UDWQ POTW Nutrient Removal Cost Impact Study: Analysis of Brigham City Wastewater Treatment Facility

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COPIES: Brigham City Waste Treatment Facility

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In partial fulfillment of the Utah Division of Water Quality *Publicly Owned Treatment Works (POTW) Nutrient Removal Cost Impacts Study,* this Technical Memorandum (TM) summarizes the process, financial and environmental evaluation of the Brigham City Wastewater Treatment Plant (BCWT) to meet the four tiers of nutrient standards presented in Table 1.

The thirty mechanical POTWs in the State of Utah were categorized into five groups to simplify process alternatives development, evaluation, and cost estimation for a large number of facilities. Similar approaches to upgrading these facilities for nutrient removal were thus incorporated into the models developed for POTWs with related treatment processes. The five categories considered were as follows:

- Oxidation Ditches (OD)
- Activated Sludge (AS)
- Membrane Bioreactors (MBR)
- Trickling Filters (TF)
- Hybrid Processes (Trickling Filter/Solids Contact (TF/SC) or Trickling Filter/Activated Sludge (TF/AS))

The BCWT fits in the Oxidation Ditch Category.

TABLE 1
Nutrient Discharge Standards for Treated Effluent

Tier	Total Phosphorus, mg/L	Total Nitrogen, mg/L
1N	0.1	10
1	0.1	No limit
2N	1.0	20
2	1.0	No limit
3	Base condition	Base condition

1. Facility Overview

BCWT has a design flow of 6 million gallons per day (mgd) and currently receives an average annual influent flow of approximately 1.4 mgd. The facility operates a nitrifying extended aeration process using oxidation ditches (closed loop reactors) with surface aeration. Secondary effluent is disinfected by ultra-violet radiation and aerated prior to discharge. Wasted solids are stabilized by aerobic digestion and dewatered using a screw press. A process flow diagram is presented in Figure 1 and an aerial photo of the POTW is shown in Figure 2. The major unit processes are summarized in Table 2.

