**40%**
1	$61.2	$66.1	$76.7
2	$28.9	$36.2	$54.4
3.1*	$42.0	$42.4	$46.1
3.2*	$22.3	$23.4	$24.6

4	$55.9	$56.4	$56.8

*Option 3.1 refers to Option 3 (CDS units located downstream of A-Canal fish screen), with a downstream A-Canal demand of 600 cfs (550 cfs treated). Option 3.2 refers to Option 3 (CDS units located downstream of A-Canal fish screen), with a downstream A-Canal demand of 900 cfs (250 cfs treated).

Using field data for particulate carbon from Table 1 as a surrogate for organic matter, and net present values from Table 7, the cost per ton of carbon removed can be calculated for the various options and sump fractions (Table 8). The estimated costs indicate that the most cost-effective of the options is Option 2 ($5,500 to $7,000 per ton), with the 20 percent sump fraction being the least expensive ($5,500 per ton). Option 2 is the only option that increases in cost when going from the 10 percent to 40 percent sump fraction, because fish-friendly pumping costs are relatively high. Option 4 is the second least expensive ($7,400 to $12,000 per ton). Although option 4 has considerable fish screen and tunneling costs, it does not have pumps and associated electricity costs. As a result, the approximate overall cost for option 4 is less than options 2 and 3 (3.1 and 3.2). Option 1 was the most expensive in terms of net present value (Table 7), but was third least expensive on a cost-per-ton basis ($9,900 to $13,100 per ton). The approximate overall costs estimated for Option 3 (3.1 and 3.2) are high, largely because of the restricted potential treatment capacity that would be available behind the A-Canal fish screens under this option. While Option 3.2 was one-third the net present value of Option 1, the cost-per-ton of removal averaged (across all sump fractions) approximately 30 percent higher than Option 1. A similar analysis could be completed for PN, PP, and BOD_u, and while values would be different, the relative ranking of alternatives would be approximately the same.

The costs for removal of nutrients (nitrogen and phosphorus) are notably higher than the cost of carbon removal regardless of the option or sump fraction (Table 8) because of the considerably smaller fraction of nitrogen and phosphorus in organic matter compared to carbon. Using the 20 percent sump fraction as an example, nitrogen removal ranged from 17.1 to 68.2 tons per treatment season[7] at a cost of $26,600 to $68,500 per ton. For phosphorus, removal ranged from 1.7 to 6.9 tons per treatment season at a cost from $262,500 to $679,900 per ton. Nutrient removal rates and costs were not the principal focus of this report, but nevertheless they provide preliminary information on the relative cost of reducing nutrients at a large scale. Basin-wide studies on nutrient removal and associated costs have not been performed to date. However, PacifiCorp funded a fencing project on a half mile section of the Sprague River as a pilot project aimed at assessing how to quantify phosphorus removal from restoration projects. The project removed approximately 4.5 pounds of phosphorus at a cost of approximately $12,500, which equates to roughly $9.4 million per ton.[8] Although these costs may not be representative of all fencing-type projects that provide nutrient reductions, awareness of the costs of

[7] For the purposes of this discussion, the treatment season runs from June 1 to September 30.
[8] The cost for fence installation and the watering system was approximately $12,500, not including land lease costs. Using the same project horizon (20-years) and inflation rate (2 percent), and a $500 per year operating and maintenance cost, the net present value was $21,250 to remove 4.5 pounds of phosphorus a year. This results in a cost per pound of phosphorus removal of approximately $4,720. Scaling the removal rate to tons yields a cost of $9.4 million per ton of phosphorus removed.

other actions that may result in nutrient reductions provides some basis to compare nutrient reduction strategies and prioritize management options.

Table 8. Based on Table 1 and 7: Cost of removal per ton per year – Carbon, Phosphorus, and Nitrogen (values reported to the nearest $100).

Option	Removed Tons[1]	T%[3]	P%[4]	Cost per Ton Removed	Removed Tons[1]	T%[3]	P%[4]	Cost per Ton Removed	Removed Tons[1]	T%[3]	P%[4]	Cost per Ton Removed
	10% Sump Fraction				20% Sump Fraction				40% Sump Fraction			
Carbon												
1	234	5.4	14.6	$13,100	334	7.6	20.6	$10,000	389	8.9	24.2	$9,900
2	234	5.4	14.6	$6,200	334	7.6	20.6	$5,500	389	8.9	24.2	$7,000
3.1[2]	156	3.0	8.0	$16,400	184	4.2	11.3	$11,700	214	4.9	13.3	$10,800
3.2[2]	71	1.3	3.7	$19,100	84	1.9	5.2	$14,200	97	2.2	6.1	$12,700
4	234	5.4	14.6	$12,000	334	7.6	20.6	$8,600	389	8.9	24.2	$7,400
Phosphorus												
1	4.9	4.5	14.6	$624,300	6.9	6.3	20.6	$479,400	8.2	7.4	24.2	$467,600
2	4.9	4.5	14.6	$295,100	6.9	6.3	20.6	$262,500	8.2	7.4	24.2	$331,500
3.1[2]	2.7	2.5	8.0	$778,700	3.8	3.5	11.3	$558,300	4.5	4.1	13.3	$510,700
3.2[2]	1.2	1.1	3.7	$912,100	1.7	1.6	5.2	$676,900	2.1	1.9	6.1	$599,800
4	4.9	4.5	14.6	$570,800	6.9	6.3	20.6	$408,700	8.2	7.4	24.2	$346,500
Nitrogen												
1	48.4	4.8	14.6	$63,300	68.2	6.8	20.6	$48,500	80.2	8.0	24.2	$47,800
2	48.4	4.8	14.6	$29,900	68.2	6.8	20.6	$26,600	80.2	8.0	24.2	$33,900
3.1[2]	26.6	2.7	8.0	$78,900	37.5	3.8	11.3	$56,500	44.1	4.4	13.3	$52,300
3.2[2]	12.1	1.2	3.7	$92,400	17.1	1.7	5.2	$68,500	20.1	2.0	6.1	$61,400
4	48.4	4.8	14.6	$57,800	68.2	6.8	20.6	$41,400	80.2	8.0	24.2	$35,500

[1]Based on values from Table 1. See also Footnote 2 for reductions in Option 3.1 and 3.2 load removed due to a lower treatment volume.
[2]Option 3.1 refers to Option 3 (CDS units located downstream of A-Canal fish screen), with a downstream A-Canal demand of 600 cfs. Treating only 550 cfs of water instead of 1,000 cfs of water reduces the potential load removed by 45 percent. Option 3.2 refers to Option 3 (CDS units located downstream of A-Canal fish screen), with a downstream A-Canal demand of 900 cfs. Treating 250 cfs of water instead of 1,000 cfs of water reduces the potential load removed by 75 percent.
[3] "T%" refers to the percent reduction in total carbon, phosphorus, or nitrogen and are based on values from Table 2.
[4]"P%" refers to the percent reduction in particulate carbon, phosphorus, or nitrogen and are based on values from Table 2.
* These findings assume that flow conditions in 2012 were representative of a typical June through September period at Link River below Eastside Powerhouse, and similarly for algae. While algae conditions are dynamic during the year, at times higher and at times lower than seasonal average conditions, this average conditions was assumed representative for this study.

4.1. Modeling Assessment

In a recent USGS study (Sullivan *et al.* 2013), a CE-QUAL-W2 model (Cole and Wells 2008) was developed to model flow and water quality conditions in Lake Ewauna-Keno Reservoir. The model calibration was based on extensive field data and has been applied for several studies (Sullivan *et al*. 2008, 2009, 2010, 2012, 2013; Poulson and Sullivan 2010; Deas and Vaughn 2011).

This model was used to identify the potential effects of reduced upstream particulate organic matter (POM) concentrations, including blue-green algae (BGA), on downstream water quality in Lake Ewauna-Keno Reservoir. The model was used to simulate three reduced upstream POM loading conditions, which were compared to a simulated base case scenario. The different loading conditions were as follows:

- No reduction, Base Case (BC)
- 20 percent reduction in upstream POM[9] (20%red)
- 30 percent reduction in upstream POM (30%red)
- 40 percent reduction in upstream POM (40%red)

The base case (BC) scenario simulated the historical conditions in Lake Ewauna-Keno Reservoir for 2006. The only changes made from the base case for the three POM loading scenarios were the seasonal reductions in POM concentrations at the upstream boundary (mouth of Link River). For those scenarios, POM levels were assumed to be reduced by 20 percent, 30 percent, and 40 percent. This range addressed the removal percentages identified in field studies (Watercourse 2013) of up to 24.2 percent, as well as potential higher reductions that may be possible with design improvements. The higher percent reductions were estimates of what might be expected with a refined design because the stormwater CDS technology used herein was essentially “off-the-shelf.” With refinements in the CDS technology to specifically address POM typically found in the project area, it is assumed that increases to between 30 and 40 percent could occur.

The modeling of seasonal reductions in POM was applied to base conditions for the period from May 1 to September 30, 2006, inclusive. In this period, POM levels were dominated by *Aphanizomenon flos aquae* (AFA) biomass coming from the upstream hypereutrophic Upper Klamath Lake (Sullivan *et al.* 2011). The effects of reduced upstream POM concentrations on downstream POM, ultimate carbonaceous biological oxygen demand ($CBOD_u$), dissolved oxygen (DO), total nitrogen (TN) and total phosphorus (TP) were assessed using model output for several locations in Keno Reservoir below the Link River inflow and at Keno Dam (Table 9 and Figure 6). Three model output locations were assessed in Lake Ewauna to determine how conditions closer to Link River (and Upper Klamath Lake) may vary compared with more distant locations from the source of POM.

Table 9. CE-QUAL-W2 Keno Reservoir output segments, locations, and distance below Link River.

Segment	Approximate Location	Approximate Distance from Link River confluence (meters)
3	Lake Ewauna below Link River	450
6	Above Railroad Bridge	1,350
10	Below Railroad Bridge	2,550
38	Miller Island	10,950
78	KRS12A (Reclamation Sampling Site)	22,950

[9] Herein, POM includes BGA.

103	Keno Dam	30,450

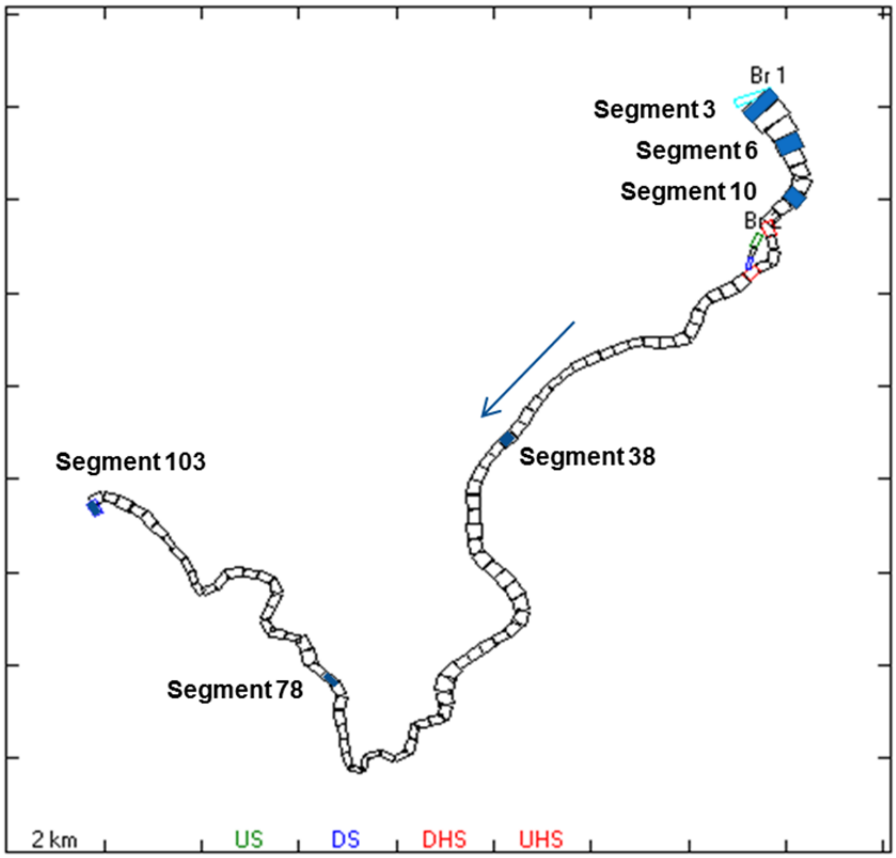


Figure 6. CE-QUAL-W2 computational grid of Keno Reservoir with model output segment locations.

The model output indicates that upstream POM concentration changes had minimal impacts on downstream concentrations of POM, $CBOD_u$, DO, TN, and TP in June, due primarily to low initial BGA populations. As the summer season progressed, the increases in upstream POM concentrations yielded more notable reductions in downstream concentrations (i.e., the separator was more effective at removing particulate matter when concentrations were higher). The model output shows reductions in POM and $CBOD_u$ concentrations upstream of Miller Island (represented by Segment 38),and POM concentrations continue to exhibit slightly lower concentrations downstream to Keno Dam (Figure 7 (Figure 8), but the reductions in $CBOD_u$ concentrations were negligible at Keno Dam. In terms of DO, the model output indicates that there was only a small increase in Lake Ewauna), a larger increase at Miller Island, and then a decrease downstream to Keno Dam (Figure 9). The model predicted that changes to upstream POM concentrations would only have a modest impact on nutrient concentrations. There were slight changes in nutrient concentrations upstream of Miller Island and from Miller Island to Keno Dam; however, the changes to TN and TP are minimal (Figure 10).

Overall, the modeling indicates that POM reductions had the largest impact on water quality in the upper part of Lake Ewauna/Keno Reservoir close to Link River (the point of highest reduction), with the exception of DO. Reductions in BGA (included in POM) probably reduced photosynthesis in the upper reaches of Keno Reservoir during peak bloom periods. Photosynthetic activity recovered downstream, and coupled with lower $CBOD_u$ load, led to higher DO concentrations downstream.

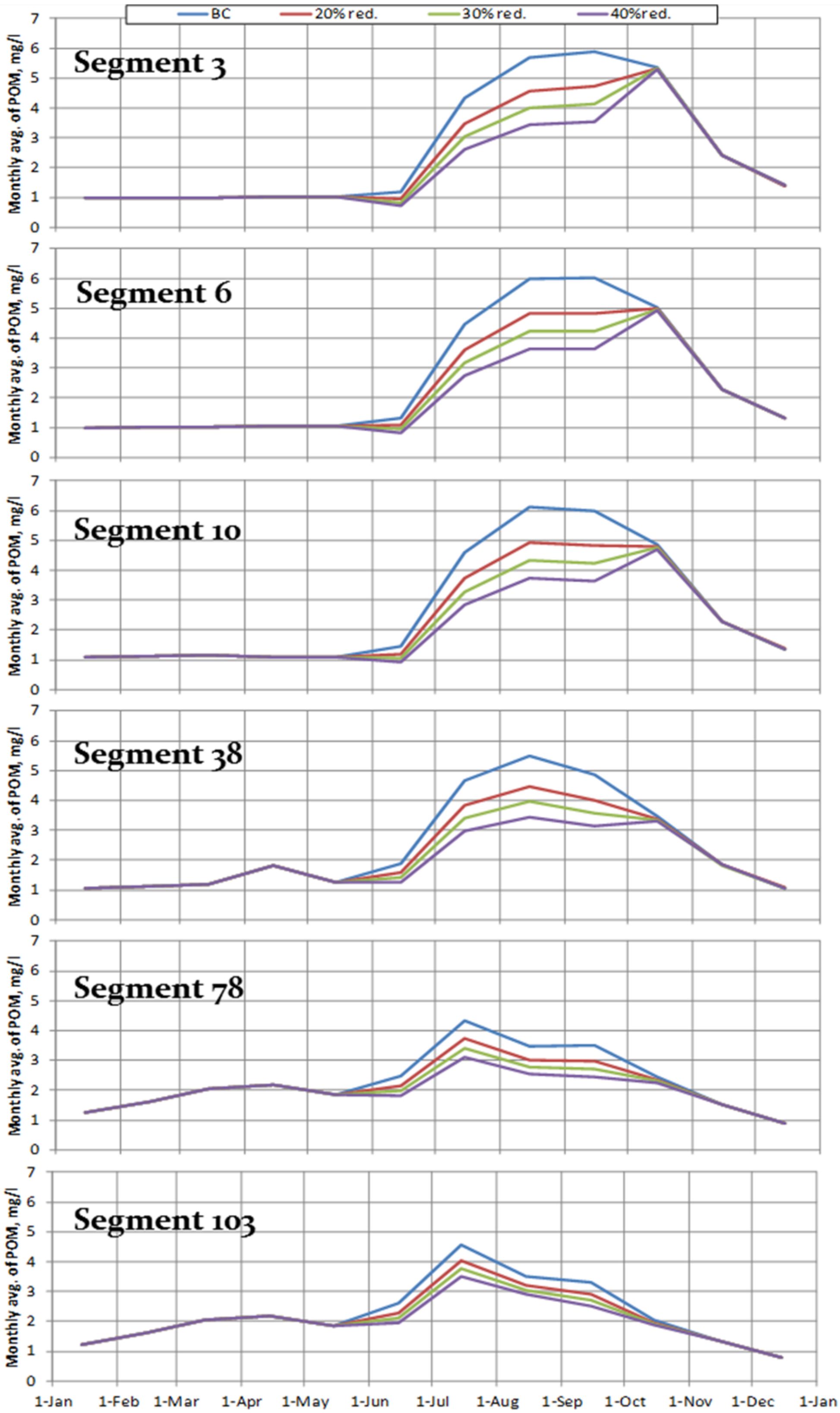


Figure 7. Monthly average POM concentrations at segments 3, 6, 10, 38, 78, and 103 for 2006. System operation extended from May through September.

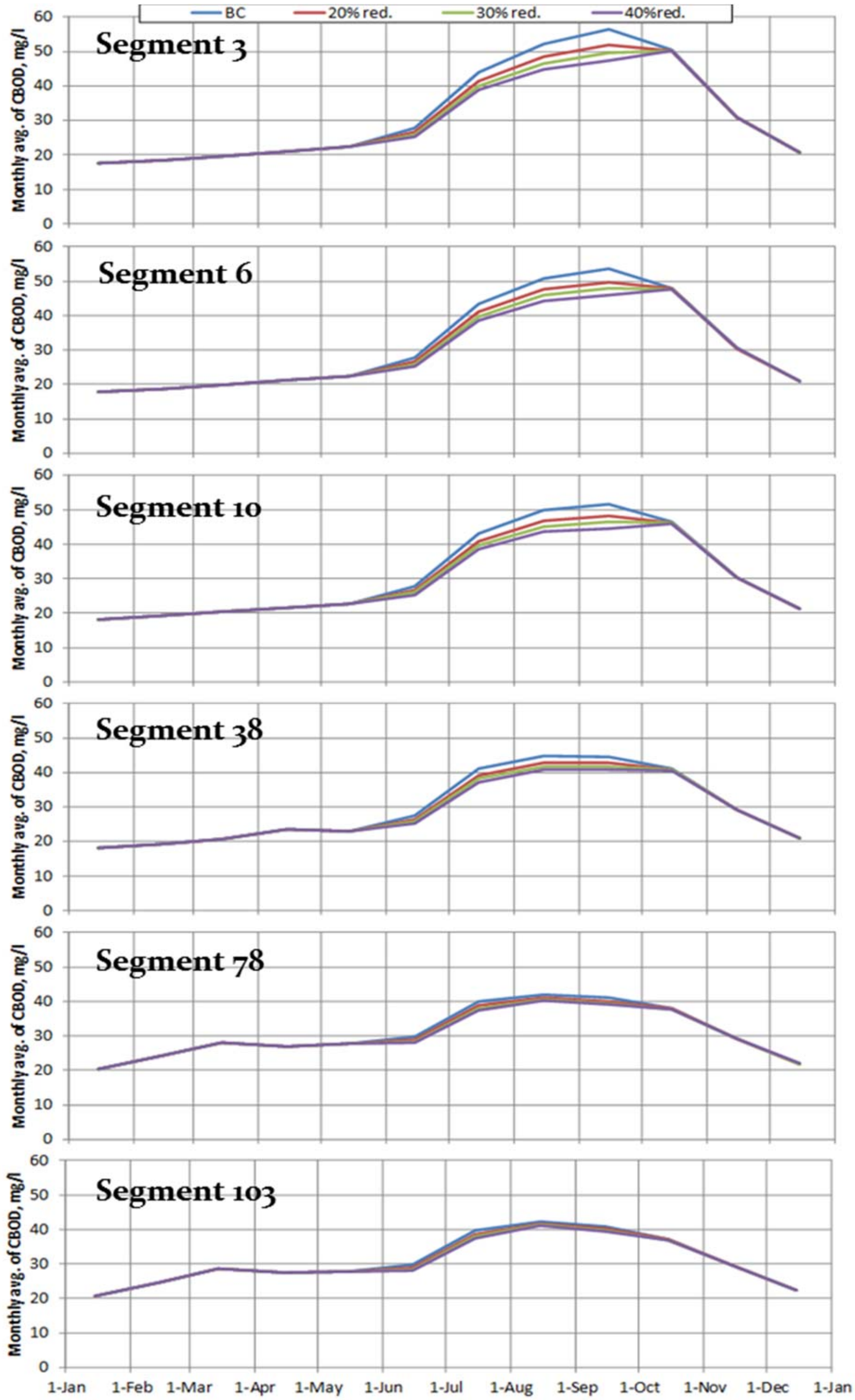


Figure 8. Monthly average $CBOD_u$ concentrations at segments 3, 6, 10, 38, 78, and 103 for 2006. System operation extended from May through September.