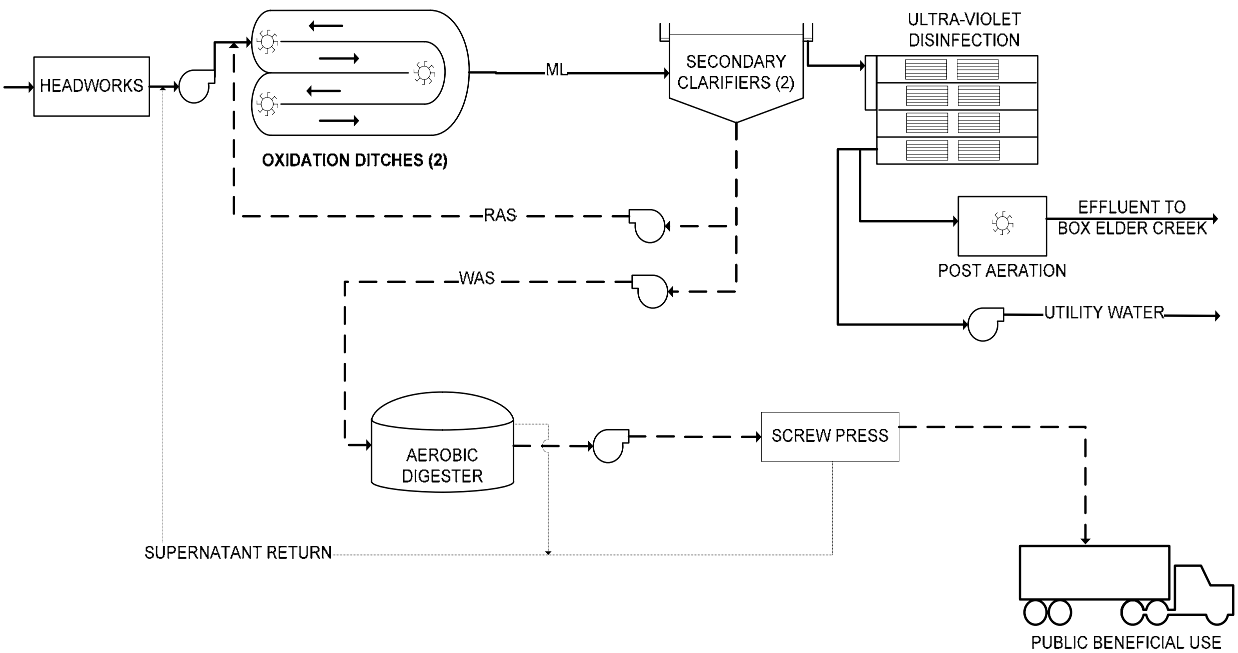

FIGURE 1
Process Flow Diagram

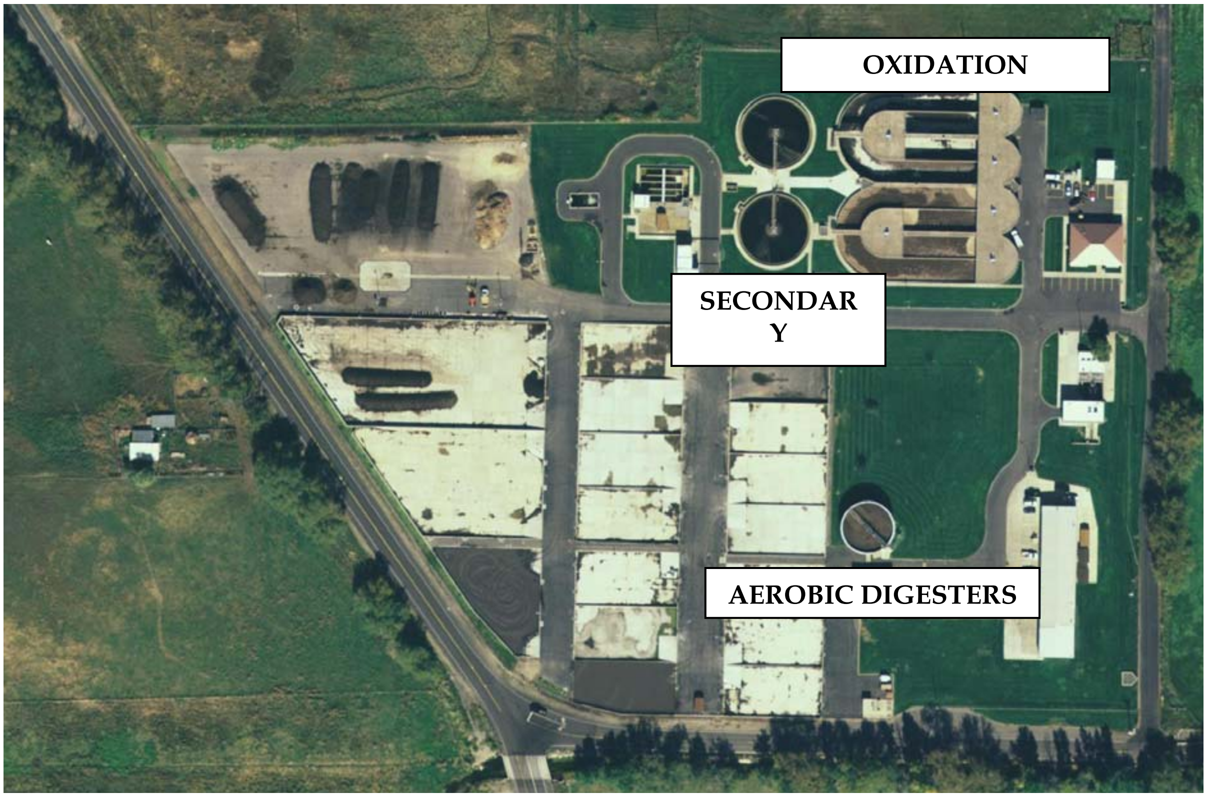

FIGURE 2
Aerial View of the Facility

TABLE 2
Summary of Major Unit Processes

Treatment step	Number of Units	Size, each	Details
Oxidation Ditches	2	2.1 MG, 14-ft SWD	Three 75 HP Surface Aerators
Secondary Clarifiers	2	85-ft diameter, 14-ft SWD	Round clarifiers
Aerobic Digester	1	0.53 MG	PD Blower
Sludge Drying Beds*	17	Total Area = 165,000 ft^2	Achieves 80% solids

* Utility currently modifying plant to screw press for dewatering.

2. Nutrient Removal Alternatives Development

A nutrient removal alternatives matrix was prepared in order to capture an array of viable approaches for OD facilities (See Attachment A). This matrix considers biological and chemical phosphorus removal approaches as well as different activated sludge configurations for nitrogen control. The alternatives matrix illustrates that there are several strategies for controlling nutrient limits. The processes that were modeled and described in the subsequent sections are considered proven methods for meeting the nutrient limits.

There may be other ways to further optimize to reduce capital and operation and maintenance (O&M) costs that are beyond the scope of this project. This TM can form the basis for an optimization study in the future should that be desired by the POTW.

BCWT currently has (2) oxidation ditches and (2) secondary clarifiers. As with all of the POTWs, the approaches were developed with the goal of utilizing the existing infrastructure to the maximum extent possible. Because the utility has adequate extended aeration reactor volume available, it was decided to maintain the existing system and implement a biological nutrient removal process with selector basins preceding the oxidation ditches. This configuration provides flexibility with future industrial loadings that are anticipated to be relatively weak (<50 mg/L of BOD). Figure 3 shows the selected upgrade approach used between each tier of nutrient control with the bullet points A through D describing each upgrade step:

A. From Tier 3 (existing) to Tier 2 phosphorus control, the existing secondary treatment system was expanded by adding an anaerobic basin upstream of the oxidation ditches to implement biological phosphorus removal. A metal-salt addition system was installed upstream of the secondary clarifiers as a back up to the biological phosphorus process.

B. To go from Tier 2 to Tier 2N, no additional process modifications were required.

C. To go from Tier 2 to Tier 1 phosphorus control, an anoxic selector was installed between the anaerobic selector and the oxidation ditches to decrease nitrate recycled in the RAS stream. A granular media filtration system was installed downstream of the secondary clarifiers to remove particulate phosphorus from the liquid stream. Metal-salt and polymer added upstream of the filters enhanced soluble phosphorus removal. A secondary effluent pump station was required to achieve hydraulic head requirements for the filtration system.

D. To go from Tier 1 to Tier 1N, no additional process modification was required.

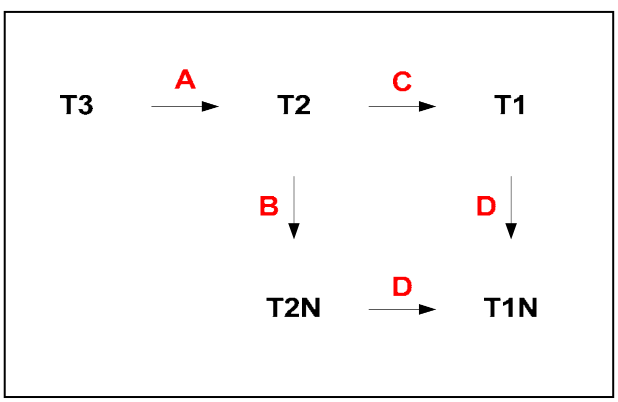

FIGURE 3
Upgrades Scheme for Meeting Increasingly More Stringent Nutrient Control

Data Evaluation, Initial Modeling, and Calibration

The selected progression of upgrades conceived for meeting the different tiers of nutrient control for BCWT was analyzed using the following four steps;

- Step 1. Review, compile, and summarize the process performance data submitted by the POTW;
- Step 2. Develop and calibrate a base model of the existing POTW using the summarized performance data;
- Step 3. Build upon the base model by sequentially modifying it to incorporate unit process additions or upgrades for the different tiers of nutrient control and use model outputs to establish unit process sizing and operating requirements;
- Step 4. Develop capital and O&M costs for each upgrade developed in Step 3.

The facility information and data received by BCWT per the initial data request was evaluated to (a) develop, and validate the base process model, and (b) size facilities to conserve the POTW's current rated capacity. Table 3 provides a summary of the reported information used as the model input conditions. See process modeling protocol for additional information.

TABLE 3

Summary of Input Conditions

Input Parameter	2009	2029	Design (3)
Flow, mgd	1.4 (1)	5 (2)	6
BOD, lb/day	2,462 (210 mg/L) (1)	7,220 (173 mg/L) (2)	8,664 (173 mg/L)
TSS, lb/day	2,345 (200 mg/L) (1)	7,220 (173 mg/L) (2)	8,664 (173 mg/L)
TKN, lb/day	435 (37 mg/L)	1,543 (37 mg/L)	1,852 (37 mg/L)
TP, lb/day	68 (6 mg/L) (1)	250 (6 mg/L)	300 (5 mg/L)

(1) Historic conditions 2007-2009

(2) Projected by the POTW

(3) Design maximum month capacity of POTW

The main sizing and operating design criteria that were associated with the system upgrade for BCWT are summarized in Table 4.