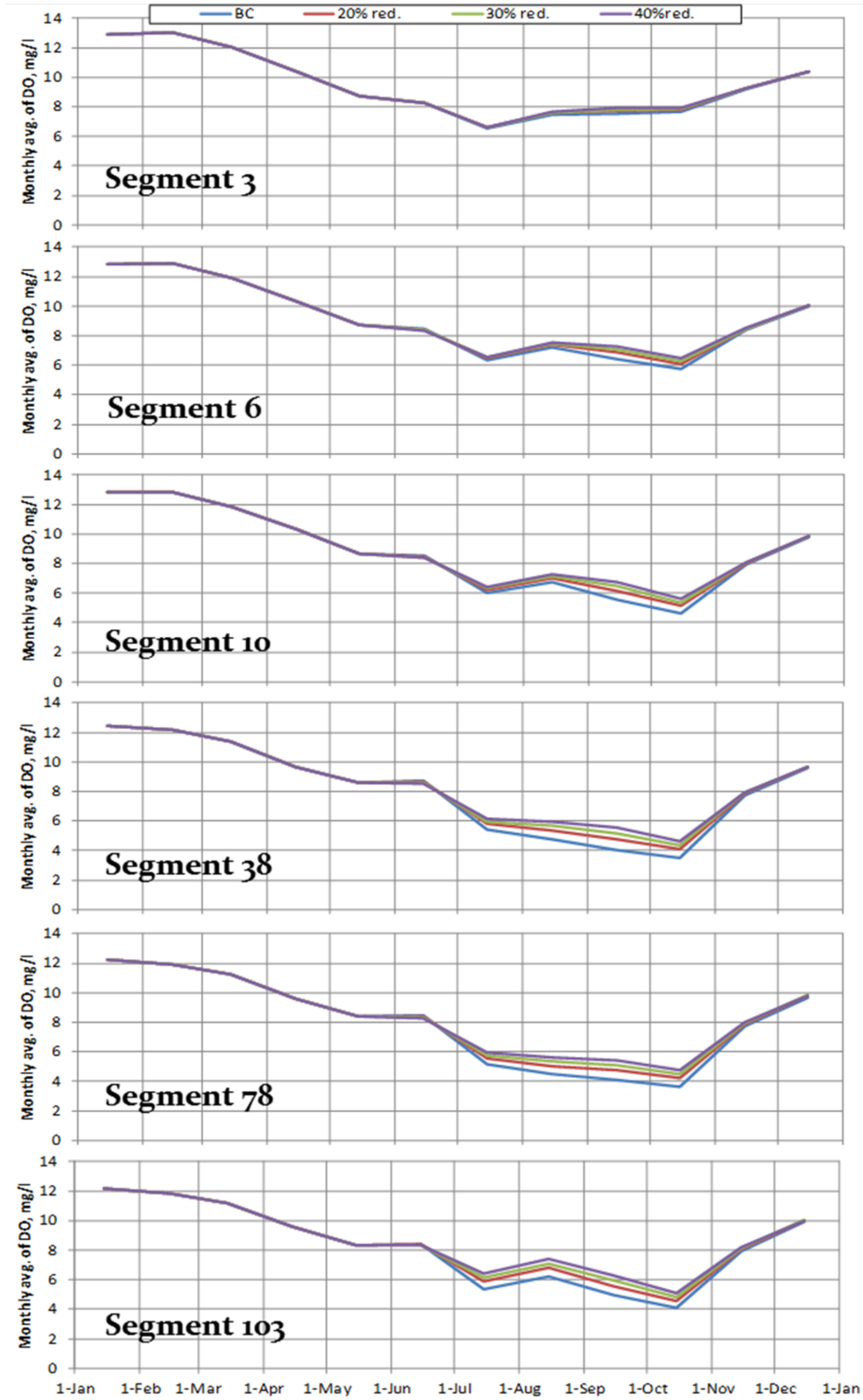


Figure 9. Monthly average DO concentrations at segments 3, 6, 10, 38, 78, and 103 for 2006. System operation extended from May through September.

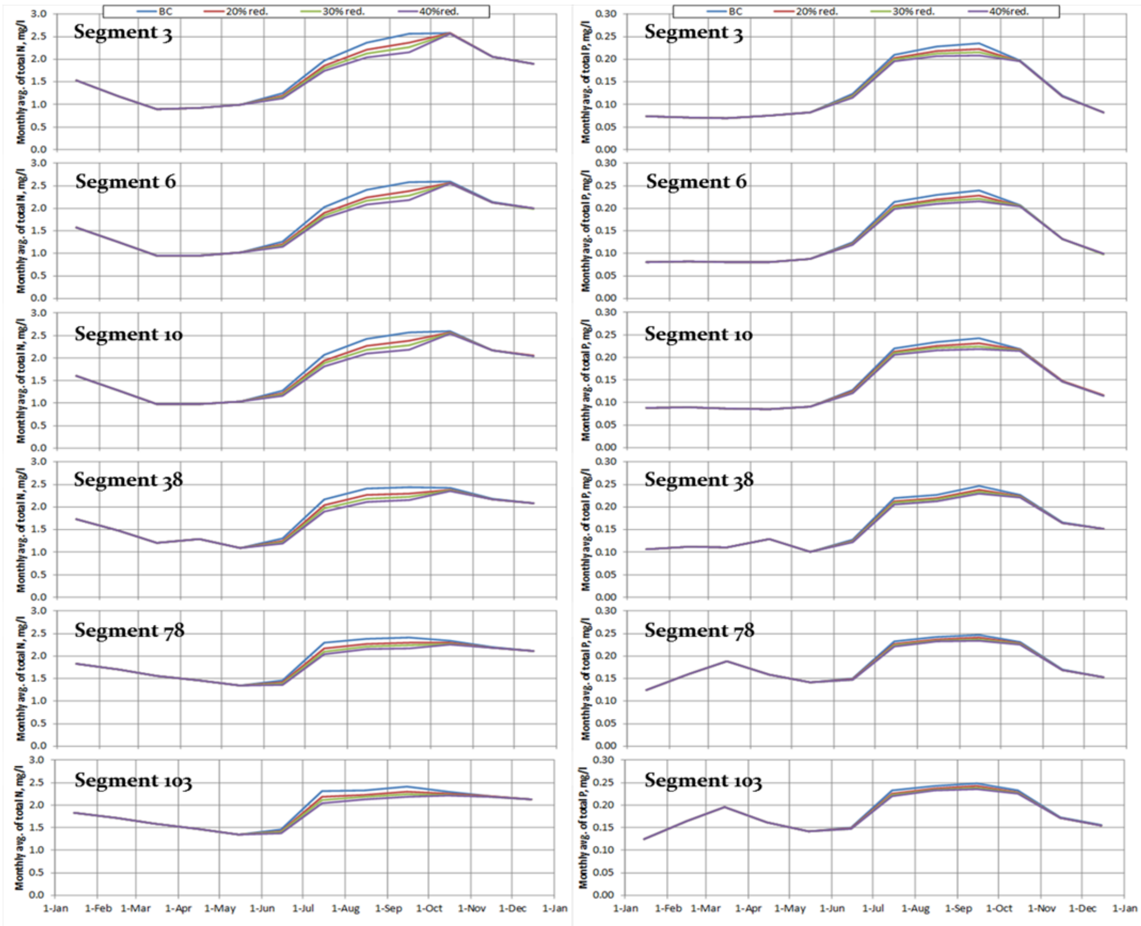


Figure 10. Monthly average TN (left) and TP (right) concentrations at segments 3, 6, 10, 38, 78, and 103 for 2006. System operation extended from May through September.

These findings suggest that while the reductions in carbon are notable, on the order of hundreds of tons, the attendant water quality response from these reductions is moderate. Locations in Keno Reservoir near Link River have the largest changes for all modeled constituents except DO. Increases in DO of over 1 mg/L in lower reaches of Keno Reservoir represent a notable improvement in water quality for the reservoir given the very low DO concentrations that can be observed in Keno Reservoir in some periods of the year. Similarly, the reductions in POM, $CBOD_u$, TN and TP are clear. However, even at the highest modeled POM removal rates (40 percent), these results suggest that other actions will likely be needed in addition to POM removal in order to achieve significant and lasting water quality improvements in Keno Reservoir and downstream Klamath River reaches.

5. Conclusion and Recommendations

Through the use of field data and conceptual designs of organic matter removal facilities employing CDS technology, estimates of costs for several conceptual design options were estimated and compared relative to each other. The four options were:

- Option 1: Eastside Forebay Facility with Fish Screen,
- Option 2: Eastside Forebay Facility without Fish Screen,
- Option 3: A-Canal Facility (without Fish Screen)
    - 3.1 Separator inflow of 550 cfs
    - 3.2 Separator inflow of 250 cfs
- Option 4: Eastside Forebay Facility with Fish Screen, no Pumping.

Key components of these options were the CDS separator units, fish screens, fish friendly pumps, water pumps, pipelines, electricity costs, and other factors. Costs for these components were developed and used in a 20 year life-cycle cost analysis to determine net present value for each alternative. Net present value figures were developed for different sump fractions: 10, 20, and 40 percent. A 40 percent sump fraction was found to have the highest removal efficiency in the field experiments, but processing larger amounts (i.e., larger sump fractions) of water for return and reuse in the A-Canal comes at the cost of larger and more numerous pumps, higher electricity costs, and a larger infrastructure to convey water. Using the net present value approach, a direct comparison could be made among the various options at various sump fractions.

These conceptual costs were then used with field data to estimate load reductions on a cost-per-ton basis. In this evaluation, particulate carbon data were used as a surrogate for organic matter. Using this metric for comparison, Option 2 was most cost-effective, largely because no fish screen was assumed. Option 4 was the second most cost-effective approach, largely because there were no pumps and associated electricity costs. Option 3 (3.1 and 3.2) both suffered because those options had restricted treatment capacities (550 cfs and 250 cfs versus 1,000 cfs for the other options), but still incurred high costs for the CDS units and to convey treated water below Link River Dam. The assumed location of the separator facility behind (downstream of) the A-Canal fish screen constrained the assumed treatment volumes to maintain delivery volumes to the A-Canal for agricultural use.

While these system options are conceptual, and costs were order of magnitude estimates for comparative assessment, the outcomes illustrate that:

- There are a variety of potential options that could arrive at similar treatment effectiveness outcomes, but at potentially quite different levels of cost-effectiveness.
- CDS units were a minor element of the overall estimated cost. Fish screens, fish friendly pumps, water pumps and electricity were the dominant cost drivers. High capacity pumps are expensive to operate from an electricity standpoint. High capacity fish-friendly pumps are expensive from a capital cost perspective.

- Life-cycle costs were important because electricity and operations and maintenance costs can play a key role in the potential costs of projects, particularly those designed to have a life-span of more than a few years.
- Different treatment levels (sump fractions) pose potential tradeoffs between reduction in mass loading and costs. Such information can be informative to decision makers by illustrating the range of potential treatment outcomes and approximate costs associated with a scaled-up organic matter removal system.

This project illustrates that detailed experiments can be designed using prototype systems to collect specific field data that can support conceptual design assessments. The experiments yield detailed information that can be used not only to estimate approximate system costs, but also to estimate associated reductions in water quality constituents and their associated per-unit-costs (e.g., dollars per ton). Further, field results can be coupled with existing water quality models to extend the analysis to water quality impacts under an assumed removal fraction. In this case, model studies suggest that particulate organic matter removal, while effective and having a direct impact on downstream water quality conditions, would not completely resolve water quality impairment in Keno Reservoir. Rather, this option would probably be most effective as one strategy in a multi-strategy approach to improving water quality in the reservoir and downstream Klamath River reaches.