TABLE 4
Main Unit Process Sizing and Operating Design Parameters

Design Parameter (Nutrient Tier)	Value
Influent design temperature (All Tiers)	11 deg C
Anaerobic fraction of bioreactor (All Tiers)	15%
Target metal:PO_4-P molar Ratio (Tier 1 and 1N)	2:1, 7:1 (1)
Metal-salt storage (All Tiers)	14 days
Fraction of mixed-liquor return flow to influent flow	150%
Granular filter loading rate (T1 and T1N)	5 gpm/ft^2 (2)

(1)Target dosing ratio at the secondary clarifiers and upstream of polishing filter, respectively. Note that polishing filter included in T1 and T1N only.

(2)Hydraulic loading rate at peak hourly flow

3. Nutrient Upgrade Approaches

The following paragraphs provide details of the upgrade approaches as presented previously in Figure 3.

Tier 2 Phosphorus (A)

The effluent limit for Tier 2 alternatives is 1.0 mg/L total phosphorus. BCWT was able to achieve this limit by adding an external anaerobic selector to the existing secondary treatment without modifying the oxidation ditches. A separate basin was constructed upstream of the oxidation ditches to provide an anaerobic environment. Dividing the required volume in two parallel zones provided operational flexibility and maintenance needs. These anaerobic basins included mixers to ensure a completely mixed environment. A metal-salt feed and storage system was installed as back-up to the biological system upstream of the secondary clarifiers. The process flow diagram for this alternative is shown as Figure 4.

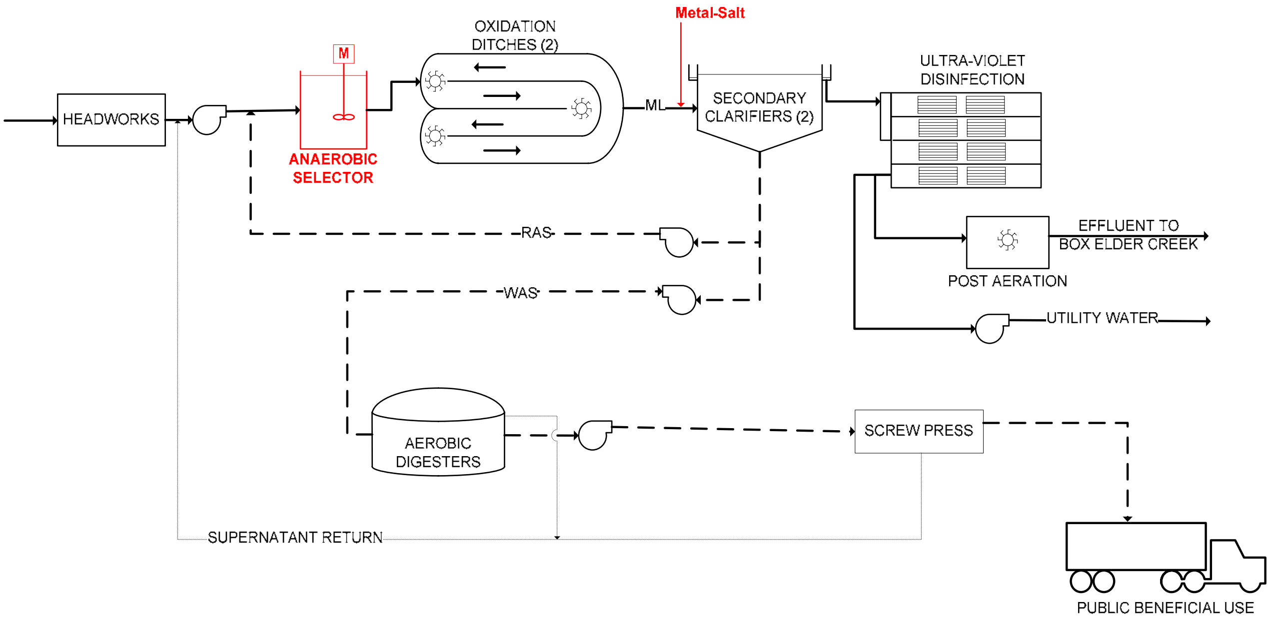

FIGURE 4
Modifications to POTW for Tier 2 Nutrient Control

Tier 2N – Phosphorus & Nitrogen (B)

The effluent limit for this alternative is 1.0 mg/L total phosphorus and 20 mg/L total nitrogen. The reactor modifications proposed for Tier 2 was capable of meeting these effluent requirements with no additional infrastructure required beyond those discussed above. Therefore, the overall process flow diagram would be the same as Figure 4.