While this report focuses on the basic technical elements and feasibility of reducing organic matter loading through the application of stormwater treatment technology with associated infrastructure costs, it is worth noting that the design components identified for this analysis could also be used to develop other options or facility layouts that could be explored, or elements of these concepts that could be applied in other manners or other venues.

5.1. Recommendations

Recommendations for potential follow-up to this study could further expand on the utility of the information for future decision-making, including:

- Explore options to reduce the particularly high-cost elements; specifically identify alternative designs or approaches to fish screening that lower cost, and identify cost-effective fish friendly pumps.
- Identify and assess potential separator entrainment impacts on juvenile fish to determine whether it may be possible to avoid the costs related to fish screening.
- Identify and assess other potential configurations, layouts, or locations that may be more effective in reducing POM loads or project costs.
- Identify and assess the potential nexus between organic matter reduction and other water quality improvement prescriptions that may be employed at Upper Klamath Lake. Evaluate possible timelines, milestones, or schedules to estimate likely project life-spans, reduction targets, and approximate costs to identify how this type of system may play a role as opportunities for improving water quality

are prioritized and strategies to improve water quality in the upper Klamath Basin are further developed.

6. References

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Appendices

Appendix A. Option Elements and Component Costs

A.1. Flow Rates

Options 1, 2, and 4 all use water from the Eastside forebay for treatment through a separator facility. Waters are diverted to the separator facility and the outflow includes "treated" water (with less organic matter) and a "sump" fraction (with increased organic matter). The treated water is discharged to Link River and the sump fraction is discharged into the A-Canal. For these options, the entire flow in the Eastside forebay – up to 1,200 cfs with current operations – could theoretically be treated. Flows in Link River range from a maximum of approximately 3,500 cfs to less than 350 cfs in June through September (inclusive).[10] For that period of record, the average daily flow in June through September was 1,061 cfs. Thus, a design flow of 1,000 cfs was assumed. The sump discharge flow rate (that fraction of flow with increased organic matter in it) would be piped to A-Canal and the volume would depend on the sump fraction (fraction of total facility inflow that goes to the sump). For the purposes of this discussion, three sump fractions were considered: 10 percent, 20 percent, and 40 percent. These correspond to removal efficiencies of 14.6, 20.6, and 24.6 percent, respectively. The amount of flow that would need to be piped to the A-Canal depends on the sump ratio (Table A-1).

Table A-1. Sump and treated flow based on a design flow of 1,000 cfs and a given sump fraction when there are no limits on required downstream A-Canal flows (Options 1, 2, and 4).

Design Flow (cfs)	Sump Fraction (%)	Sump Flow (cfs)	Treated Flow (cfs)
1,000	10	100	900
1,000	20	200	800
1,000	40	400	600

For Option 3, water would be withdrawn from the A-Canal. The treated water would be piped to Link River/Eastside forebay and the sump water would be returned to A-Canal. The maximum volume of water that could be treated In the A-Canal is 1,150 cfs (maximum allowable flow into the A-Canal at the head gates). The flow in the A-Canal downstream of the sump return flow must meet the downstream A-Canal demands. As a result, it is likely that not all of the inflow to the A-Canal could be treated. Based on data from USGS (Risley 2006), average flow in the A-Canal ranged from approximately 600 cfs to 900 cfs from June through September (for 1983 through 2004, inclusive).

The flows from A-Canal to Eastside forebay would depend on the sump fraction. A higher sump fraction would result in less flow to Link River. Overall, the treatment volume is constrained by downstream A-Canal demands in June through September (inclusive) (Table A-2).

[10] Based on the daily flow record at USGS Station 11507500 (http://waterdata.usgs.gov/nwis/sw) from January 1, 2000 through December 31, 2013 (inclusive). The date ranged selected was arbitrary, but covered the last fourteen years of data which is assumed to be representative.

Table A-2. Sump and treated flow based on a design flow of 1,000 cfs and a given sump fraction.

Option	Downstream Target	Sump Fraction (%)	Inflow (cfs)	Sump Flow (cfs)	Treated Flow (cfs)
3.1	900	10	610	60	550
3.1	900	20	690	140	550
3.1	900	40	920	370	550
3.2	600	10	275	30	250
3.2	600	20	310	65	250
3.2	600	40	420	170	250

A.2. Implementation Costs

While each of the four options presented above has different costs associated with them, they have similar elements (Table A-3). The net present value assumes an annual operating and maintenance cost equal to approximately 2 percent of the capital cost, a 20-year project life span, 3.5 percent discount rate, 2.0 percent inflation rate, and 12 cents per kilowatt hour power costs. A factor of safety of 1.35 was applied to total costs.

Table A-3. Net present value for the five design alternatives, with three different sump fractions.

Option	Net Present Value ($Million)		
Sump Fraction →	**10%**	**20%**	**40%**
1	$59.5	$63.8	$72.9
2	$27.6	$34.7	$52.3
3.1*	$37.8	$38.2	$41.9
3.2*	$20.3	$21.3	$22.5
4	$54.9	$55.4	$55.8

*Option 3.1 refers to Option 3 (CDS units located downstream of A-Canal fish screen), with a downstream A-Canal demand of 600 cfs. Option 3.2 refers to Option 3 (CDS units located downstream of A-Canal fish screen), with a downstream A-Canal demand of 900 cfs.

A.2.1. CDS Facility

The CDS facility consists of CDS units and stilling basins. The units serve to separate organic matter from the water and stilling basins serve as a collection facility from which pumped waters are drawn. These facilities also include erosion protection where waters are discharged from the CDS units to the river.

A.2.1.1. CDS Facility

The CDS facility will be composed of multiple CDS units designed to operate in parallel. Water diversions will occur from either Eastside forebay or A-Canal, depending on the particular option. The inflow is assumed to be divided among the active CDS units. The treated outflow from the separator will be collected in a stilling basin before being transported or released into Link River. For Options 1, 2, and 4, the treated water will be directly released to Link River. Option 3 requires that the treated water be transported from A-Canal to Link River via pipeline. The sump fraction is either pumped to A-Canal or released directly to A-Canal depending on the facility location (option).

The largest pre-cast CDS unit treats approximately 50 cfs. While CDS units can be cast in place, pre-cast units are assumed herein. The number of CDS units needed depends on the target volume of water to be treated. For Options 1, 2, and 4, the design flow rate is 1,000 cfs, which would require 20 units to be operated in parallel. For Option 3, the treatment volume is limited by the capacity of the A-Canal and the downstream flow requirements (Table A-2). The number of units could range from 6 to 19, depending on downstream flow requirements.

The CDS units were designed to treat stormwater runoff, which means they would not normally operate on a continuous basis. Additional units would be required so that while some units undergo maintenance, the system would still be capable of treating the design volume. Assuming a redundancy factor of 1.5, approximately 30 units would be required to treat the targeted volume (1,000 cfs) for Options 1, 2, and 4. For Option 3, between 9 and 20 units are needed. Each CDS unit is approximately 20 feet in diameter and 17 feet tall (final height varies).[11] Regardless of the location, the basic components of the CDS facility will be similar. The site would need to be prepared for construction and then construction and placement of the units would occur. Sufficient space would need to be trenched to cast and/or install the CDS facilities. Site facilities include walkways, fences, pads, and other infrastructure for safety, and maintenance of the units.

For Options 1, 2, and 4, the cost of installed CDS units is approximately $5.3 million (fabrication and installation costs are approximately $175,000 for each CDS unit). For Option 3, the cost of the CDS units ranges from $1.6 million to $5.1 million (Table A-4). Flow through the CDS facilities would be driven by the differential head provided by water surface elevation differences at Link River Dam and the A-Canal. Flow control facilities would be required to operate the desired units while others were undergoing maintenance or were off-line. Piping, valves, and associated infrastructure, as well as costs associated with permitting, site preparation, dewatering, were assumed to be 25 percent of the installed unit cost. Total CDS costs are shown in Table A-5.

Table A-4. CDS unit costs by option.

	CDS Unit Costs ($M)*		
Option/Sump Ratio (%)	**10%**	**20%**	**40%**
Options 1, 2, and 4	$5.3	$5.3	$5.3
Option 3.1	$3.5	$3.7	$5.1
Option 3.2	$1.6	$1.9	$2.5

[11] Discussions with a Contech design engineer indicated that the overall size of the unit (height) may be less than initially specified if the system does not need to store the sump fraction. The units are designed to treat stormwater and to store up to two years' worth of sediment. If storage is not needed, then a sump vault may not be needed. Alternatively, the sump vault may be used as a stilling basin for the sump water prior to transport to the release point.

Table A-5. Total estimated CDS unit costs plus infrastructure costs by option.

	CDS Unit Costs ($M)*		
Option/Sump Ratio (%)	**10%**	**20%**	**40%**
Options 1, 2, and 4	$1.33	$1.33	$1.33
Option 3.1	$0.88	$0.93	$1.28
Option 3.2	$0.40	$0.48	$0.63

A.2.1.2. Stilling Basins

The treated water and/or sump waters from the CDS units would need to be collected prior to being released to Link River or the A-Canal (depending on the design configuration). The purpose of the stilling basin would be to dissipate the energy of the outflow. Large storage volumes would not be needed (e.g., the basin could be sized to retain water for only a brief period), and the size of the stilling basin would depend on the volume of water that would need to be stored.

The design of the CDS units includes a sump storage compartment at the base of the CDS unit. It may be possible to modify this storage basin to act as the stilling basin for the sump flows. If this is possible, then an additional stilling basin for the sump flows may not be needed. A stilling basin for the treated water outflows would be needed (i.e., there is no treated water storage compartment built into the CDS unit).

For Options 1, 2, and 4, the sump flows ranged from 100 to 400 cfs and the treated flow volumes range from 600 cfs to 900 cfs, depending on the sump fraction. For Option 3, the sump flows range from 60 to 370 cfs and the treated flow volume is approximately 550 cfs. If the stilling basins had a residence time of 10 seconds, then the sump basin would range from 20 to 150 cubic yards, while the treated flow basin would range from 200 to 350 cubic yards. A single basin or multiple basins could be constructed to hold portions of the flow (e.g., three basins could be constructed each to hold the discharge from 10 individual CFS units). The basins could be open or covered.