Tier 1 –Phosphorus (C)

The effluent limit for this alternative is 0.1 mg/L total phosphorus. This approach builds upon the Tier 2 approach by adding an anoxic selector downstream of the anaerobic selector. The addition of the anoxic zone promoted denitrification which has a beneficial impact on biological phosphorus removal. In addition, a granular media filtration system was added downstream of the secondary clarifiers for chemical phosphorus polishing. Metal-salt was dosed to the liquid stream upstream of the filter units to enhance phosphorus removal. A secondary effluent pump station was required to provide the hydraulic head to feed the filtration system. A process schematic is shown as Figure 5.

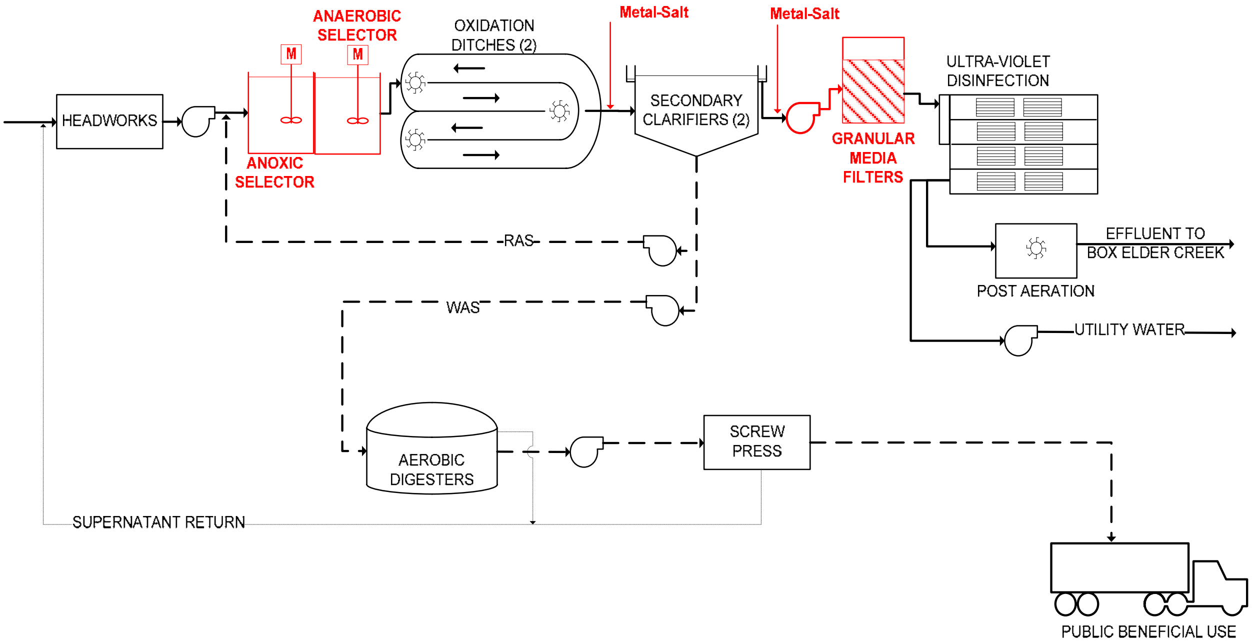

FIGURE 5
Modifications to POTW for Tier 1 Nutrient Goal

Tier 1N – Phosphorus & Nitrogen (D)

The effluent limit for this alternative is 0.1 mg/L total phosphorus and 10 mg/L total nitrogen. The reactor modifications proposed for Tier 1 was capable of meeting these effluent requirements with no additional infrastructure required beyond those discussed above. Therefore, the overall process flow diagram would be the same as Figure 5.

4. Capital and O&M Cost Estimates for Nutrient Control

This section formalizes the cost-impact results from this nutrient control analysis. These outputs were used in the financial cost model and subsequent financial analyses.

Table 5 presents a summary of the major facility upgrade components identified for meeting each tier of nutrient control. For Tier 2 and Tier 2N, an anaerobic selector upstream of the oxidation ditches and some minor mechanical modifications were required along with metal-salt storage facility and new feed pumps. For Tier 1 and 1N, an anoxic selector and mixed liquor return pumps were installed to enhance biological phosphorus removal and reduce total nitrogen of the effluent stream. A secondary effluent pump station was needed to lift the flow to new deep bed granular media filters with new metal-salt feed pumps.