Construction would require trenching, grading and support, casting of the basin or installation of a pre-fabricated basin, plus walkways for maintenance, fencing for security, and any other associated infrastructure. Trenching costs between $5 and $15 per cubic yard when using an excavator (RSMeans, page 596) in sand, loam, clay, or gravel. Costs vary depending on the depth of the trench, the size of the excavator, and the material being excavated. The A-Canal fish screen excavated rock material at a cost of approximately $32 per cubic yard (in 2014 dollars). Depending on the location(s) of the stilling basins, dewatering may be needed prior to trenching. Dewatering costs range from $10 to $16 per cubic yard (RSMeans, page 598). Additionally, there will be costs associated with hauling the excavated material away from the site (ranging from $3 to $15 per loose cubic yard). Overall, the trenching, dewatering, and haul away could cost from $18 to $63 per cubic yard. Site preparation was assumed covered in CDS unit costs (i.e., included in Table A-5). The basins would need to be lined (e.g., concrete) or a pre-fabricated basin would need to be added. Concrete costs on the order of $90 per cubic yard, but prices vary depending on the type of concrete. Fencing costs approximately $20 to $200 per linear foot, depending on the type, gauge, and size. If the basins are to be covered, metal floor grating ranges from $20 to $50 per square foot depending on material (e.g., aluminum versus steel), size, and thickness.

Total costs for the sump and treated water basins range from about $60,000 to $210,000[12] (Table A-6).

Table A-6. Stilling basin costs ($M).

	Stilling Basin Costs ($M)*		
Option/Sump Ratio (%)	**10%**	**20%**	**40%**
Options 1, 2, and 4	$0.21	$0.21	$0.21
Option 3.1	$0.06	$0.07	$0.09
Option 3.2	$0.13	$0.15	$0.20

A.2.2. Fish Screen

In 2003, Reclamation constructed a fish screen facility at the entrance to the A-Canal. This facility included a fish screen built into the A-Canal, a fish collection/transport facility, a pump facility, a pressure pipeline to convey water and fish to the middle of the Link River, and a gravity fed pipeline to convey water and fish to the Link River below Link River Dam. Many of these facilities would be needed for any of the four design options proposed (Table A-7).

Table A-7. Reclamation A-Canal fish screen elements needed for Options 1, 2, 3, and 4.

	Option 1	Option 2	Option 3	Option 4
Fish Screen	Yes	-	-	Yes
Fish Collection/Transport Facility	Yes	Yes	-	Yes
Pump Station	Yes	Yes	Yes	Yes
Pressure Pipe	Yes	Potentially	-	-
Gravity Pipe	-	Potentially	Yes	Yes

Installation of the fish screen at the A-Canal was a multi-step process. The steps and components of the A-Canal fish screen construction were documented by Reclamation and the major steps are outlined below (note that this is not a comprehensive list, but is provided for illustrative purposes only).

1. Site studies and fish screen design, permitting
2. Cofferdam construction for site dewatering
3. Site preparation
4. Fish screen installation
5. Trash rack installation

[12] This estimate assumes square basins, sized to hold approximately 10seconds of maximum discharge. The trenching would occur in primarily rock-based soils (using the A-Canal Fish Screen cost estimate). The concrete is assumed to be approximately 12inches thick.

6. Power (incidental power on sight for basic lighting, monitoring, lifts/winches, etc.)
7. Building (to house any operations and/or maintenance related elements of the screen)
8. Basic infrastructure and supplies (safety fencing and facilities, access pathways, storage areas, maintenance equipment, etc.)

For Options 1 and 4, a fish screen is proposed to be installed near the head of the Eastside forebay to prevent the entrainment of fish into the separators. The fish screen would likely be similar in design and size to the facility at the head of the A-Canal. A fish collected by the screening system is assumed to be released into Link River downstream of the Eastside forebay. The cost of designing and constructing the fish screen at the A-Canal was approximately $15 million in 2003 (Reclamation 2009). Adjusting for the cost of inflation, the cost of a fish screen similar to the one at A-Canal would be on the order of $19 million (in 2014 dollars).[13]

A.2.3. Water Conveyance Facilities

Water conveyance facilities include pipes and tunnels. Included in the conveyance facility costs are the discharge facilities costs, which consist of properly designed and placed riprap to control erosion.

For Options 1 and 2, the sump flows are conveyed from the Eastside forebay location to the head of the A-Canal, requiring a pipe and a pumping station. The treated flows would be discharged directly into Link River downstream of Link River dam. For Option 3, the treated waters are pumped from the separator system site at the A-Canal to a conveyance that ultimately discharges near the Eastside forebay. The sump flows would be discharged into the A-Canal. Under Option 4, sump water would be conveyed via gravity through a tunnel from the Eastside forebay to the A-Canal when it emerges in Klamath Falls. The treated flows would be discharged directly into Link River or the Eastside forebay, and no pumping is necessary for this alternative. The pipeline, tunnel, and discharge facility cost estimates are outlined below.

A.2.3.1. Pipes

The Eastside forebay tunnel and the A-Canal are approximately 0.5 mile apart (along the access road). From the start of the A-Canal to downstream of the fish screen is another 0.15 miles. Depending on whether the transport pipe is buried along the access road, routed directly, or some other configuration, as much as 0.5 mile of pipe could be needed. For Options 1, 3, and 4, the pipe could be pressurized because only water (treated or sump) would be transported. In Option 2, the transported water includes fish screened from the Eastside forebay. Pressurized pipe is still possible, but additional investigation into the maximum allowable pressure and exposure time for fish, among other things,

[13] The United States Bureau of Labor Statistics' Consumer Price Index Inflation Calculator uses 1.292934783 percent as the adjustment between 2003 and 2014. URL: http://www.bls.gov/data/inflation_calculator.htm

would need to occur. Option 3 could also make use of an open channel, but additional analysis would be required. Option 4 assumed a tunnel (lined), and thus, no piping costs.

The cost of the pipe installation will partially depend on the size of the pipe. For Options 1 and 2, only the sump fraction will need to be conveyed (up to 400 cfs, assuming 1,000 cfs of inflow and a 40 percent ratio). For Option 3, the entire volume of treated flow will need to be conveyed (up to 550 cfs, assuming a downstream target of 600 cfs and a 40 percent sump ratio). The type of pipe will also need to be determined (i.e., concrete, steel, plastic, etc.).

Cost of piping depends on the size of the pipe (diameter), thickness of the pipe wall, and pipe material (e.g., high-density polyethylene (HDPE), corrugated metal pipe (CMP), reinforced concrete pipe (RCP), steel, etc.) (Table A-8). Costs range from less than $100 per linear foot to over $300 per linear foot (Rockville 2010).

There is approximately 7 feet of elevation difference between A-Canal and the Eastside forebay. Assuming a distance of approximately 2,500 feet, the slope would be approximately 0.0028 feet per foot. Using the Hazen-Williams equation to estimate velocity and flow for a given pipe (assuming full flow), a 36-inch pipe could transport approximately 45 cfs of flow.[14] A 48-inch pipe could transport approximately 100 cfs. To transport 400 cfs, the pipe would need to be approximately 84inches in diameter. The largest proposed flow to transport between the A-Canal and the Eastside forebay is 550 cfs (treated flow), which would require a pipe of approximately 96inches in diameter. HDPE pipe may not be generally available in sizes greater than 63inches, indicating that larger diameter pipes may require alternative material (e.g., concrete) or special order/manufacturing of larger pipe. Alternatively, multiple pipes could be used to convey the target volume of water.

Table A-8. Estimated full pipe flow using the Hazen-Williams equation (friction factor is 150 for HDPE, 120 for CMP, and 100 for RCP, slope = 0.0028).

Pipe Diameter (in)	Estimated Flow (cfs) (To Nearest 5 cfs)	Approximate Pipe Cost ($/ft)[1]		
		HDPE	CMP	RCP
36	35-50	87	80	140
48	70-105	109	130	200
60	125-190	-	170	250
72	200-300	-	250	300
84	300-455	-	375	-
96	430-645	-	-	-
108	585-880	-	-	-
120	770-1,160	-	-	-

[1]Costs based on Standard Prices for Cost Estimating, December 2010, City of Rockville, MD, Department of Public Works.

[14] Assuming a 0.0028 slope and 140 friction factor.

Overall, the average cost of piping would be on the order of $700,000 to $2,500,000, depending on the number of pipes, pipe size, and material used (Table A-9). This does not include the cost of any special joints, supports, or other associated infrastructure components.

Table A-9. Range of pipe costs ($M).

	Range of Pipe Costs ($M)*		
Option/Sump Ratio (%)	**10%**	**20%**	**40%**
Options 1, 2, and 4	$0.3 - $1.4	$0.5 - $2.4	$0.9 - $4.5
Option 3.1	$1.2 - $5.9	$1.2 - $5.9	$1.2 - $5.9
Option 3.2	$0.6 - $2.8	$0.6 - $2.8	$0.6 - $2.8

*These costs do not include any associated with joints, supports, site preparation, or other related activities.

Installation costs vary depending on whether the pipe is laid above or below ground. For Options 1 and 2, the pipe is assumed to be constructed below grade. At a minimum, this would involve construction site preparation, trenching and installation, backfilling, and then site restoration and clean-up. For the A-Canal Fish Screen Project, the cost of dewatering and rock excavation was approximately $700,000[15]. There would be other costs associated with laying the pipe (e.g., backfill, supports, etc.), and a factor of 1.25 was applied to cover such expenses, bringing the total to $875,000.

A.2.3.2. Tunnels

Option 4 includes a tunnel that would convey sump discharge waters from the CDS facility to the A-Canal at a downstream location to be dug under existing portions of Klamath Falls. A straight line tunnel from the Eastside forebay to where the A-Canal emerges in Klamath Falls would be approximately 3,800 feet (0.72 miles). Drilling and blasting costs range from $100 to $350 per cubic yard depending on the material, the location of the drilling/blasting, and the amount of material to be removed. The size of the tunnel depends on the volume of water to be transported. Costs to drill/blast a tunnel from the Eastside forebay to the A-Canal discharge location were estimated to range from approximately $1,300,000 to $1,700,000 (RSMeans, section 31-23).

A.2.3.3. Discharge Facility

The discharge of sump flow that will be released into the A-Canal will need to be configured so that the discharge velocities do not damage the A-Canal. The location where the discharge source enters the canal would need to be designed to minimize erosion, avoid modifying channel capacities, and minimize maintenance. Riprap or similar bank protection could be added to further protect the canal on the side opposite of where the sump flow enters.

Riprap, commonly used for bank protection, costs between $35 and $125 per square yard (RSMeans, page 612). The A-Canal Fish Screen project used 18” riprap. The costs will depend on the size of the area covered in riprap, but are estimated to be approximately $21,000.

[15] *Ibid*.

A.2.4. Pumping Facilities

Pumping facilities vary by option and include water pumps, fish friendly pumps, pump control facilities, and electricity costs. Water pumps move treated and sump flows that do not potentially include fish, while fish friendly pumps can convey the appropriate life-stage of fish (e.g., juvenile suckers) with little or no harm. Included in the fish friendly pump costs is associated infrastructure to effectively implement and operate such machinery.

A.2.4.1. Water Pumps

Pumps will be needed to transport water between Eastside forebay and the A-Canal depending on the option. For Option 1, the sump volume will need to be transported from Eastside forebay to the A-Canal. The discharge elevation for the CDS units located at Eastside forebay is at a lower elevation than the A-Canal, so the water would need to be pumped. For Option 3, the treated water will need to be transported from A-Canal to Eastside forebay. While the A-Canal is higher in elevation of Link River below the Eastside forebay, the CDS system will be below grade, so the treated water would need to be pumped to the vicinity of the Eastside forebay. Pump costs are estimated to range from $300,000 to over $1,800,000 depending on the option and type.