TABLE 5

Major Facility Upgrade Summary

Processes	Tier 2	Tier 2N	Tier 1	Tier 1N
Anaerobic selector	X	X	X	X
Piping modifications	X	X	X	X
Anoxic selector			X	X
Mixed liquor recirculation system			X	X
Metal-salt feed & storage system	X	X	X	X
Secondary effluent pump station			X	X
Deep bed granular media filters			X	X

The capital cost estimates shown in Table 6 were generated for the facility upgrades summarized in Table 5. These estimates were prepared in accordance with the guidelines of the Association for the Advancement of Cost Engineering (AACE) International and defined as a Class 4 estimate. The expected accuracy range for the estimates shown in Table 6 is -30%/+50%.

TABLE 6
Capital Cost Estimates ($ Million)

Unit Process Facility	Tier 2	Tier 2N	Tier 1	Tier 1N
Metal-salt feed & storage system	$0.15	$0.15	$0.68	$0.68
Flow split structure and piping modifications	$0.54	$0.54	$0.54	$0.54
Anaerobic selector	$1.67	$1.67	$1.67	$1.67
Anoxic selector	$0.00	$0.00	$1.84	$1.84
Mixed liquor recirculation system	$0.00	$0.00	$0.20	$0.20
Secondary effluent pump station	$0.00	$0.00	$2.59	$2.59
Deep bed granular media filters	$0.00	$0.00	$13.34	$13.34
TOTAL TIER COST	**$2.36**	**$2.36**	**$20.86**	**$20.86**

December 2009 US Dollars

Incremental O&M costs associated with meeting each tier of nutrient standard were generated for the years 2009 and 2029. The unit costs were assumed based on the average costs in the State of Utah, and are presented in Table 7. A straight line interpolation was used to estimate the differential cost for the two years. O&M costs for each upgrade included the following components:

- Chemical consumption costs: metal-salt, and, polymer
- Power costs for the major mechanized process equipment: secondary effluent pumps, backwash pumps and dewatering units

Biosolids hauling and disposal costs were not considered as it is understood that currently BCWT composts all of their biosolids on site, thus these costs would not be applicable.

TABLE 7
Operating and Maintenance Unit Costs

Parameter	Value
Alum	$480/ton
Polymer	$1/lb
Power	$0.06/kwh

Increased O&M relative to the current O&M cost (Tier 3) are presented in Table 8 and shown graphically in Figure 6.

TABLE 8
Estimated Impact of Nutrient Control on O&M Costs

	Tier 2		Tier 2N		Tier 1		Tier 1N	
	2009	**2029**	**2009**	**2029**	**2009**	**2029**	**2009**	**2029**
Biosolids	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Metal-salt	$0.01	$0.01	$0.01	$0.01	$0.02	$0.07	$0.02	$0.07
Polymer	$0.00	$0.01	$0.00	$0.01	$0.00	$0.00	$0.00	$0.00
Power	$0.01	$0.02	$0.01	$0.02	$0.05	$0.13	$0.05	$0.13
Total O&M	**$0.01**	**$0.04**	**$0.01**	**$0.04**	**$0.07**	**$0.21**	**$0.07**	**$0.21**

Note: $ (US) in December 2009.

Costs shown are the annual differential costs relative to the base line O&M cost of the POTW

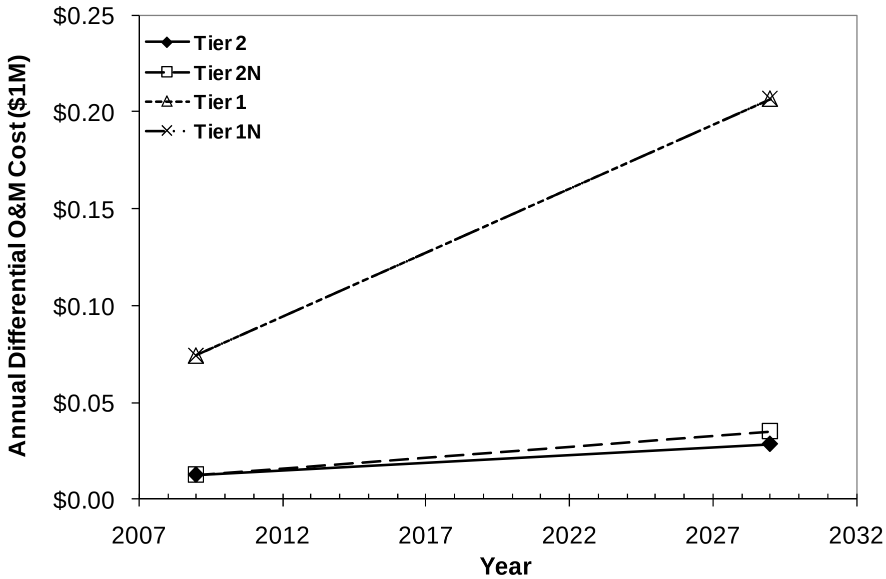

FIGURE 6
Impact of Nutrient Control on O&M Costs over 20 year evaluation period

5. Financial Impacts

This section presents the estimated financial impacts that will result from the implementation of nutrient discharge standards for BCWT. Financial impacts were summarized for each POTW on the basis of three primary economic parameters: 20-year life cycle costs, user charge impacts, and community financial impacts. The basis for the financial impact analysis is the estimated capital and incremental O&M costs established in the previous sections.

Life Cycle Costs

Life cycle cost analysis refers to an assessment of the costs over the life of a project or asset, emphasizing the identification of cost requirements beyond the initial investment or capital expenditure.

For each treatment upgrade established to meet the studied nutrient limits (Tier 2, Tier 2N, Tier 1, and Tier 1N), a multi-year life cycle cost forecast was developed that is comprised of both capital and O&M costs. Cost forecasts are organized with initial capital expenditures in year 0 (2009), and incremental O&M forecasts from year 1 (2010) through year 20 (2029). The cost forecast for each treatment alternative was developed in current (2009) dollars, and discounted to yield the net present value (NPV).

The NPV was divided by the estimated 20-year nutrient discharge mass reduction for each tier, resulting in a cost per pound estimate for nutrient removal. This calculation represents an appropriate matching of costs with receiving stream load reduction over the same time period. Table 9 presents the results of the life cycle cost analysis for BCWT.

TABLE 9

Nutrient Removal: 20-Year Life Cycle Cost per Pound [1]				
	Tier 2	**Tier 2N**	**Tier 1**	**Tier 1N**
Phosphorus Removal (pounds)[2]	524,232	524,232	704,590	704,590
Nitrogen Removal (pounds)[2]	-	meets limit	-	2,003,978
Net Present Value of Removal Costs[3]	**$ 2,654,951**	**$ 2,654,951**	**$ 22,975,394**	**$ 22,975,394**
NPV: Phosphorus Allocation	2,654,951	2,654,951	22,975,394	22,975,394
NPV: Nitrogen Allocation[4]		-		-
TP Cost per Pound[5]	**$ 5.06**	**$ 5.06**	**$ 32.61**	**$ 32.61**
TN Cost per Pound[5]		**NA**		**$ -**

1 - For facilities that are already meeting one or more nutrient limits, "meets limit" is displayed for nutrient removal mass and "NA" is displayed for cost per pound metrics

2 - Total nutrient removal over a 20-year period, from 2010 through 2029

3 - Net present value of removal costs, including capital expenditures and incremental O&M over a 20-year period

4 - For simplicity, it was assumed that the nitrogen cost allocation was the incremental difference between net present value costs across Tiers for the same phosphorus limit (i.e. Tier 2 to Tier 2N); differences in technology recommendations may result in different cost allocations for some facilities

5 - Cost per pound metrics measured over a 20-year period are used to compare relative nutrient removal efficiencies among treatment alternatives and different facilities

Customer Financial Impacts

The second financial parameter measures the potential impact to user rates for those customers served by the POTW. The financial impact was measured both in terms of potential rate increases for the POTW's associated service provider, and the resulting monthly bill impacts for the typical residential customer of the system.

Customer impacts were estimated by calculating annual increased revenue requirements for the POTW. Implementation of each treatment upgrade will increase the annual revenue requirements for debt service payments (related to initial capital cost) and incremental O&M costs.

The annual cost increase was then divided by the number of customers served by the POTW, as measured by equivalent residential units (ERUs), to establish a monthly rate increase per ERU. The monthly rate increase associated with each treatment alternative was estimated by adding the projected monthly rate increase to the customer's current average monthly bill. Estimated financial impacts for customers of the BCWT are presented in Table 10.

TABLE 10

Projected Monthly Bill Impact per Equivalent Residential Unit (ERU) for Treatment Alternatives

	Tier 2	Tier 2N	Tier 1	Tier 1N
Initial Capital Expenditure	$ 2,346,000	$ 2,346,000	$ 20,863,000	$ 20,863,000
Estimated Annual Debt Service[1]	$ 188,200	$ 188,200	$ 1,674,100	$ 1,674,100
Incremental Operating Cost[2]	13,300	13,300	81,200	81,200
Total Annual Cost Increase	$ 201,500	$ 201,500	$ 1,755,300	$ 1,755,300
Number of ERUs	5,800	5,800	5,800	5,800
Annual Cost Increase per ERU	$34.74	$34.74	$302.64	$302.64
Monthly Cost Increase per ERU[3]	**$2.90**	**$2.90**	**$25.22**	**$25.22**
Current Average Monthly Bill[4]	$25.22	$25.22	$25.22	$25.22
Projected Average Monthly Bill[5]	**$28.11**	**$28.11**	**$50.44**	**$50.44**
Percent Increase	**11.5%**	**11.5%**	**100.0%**	**100.0%**