To convey water without fish, an 825 horsepower centrifugal pump rated at 52,100 gallons per minute (116 cfs) was assumed. To accommodate higher flows, multiple pumps would be necessary. Cost per pump and motor is $95,000 (pers. comm. Dominic Piazza, Machinery and Equipment Co., Inc., San Francisco, CA). Solid state reduced voltage starter and clutch controls on a per unit basis is $40,000 (pers. comm. Steve Webber, Siemens Industry, Inc.). Assuming a 1.50 factor on delivery of power, appurtenant materials, and installation, total pump cost per 100 cfs was estimated as $202,500. Pump costs for all options associated with 10, 20, and 40 percent sump ratios are shown in Table A-10.

A.2.4.2. Fish Friendly Pumps

Fish friendly pump (Option 2) costs vary depending on the volume of water conveyed. Reclamation estimated the cost of a 28-inch Wemco hidrostal fish friendly pump to be approximately $1.3 million (in 2014 dollars) (Reclamation, 2011). The 28-inch pump was able to pump approximately 40 cfs. Depending on the volume of water necessary to pump from Eastside forebay to the A-Canal, up to ten pumps may be required (maximum sump flow is 400 cfs). Fish friendly pump costs range from $4.0 million to $13.2 million depending on the volume to be pumped (Table A-10). This does not include the cost of associated infrastructure or parts (e.g., joints, inflow piping, etc.). Electricity costs are estimated separately.

Table A-10. Water and fish friendly pump costs ($M).

	Pump Costs ($M)*		
Option/Sump Ratio (%)	**10%**	**20%**	**40%**

Option 1 (Sump to A-Canal)	$0.2	$0.4	$0.8
Options 2 (Fish Friendly)	$4.0	$6.6	$13.2
Option 3.1 (Treated to Eastside)	$1.2	$1.2	$1.2
Option 3.2 (Treated to Eastside)	$0.6	$0.6	$0.6
Option 4 (Tunnel)	n/a	n/a	n/a

*These costs do not include any associated with permitting, site preparation, or other related activities.

A.2.4.3. Pump Control Facility

A control structure to house the pump controls, monitoring equipment, and other electrical equipment will be needed at the site of the CDS units. This could be a pre-fabricated facility delivered to the site. Once installed (or constructed), the structure would need to have a reliable power supply for the monitoring and control equipment, along with a climate control system (to prevent overheating or freezing of the electrical system). The A-Canal Fish Screen project included a pump control building on site (two stories). The cost was approximately $560,000 (in 2014 dollars). A factor of 1.25 was included to cover costs of site preparation, permitting, grading/leveling, basic controls and monitoring equipment, for a total cost of $700,000 (in 2014 dollars).

A.2.4.4. Electricity Costs

While several aspects of a complete system will require power for basic operation and safety, the electricity use by pumps was separated out because of the potentially notable expense. The amount of electricity required over the course of a year depends on the type and size of the pumps and the amount of flow that would be pumped (Table A-11). The pumps are assumed to be running from June through September (inclusive). The cost of electricity is estimated to be approximately $0.12 per kilowatt hour.

Table A-11. Estimated electrical costs for pumping ($M).

	Electrical Costs for Pumping ($M/yr)		
Option/Sump Ratio (%)	**10%**	**20%**	**40%**
Option 1 (Sump to A-Canal)	$0.04	$0.07	$0.14
Options 2 (Fish Friendly)	$0.01	$0.02	$0.03
Option 3.1 (Treated to Eastside)	$0.19	$0.19	$0.19
Option 3.2 (Treated to Eastside)	$0.09	$0.09	$0.09
Option 4 (Tunnel)	-	-	-

*These estimates do not include power requirements for non-pump equipment.

A.3. Cost Summary for Each Design Option

The estimated cost associated with each design option is presented in Table A-12 through Table A-16.

Table A-12. Estimated costs of organic matter removal project elements: Option 1

Element[1]	Component	Purpose	Options	Estimated Capital Cost		
				10%	**20%**	**40%**
Separator Unit	CDS Units[2]	Remove algae and other particulate organic matter from the water.	All	$6,600,000	$6,600,000	$6,600,000
	Stilling Basins[3]	Reduce local CDS outflow velocities prior to transport to the discharge locations.	All	$220,000	$220,000	$220,000
Fish Screen	Fish Screen[4]	Prevent entrainment of fish into CDS units.	1, 4	$19,000,000	$19,000,000	$19,000,000
Conveyance	Piping[5]	Convey water from CDS units to discharge locations.	All	$1,790,000	$2,190,000	$3,290,000
	Tunnel	Option 4 proposes a tunnel to convey water from the CDS units to A-Canal downstream of the underground section through the city of Klamath Falls.	4	n/a	m/a	n/a
	Discharge Facility[6]	To prevent scour or damage to the bank at the discharge location.	All	$21,000	$21,000	$21,000
Pumping	Pumps[7]	Convey water from the CDS units to the discharge location.	All	$210,000	$410,000	$810,000
	Fish Friendly Pumps[8]	Fish Collection/Transport Facility to transport water and fish from CDS units at Eastside Forebay to A-Canal.	2	n/a	n/a	n/a
	Control Facility[9]	A housing unit to contain the pump controls and monitoring equipment.	All	$560,000	$560,000	$560,000
	Power Require-ments[10]	Electrical cost of powering the pumps (per year).	All	$216,000	$432,000	$865,000

[1]Not all elements are needed for all options. Capital costs presented herein represent a conservative cost estimate of infrastructure elements (pumps, CDS, units, fish screens, etc.) based on current information. Some costs include rough estimates for associated labor, but specific, local labor costs were not included. Final costs for each element may be higher or lower than estimated, but overall project costs are expected to be slightly higher when site preparation, permitting, and other associated costs are included. More comprehensive cost details presented in Appendix.
[2]Cost is based on 30 pre-cast units, constructed by Contech (pers. comm. John Pedrick). Basic installation costs are included, but for difficult locations, installation costs would increase. Cost do not include associated safety infrastructure that may be needed (e.g., overhead walkways, fencing, etc.).
[3]Includes the estimated cost for trenching, dewatering, hauling, lining, and fencing. Does not include costs for site preparation, leveling/grading, permitting, etc. Basin sizing was based on the maximum storage volume needed to hold 10 seconds of outflow from the CDS units (treated and sump combined). A 14-ft deep square basin was assumed. The concrete lining was assumed to be 12inches thick with appropriate reinforcement.
[4]Costs are based on the cost of installing the fish screen and associated elements at A-Canal in 2003 (adjusted to 2014 dollars (ratio of 1.293)) (Reclamation, 2005).
[5]Piping costs are estimated based on the costs of HDPE, metal (CMP), and concrete (RCP) pipe from the Department of Public Works, City of Rockville, MD (adjusted to 2014 dollars) (Rockville, 2010). Piping costs are $1.3 million dollars. Included herein are trenching costs of $875,000 based on the trenching associated with the A-Canal fish screen, where a 36” pipe extended from A-Canal to Eastside forebay. Total cost estimated at $2.175 million dollars.
[6]Riprap costs are based on estimated cubic yard costs (RSMeans 2013) and A-Canal fish screen project (Reclamation, 2005).
[7]Based on the cost of a 200 cfs pumping facility. Sump flows range from 100 cfs to 350 cfs, indicating that one or two large pumping facilities may be required.
[8]Cost of fish friendly screw pumps are based on 2011 cost estimates published by Reclamation for the Tracy Pumping Plant project. The cost was $5,000,000 (in 2011 dollars) for 4, 28-inch (40 cfs) Wemco Hidrostal pumps (Reclamation, 2011).
[9]Control Facility/building cost is based on the cost of the control building installed for the A-Canal fish screen project.
[10]Pumping costs based on rate of $0.12/kWh and size of the pumps. Electrical costs are not adjusted per year.
* Unless otherwise noted, costs are based on construction information from RS Means (2013, 2014)

Table A-13. Estimated costs of organic matter removal project elements: Option 2

Element[1]	Component	Purpose	Options	Estimated Capital Cost		
				10%	20%	40%
Separator Unit	CDS Units[2]	Remove algae and other particulate organic matter from the water.	All	$6,600,000	$6,600,000	$6, 600,000
	Stilling Basins[3]	Reduce local CDS outflow velocities prior to transport to the discharge locations.	All	$220,000	$220,000	$220,000
Fish Screen	Fish Screen[4]	Prevent entrainment of fish into CDS units.	1, 4	n/a	n/a	n/a
Conveyance	Piping[5]	Convey water from CDS units to discharge locations.	All	$1,790,000	$2,190,000	$3,290,000
	Tunnel	Option 4 proposes a tunnel to convey water from the CDS units to A-Canal downstream of the underground section through the city of Klamath Falls.	4	n/a	n/a	n/a
	Discharge Facility[6]	To prevent scour or damage to the bank at the discharge location.	All	$21,000	$21,000	$21,000
Pumping	Pumps[7]	Convey water from the CDS units to the discharge location.	All	n/a	n/a	n/a
	Fish Friendly Pumps[8]	Fish Collection/Transport Facility to transport water and fish from CDS units at Eastside Forebay to A-Canal.	2	$4,000,000	$6,700,000	$13,300,000
	Control Facility[9]	A housing unit to contain the pump controls and monitoring equipment.	All	$560,000	$560,000	$560,000
	Power Require-ments[10]	Electrical cost of powering the pumps (per year).	All	$98,000	$164,000	$328,000

*See Table A-12 for footnote descriptions.

Table A-14. Estimated costs of organic matter removal project elements: Option 3.1 (550 cfs)

Element[1]	Component	Purpose	Options	Estimated Capital Cost		
				10%	20%	40%
Separator Unit	CDS Units[2]	Remove algae and other particulate organic matter from the water.	All	$4,400,000	$4,600,000	$6,400,000
	Stilling Basins[3]	Reduce local CDS outflow velocities prior to transport to the discharge locations.	All	$140,000	$150,000	$200,000
Fish Screen	Fish Screen[4]	Prevent entrainment of fish into CDS units.	1, 4	n/a	n/a	n/a
Conveyance	Piping[5]	Convey water from CDS units to discharge locations.	All	$3,390,000	$3,390,000	$3,390,000
	Tunnel	Option 4 proposes a tunnel to convey water from the CDS units to A-Canal downstream of the underground section through the city of Klamath Falls.	4	n/a	n/a	n/a
	Discharge Facility[6]	To prevent scour or damage to the bank at the discharge location.	All	$21,000	$21,000	$21,000
Pumping	Pumps[7]	Convey water from the CDS units to the discharge location.	All	$1,220,000	$1,220,000	$1,220,000
	Fish Friendly Pumps[8]	Fish Collection/Transport Facility to transport water and fish from CDS units at Eastside Forebay to A-Canal.	2	n/a	n/a	n/a
	Control Facility[9]	A housing unit to contain the pump controls and monitoring equipment.	All	$560,000	$560,000	$560,000
	Power Require-ments[10]	Electrical cost of powering the pumps (per year).	All	$1,297,000	$1,297,000	$1,297,000

*See Table A-12 for footnote descriptions.

Table A-15. Estimated costs of organic matter removal project elements: Option 3.2 (250 cfs)

Element[1]	Component	Purpose	Options	Estimated Capital Cost		
				10%	20%	40%
Separator Unit	CDS Units[2]	Remove algae and other particulate organic matter from the water.	All	$2,000,000	$2,500,000	$3100,000
	Stilling Basins[3]	Reduce local CDS outflow velocities prior to transport to the discharge locations.	All	$70,000	$80,000	$100,000
Fish Screen	Fish Screen[4]	Prevent entrainment of fish into CDS units.	1, 4	n/a	n/a	n/a
Conveyance	Piping[5]	Convey water from CDS units to discharge locations.	All	$2,290,000	$2,290,000	$2,290,000
	Tunnel	Option 4 proposes a tunnel to convey water from the CDS units to A-Canal downstream of the underground section through the city of Klamath Falls.	4	n/a	n/a	n/a
	Discharge Facility[6]	To prevent scour or damage to the bank at the discharge location.	All	$21,000	$21,000	$21,000
Pumping	Pumps[7]	Convey water from the CDS units to the discharge location.	All	$610,000	$610,000	$610,000
	Fish Friendly Pumps[8]	Fish Collection/Transport Facility to transport water and fish from CDS units at Eastside Forebay to A-Canal.	2	n/a	n/a	n/a
	Control Facility[9]	A housing unit to contain the pump controls and monitoring equipment.	All	$560,000	$560,000	$560,000
	Power Require-ments[10]	Electrical cost of powering the pumps (per year).	All	$648,000	$648,000	$648,000

*See Table A-12 for footnote descriptions.

Table A-16. Estimated costs of organic matter removal project elements: Option 4

Element[1]	Component	Purpose	Options	Estimated Capital Cost		
				10%	20%	40%
Separator Unit	CDS Units[2]	Remove algae and other particulate organic matter from the water.	All	$6,600,000	$6,600,000	$6,600,000
	Stilling Basins[3]	Reduce local CDS outflow velocities prior to transport to the discharge locations.	All	$220,000	$220,000	$220,000
Fish Screen	Fish Screen[4]	Prevent entrainment of fish into CDS units.	1, 4	$19,000,000	$19,000,000	$19,000,000
Conveyance	Piping[5]	Convey water from CDS units to discharge locations.	All	n/a	n/a	n/a
	Tunnel	Option 4 proposes a tunnel to convey water from the CDS units to A-Canal downstream of the underground section through the city of Klamath Falls.	4	$1,260,000	$1,490,000	$1,700,000
	Discharge Facility[6]	To prevent scour or damage to the bank at the discharge location.	All	$21,000	$21,000	$21,000
Pumping	Pumps[7]	Convey water from the CDS units to the discharge location.	All	n/a	n/a	n/a
	Fish Friendly Pumps[8]	Fish Collection/Transport Facility to transport water and fish from CDS units at Eastside Forebay to A-Canal.	2	n/a	n/a	n/a
	Control Facility[9]	A housing unit to contain the pump controls and monitoring equipment.	All	$560,000	$560,000	$560,000
	Power Require-ments[10]	Electrical cost of powering the pumps (per year).	All	n/a	n/a	n/a

*See Table A-12 for footnote descriptions.

Appendix B. Net Present Value Spreadsheets

Life-cycle costs for each option assuming a 20 percent sump fraction are included herein. 10 percent and 40 percent calculations are similar, but not included.

PacifiCorp - Organic Matter Removal Project

Specify Option (1, 2, 3, or 4)	1	
Specify Operations and Maintenance (O&M) Percentage	2%	%
CDS Unit Location:	Eastside Bypass	
Sump Water Discharge Location:	A-Canal, Downstream of Fish Screen	

Model Assumptions:

Cost Per Kilowatt-Hour of Electricity [1]	$ 0.120	
Duration of Project	20	yrs
Estimated Discount Rate [2]	3.5%	%
Annual Rate of Inflation [3]	2%	%
Salvage Value	$ -	
Safety Factor	1.35	

Potential Project Elements and Costs

Element	Cost (2014)	Included or Not Included
CDS Units	$ 6,600,000	Included
Stilling Basins	$ 220,000	Included
Fish Screen	$19,000,000	Included
Piping	$ 1,300,000	Included
Trenching	$ 890,000	Included
Canal	$ -	n/a
Tunnelling	$ -	n/a
Fish Friendly Pumps	$ -	n/a
Pumps	$ 410,000	Included
Control Facility	$ 560,000	Included
Discharge Facility	$ 21,000	Included
Power Requirement for Pumps:	3,602,625	kWh/yr

Project Duration and Costs

Expected Life (Starting January 1, 2015)	20	yrs
Capital and Design Costs for the System	$39,151,350	*(2014 dollars)*
Annual O&M	$ 1,057,086	*(2014 dollars)*
Electricity Usage for Project	$ 432,315	*(2014 dollars)*
Salvage Value of CDS System - Year 20	$ -	

NOTES

[1] : For simplicity, the per-kilowatt-hour cost of electricity is not escalated.

[2] : Estimated based on the current Daily Municipal Bond Index average yield to maturity as published in the Wall Street Journal (7/7/14).

[3] : Estimated based on the annual change in the Consumer Price Index (7/7/14).

[4] : Financed over 20 years using the estimated discount rate. Full amortization of principal is assumed.

[5] : Calculated based on first year operations and maintenance estimate and escalated using the annual rate of inflation.

Life-Cycle Cost Analysis:	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
OM Separator System										
Capital and Design Costs [4]	$39,151,350									
Annual O&M Fee[7]	$ -	$ 1,079,285	$1,101,950	$1,125,091	$ 1,148,718	$1,172,841	$ 1,197,471	$1,222,618	$1,248,293	$1,274,507
Electricity	$ -	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315
Salvage Value at Year 20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$39,151,350	$ 1,511,600	$1,534,265	$1,557,406	$ 1,581,033	$1,605,156	$ 1,629,786	$1,654,933	$1,680,608	$1,706,822
Annual Total - Discounted	$39,151,350	$ 1,461,048	$1,433,361	$1,406,321	$ 1,379,911	$1,354,113	$ 1,328,910	$1,304,287	$1,280,226	$1,256,712

Life-Cycle Cost Analysis:	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
OM Separator System											
Capital and Design Costs [4]											
Annual O&M Fee[7]	$1,301,272	$1,328,598	$1,356,499	$1,384,985	$1,414,070	$1,443,765	$1,474,084	$1,505,040	$1,536,646	$1,568,916	$ 1,601,863
Electricity	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315	$ 432,315
Salvage Value at Year 20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$1,733,587	$1,760,913	$1,788,814	$1,817,300	$1,846,385	$1,876,080	$1,906,399	$1,937,355	$1,968,961	$2,001,231	$ 2,034,178
Annual Total - Discounted	$1,233,732	$1,211,269	$1,189,311	$1,167,843	$1,146,853	$1,126,327	$1,106,253	$1,086,619	$1,067,413	$1,048,625	$ 1,030,242

NPV (sum of Discounted Annual Totals)	**$ 63,770,726**

Figure B-1. Net present value spreadsheet for Option 1, 20 percent sump fraction.

PacifiCorp - Organic Matter Removal Project

Specify Option (1, 2, 3, or 4)	2	
Specify Operations and Maintenance (O&M) Percentage	2%	%
CDS Unit Location:	Eastside Bypass	
Sump Water Discharge Location:	A-Canal	

Model Assumptions:

Cost Per Kilowatt-Hour of Electricity [1]	$ 0.120	
Duration of Project	20	yrs
Estimated Discount Rate [2]	3.5%	%
Annual Rate of Inflation [3]	2%	%
Salvage Value	$ -	
Safety Factor	1.35	

Potential Project Elements and Costs

Element	**Cost (2014)**	**Included or Not Included**
CDS Units	$ 6,600,000	Included
Stilling Basins	$ 220,000	Included
Fish Screen	$ -	n/a
Piping	$ 1,300,000	Included
Trenching	$ 890,000	Included
Canal	$ -	n/a
Tunnelling	$ -	n/a
Fish Friendly Pumps	$ 6,700,000	Included
Pumps	$ -	Included
Control Facility	$ 560,000	Included
Discharge Facility	$ 21,000	Included
Power Requirement for Pumps:	1,365,180	kWh/yr

Project Duration and Costs

Expected Life (Starting January 1, 2015)	20	yrs
Capital and Design Costs for the System	$21,992,850	*(2014 dollars)*
Annual O&M	$ 593,807	*(2014 dollars)*
Electricity Usage for Project	$ 163,822	*(2014 dollars)*
Salvage Value of CDS System - Year 20	$ -	

NOTES

[1] : For simplicity, the per-kilowatt-hour cost of electricity is not escalated.

[2] : Estimated based on the current Daily Municipal Bond Index average yield to maturity as published in the Wall Street Journal (7/7/14).

[3] : Estimated based on the annual change in the Consumer Price Index (7/7/14).

[4] : Financed over 20 years using the estimated discount rate. Full amortization of principal is assumed.

[5] : Calculated based on first year operations and maintenance estimate and escalated using the annual rate of inflation.

Life-Cycle Cost Analysis:	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
OM Separator System											
Capital and Design Costs [4]	$21,992,850										
Annual O&M Fee[7]	$ -	$ 606,277	$ 619,009	$ 632,008	$ 645,280	$ 658,831	$ 672,666	$ 686,792	$ 701,215	$ 715,941	$ 730,975
Electricity	$ -	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822
Salvage Value at Year 20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$21,992,850	$ 770,098	$ 782,830	$ 795,829	$ 809,102	$ 822,653	$ 836,488	$ 850,614	$ 865,037	$ 879,762	$ 894,797
Annual Total - Discounted	$21,992,850	$ 744,344	$ 731,346	$ 718,625	$ 706,176	$ 693,991	$ 682,064	$ 670,386	$ 658,953	$ 647,758	$ 636,795

Life-Cycle Cost Analysis:	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
OM Separator System										
Capital and Design Costs [4]										
Annual O&M Fee[7]	$ 746,326	$ 761,999	$ 778,001	$ 794,339	$ 811,020	$ 828,051	$ 845,440	$ 863,194	$ 881,322	$ 899,829
Electricity	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822	$ 163,822
Salvage Value at Year 20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$ 910,147	$ 925,820	$ 941,822	$ 958,160	$ 974,841	$ 991,873	$1,009,262	$1,027,016	$1,045,143	$ 1,063,651
Annual Total - Discounted	$ 626,058	$ 615,541	$ 605,239	$ 595,146	$ 585,257	$ 575,568	$ 566,072	$ 556,766	$ 547,645	$ 538,703

NPV (sum of Discounted Annual Totals)	**$ 34,695,284**

Figure B-2. Net present value spreadsheet for Option 2, 20 percent sump fraction.

PacifiCorp - Organic Matter Removal Project

Specify Option (1, 2, 3, or 4)	3	
Specify Operations and Maintenance (O&M) Percentage	2%	%
CDS Unit Location:	A-Canal	
Sump Water Discharge Location:	A-Canal, Downstream of Fish Screen	

Model Assumptions:

Cost Per Kilowatt-Hour of Electricity [1]	$ 0.120	
Duration of Project	20	yrs
Estimated Discount Rate [2]	3.5%	%
Annual Rate of Inflation [3]	2%	%
Salvage Value	$ -	
Safety Factor	1.35	

Potential Project Elements and Costs

Element	**Cost (2014)**	**Included or Not Included**
CDS Units	$ 4,600,000	Included
Stilling Basins	$ 150,000	Included
Fish Screen	$ -	n/a
Piping	$ 2,500,000	Included
Trenching	$ 890,000	Included
Canal	$ -	Included
Tunnelling	$ -	n/a
Fish Friendly Pumps	$ -	n/a
Pumps	$ 1,220,000	Included
Control Facility	$ 560,000	Included
Discharge Facility	$ 21,000	Included
Power Requirement for Pumps:	10,807,875	kWh/yr

Project Duration and Costs

Expected Life (Starting January 1, 2015)	20	yrs
Capital and Design Costs for the System	$13,420,350	*(2014 dollars)*
Annual O&M	$ 362,349	*(2014 dollars)*
Electricity Usage for Project	$ 1,296,945	*(2014 dollars)*
Salvage Value of CDS System - Year 20	$ -	

NOTES

[1] : For simplicity, the per-kilowatt-hour cost of electricity is not escalated.

[2] : Estimated based on the current Daily Municipal Bond Index average yield to maturity as published in the Wall Street Journal (7/7/14).

[3] : Estimated based on the annual change in the Consumer Price Index (7/7/14).

[4] : Financed over 20 years using the estimated discount rate. Full amortization of principal is assumed.

[5] : Calculated based on first year operations and maintenance estimate and escalated using the annual rate of inflation.

Life-Cycle Cost Analysis:	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
OM Separator System											
Capital and Design Costs [4]	$13,420,350										
Annual O&M Fee[7]	$ -	$ 369,959	$ 377,728	$ 385,660	$ 393,759	$ 402,028	$ 410,471	$ 419,090	$ 427,891	$ 436,877	$ 446,052
Electricity	$ -	$ 1,296,945	$1,296,945	$1,296,945	$ 1,296,945	$1,296,945	$ 1,296,945	$1,296,945	$1,296,945	$1,296,945	$1,296,945
Salvage Value at Year 20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$13,420,350	$ 1,666,904	$1,674,673	$1,682,605	$ 1,690,704	$1,698,973	$ 1,707,416	$1,716,035	$1,724,836	$1,733,822	$1,742,997
Annual Total - Discounted	$13,420,350	$ 1,611,158	$1,564,534	$1,519,374	$ 1,475,631	$1,433,257	$ 1,392,209	$1,352,443	$1,313,918	$1,276,592	$1,240,429

Life-Cycle Cost Analysis:	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
OM Separator System										
Capital and Design Costs [4]										
Annual O&M Fee[7]	$ 455,419	$ 464,982	$ 474,747	$ 484,717	$ 494,896	$ 505,289	$ 515,900	$ 526,734	$ 537,795	$ 549,089
Electricity	$1,296,945	$1,296,945	$1,296,945	$1,296,945	$1,296,945	$1,296,945	$1,296,945	$1,296,945	$1,296,945	$ 1,296,945
Salvage Value at Year 20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$1,752,364	$1,761,927	$1,771,692	$1,781,662	$1,791,841	$1,802,234	$1,812,845	$1,823,679	$1,834,740	$ 1,846,034
Annual Total - Discounted	$1,205,388	$1,171,435	$1,138,534	$1,106,651	$1,075,752	$1,045,807	$1,016,784	$ 988,653	$ 961,385	$ 934,954

NPV (sum of Discounted Annual Totals)	**$ 38,245,238**

Figure B-3. Net present value spreadsheet for Option 3.1, 20 percent sump fraction.

PacifiCorp - Organic Matter Removal Project

Specify Option (1, 2, 3, or 4)	3.5	
Specify Operations and Maintenance (O&M) Percentage	2%	%
CDS Unit Location:	n/a	
Sump Water Discharge Location:	n/a	

Model Assumptions:

Cost Per Kilowatt-Hour of Electricity [1]	$ 0.120	
Duration of Project	20	yrs
Estimated Discount Rate [2]	3.5%	%
Annual Rate of Inflation [3]	2%	%
Salvage Value	$ -	
Safety Factor	1.35	

Potential Project Elements and Costs

Element	Cost (2014)	Included or Not Included
CDS Units	$ 2,500,000	Included
Stilling Basins	$ 80,000	Included
Fish Screen	$ -	n/a
Piping	$ 1,400,000	Included
Trenching	$ 890,000	Included
Canal	$ -	Included
Tunnelling	$ -	n/a
Fish Friendly Pumps	$ -	n/a
Pumps	$ 610,000	Included
Control Facility	$ 560,000	Included
Discharge Facility	$ 21,000	Included
Power Requirement for Pumps:	5,403,937	kWh/yr

Project Duration and Costs

Expected Life (Starting January 1, 2015)	20	yrs
Capital and Design Costs for the System	$ 8,182,350	*(2014 dollars)*
Annual O&M	$ 220,923	*(2014 dollars)*
Electricity Usage for Project	$ 648,472	*(2014 dollars)*
Salvage Value of CDS System - Year 20	$ -	

NOTES

[1] : For simplicity, the per-kilowatt-hour cost of electricity is not escalated.
[2] : Estimated based on the current Daily Municipal Bond Index average yield to maturity as published in the Wall Street Journal (7/7/14).
[3] : Estimated based on the annual change in the Consumer Price Index (7/7/14).
[4] : Financed over 20 years using the estimated discount rate. Full amortization of principal is assumed.
[5] : Calculated based on first year operations and maintenance estimate and escalated using the annual rate of inflation.

Life-Cycle Cost Analysis:	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
OM Separator System																					
Capital and Design Costs [4]	$ 8,182,350																				
Annual O&M Fee[7]	$ -	$ 225,563	$ 230,300	$ 235,136	$ 240,074	$ 245,115	$ 250,263	$ 255,518	$ 260,884	$ 266,363	$ 271,956	$ 277,667	$ 283,498	$ 289,452	$ 295,530	$ 301,737	$ 308,073	$ 314,543	$ 321,148	$ 327,892	$ 334,778
Electricity	$ -	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472	$ 648,472
Salvage Value at Year 20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$ 8,182,350	$ 874,035	$ 878,772	$ 883,608	$ 888,546	$ 893,588	$ 898,735	$ 903,991	$ 909,357	$ 914,835	$ 920,429	$ 926,140	$ 931,971	$ 937,924	$ 944,003	$ 950,209	$ 956,546	$ 963,015	$ 969,620	$ 976,365	$ 983,250
Annual Total - Discounted	$ 8,182,350	$ 844,805	$ 820,978	$ 797,889	$ 775,515	$ 753,833	$ 732,819	$ 712,454	$ 692,715	$ 673,582	$ 655,036	$ 637,059	$ 619,630	$ 602,734	$ 586,352	$ 570,469	$ 555,068	$ 540,133	$ 525,651	$ 511,605	$ 497,983

NPV (sum of Discounted Annual Totals)	**$ 21,288,661**

Figure B-4. Net present value spreadsheet for Option 3.2, 20 percent sump fraction.

PacifiCorp - Organic Matter Removal Project		
Specify Option (1, 2, 3, or 4)	4	
Specify Operations and Maintenance (O&M) Percentage	2%	%
CDS Unit Location:	Eastside Bypass	
Sump Water Discharge Location:	A-Canal, Downstream of Underground	

Model Assumptions:

Cost Per Kilowatt-Hour of Electricity [1]	$ 0.120	
Duration of Project	20	yrs
Estimated Discount Rate [2]	3.5%	%
Annual Rate of Inflation [3]	2%	%
Salvage Value	$ -	
Safety Factor	1.35	

Potential Project Elements and Costs

Element	Cost (2014)	Included or Not Included
CDS Units	$ 6,600,000	Included
Stilling Basins	$ 220,000	Included
Fish Screen	$19,000,000	Included
Piping	$ -	Included
Trenching	$ -	Included
Canal	$ -	n/a
Tunnelling	$ 1,490,000	Included
Fish Friendly Pumps	$ -	n/a
Pumps	$ -	Included
Control Facility	$ 560,000	Included
Discharge Facility	$ 21,000	Included
Power Requirement for Pumps:	0	kWh/yr

Project Duration and Costs

Expected Life (Starting January 1, 2015)	20	yrs
Capital and Design Costs for the System	$37,652,850	*(2014 dollars)*
Annual O&M	$ 1,016,627	*(2014 dollars)*
Electricity Usage for Project	$ -	*(2014 dollars)*
Salvage Value of CDS System - Year 20	$ -	

NOTES

[1] : For simplicity, the per-kilowatt-hour cost of electricity is not escalated.

[2] : Estimated based on the current Daily Municipal Bond Index average yield to maturity as published in the Wall Street Journal (7/7/14).

[3] : Estimated based on the annual change in the Consumer Price Index (7/7/14).

[4] : Financed over 20 years using the estimated discount rate. Full amortization of principal is assumed.

[5] : Calculated based on first year operations and maintenance estimate and escalated using the annual rate of inflation.

Life-Cycle Cost Analysis:	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year
	0	1	2	3	4	5	6	7	8	9	10
OM Separator System											
Capital and Design Costs [4]	$37,652,850										
Annual O&M Fee[7]	$ -	$ 1,037,976	$1,059,774	$1,082,029	$ 1,104,751	$1,127,951	$ 1,151,638	$1,175,823	$1,200,515	$1,225,726	$1,251,466
Electricity	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Salvage Value at Year 20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$37,652,850	$ 1,037,976	$1,059,774	$1,082,029	$ 1,104,751	$1,127,951	$ 1,151,638	$1,175,823	$1,200,515	$1,225,726	$1,251,466
Annual Total - Discounted	$37,652,850	$ 1,003,263	$ 990,075	$ 977,060	$ 964,217	$ 951,542	$ 939,034	$ 926,690	$ 914,509	$ 902,487	$ 890,624

Life-Cycle Cost Analysis:	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
	Year	Year	Year	Year	Year	Year	Year	Year	Year	Year
	11	12	13	14	15	16	17	18	19	20
OM Separator System										
Capital and Design Costs [4]										
Annual O&M Fee[7]	$1,277,747	$1,304,579	$1,331,976	$1,359,947	$1,388,506	$1,417,665	$1,447,436	$1,477,832	$1,508,866	$ 1,540,552
Electricity	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Salvage Value at Year 20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Subtotal	$1,277,747	$1,304,579	$1,331,976	$1,359,947	$1,388,506	$1,417,665	$1,447,436	$1,477,832	$1,508,866	$ 1,540,552
Annual Total - Discounted	$ 878,916	$ 867,363	$ 855,961	$ 844,709	$ 833,606	$ 822,648	$ 811,834	$ 801,162	$ 790,631	$ 780,238

NPV (sum of Discounted Annual Totals)	**$ 55,399,419**

Figure B-5. Net present value spreadsheet for Option 4, 20 percent sump fraction.