1 - Assumes a financing term of 20 years and an interest rate of 5.0 percent

2 - Incremental annual increase in O&M for each upgrade, based on chosen treatment technology, estimated for first operational year

3 - Projected monthly bill impact per ERU for each upgrade, based on estimated increase in annual operating costs

4 - Estimated 2009 average monthly bill for a typical residential customer (ERU) within the service area of the facility

5 - Projected average monthly bill for a typical residential customer (ERU) if treatment upgrade is implemented

Community Financial Impacts

The third and final parameter measures the financial impact of nutrient limits from a community perspective, and accounts for the varied purchasing power of customers throughout the state. The metric is the ratio of the projected monthly bill that would result from each treatment alternative to an affordable monthly bill, based on a parameter established by the State Water Quality Board to determine project affordability.

The Division employs an affordability criterion that is widely used to assess the affordability of projects. The affordability threshold is equal to 1.4 percent of the median annual gross household income (MAGI) for customers served by a POTW. The MAGI estimate for customers of each POTW is multiplied by the affordability threshold parameter, then divided by 12 (months) to determine the monthly 'affordable' wastewater bill for the typical customer.

The projected monthly bill for each nutrient limit was then expressed as a percentage of the monthly affordable bill. The resulting affordability ratio for each nutrient limit for the BCWT is shown in Table 11.

TABLE 11

Community Financial Impacts: Affordability of Treatment Alternatives

	Tier 2	Tier 2N	Tier 1	Tier 1N
Median Annual Gross Income (MAGI)[1,2]	$ 38,400	$ 38,400	$ 38,400	$ 38,400
Affordability Threshold (% of MAGI)[3]	1.4%	1.4%	1.4%	1.4%
Monthly Affordability Criterion	**$44.80**	**$44.80**	**$44.80**	**$44.80**
Projected Average Monthly Bill	$28.11	$28.11	$50.44	$50.44
Meets State's Affordability Criterion?	Yes	Yes	No	No
Estimated Bill as % of State Criterion	**63%**	**63%**	**113%**	**113%**

1 - Based on the average MAGI of customers within the service area of the facility

2 - MAGI statistics compiled from 2008 census data

3 - Parameter established by the State Water Quality Board to determine project affordability for POTWs

6. Environmental Impacts of Nutrient Control Analysis

This section summarizes the potential environmental benefits and impacts that would result from implementing the process upgrades established for the various tiers of nutrient control detailed in Section 3. The following aspects were considered for this evaluation:

- Reduction of nutrient loads from POTW to receiving water bodies
- Changes in chemical consumption
- Changes in biosolids production
- Changes in energy consumption

As per the data received from BCWT and per process modeling of the base condition (Tier 3), BCWT is able to meet an effluent total nitrogen concentration of 10 mg/L and Tier 2 level of phosphorus control with its existing infrastructure. Table 12 summarizes the annual reduction in nutrient loads in BCWT effluent discharge if the process upgrades were implemented. The values shown are for the current (2009) flow and load conditions. It should be noted that any increase in flow or load to the POTW will result in higher reductions.

TABLE 12

Estimated Environmental Benefits of Nutrient Control

	Tier 2	Tier 2N	Tier 1	Tier 1N
Total phosphorus removed, lb/year	8,525	8,525	12,360	12,360
Total nitrogen removed, lb/year	----	0	----	42,620

Note: Nutrient loads shown are the annual differential loads relative to the baseline (Tier 3) condition of the POTW for the year 2009.

The nutrient content of POTWs' discharges and their receiving waters were also summarized to examine the potential of various treatment alternatives for reducing nutrient loads to those water bodies. The POTW loads were paired with estimated loads in the upstream receiving waters to create estimated downstream combined loads. Those combined stream and POTW loads could then be examined for the potential effects of future POTW nutrient removal alternatives. The average total nitrogen and phosphorus concentrations discharged by each POTW were either provided by the POTW during the data collection process or obtained from process modeling efforts. Upstream receiving historical water quality data was obtained from STORET. Data from STORET was summarized in order to yield average total nitrogen and total phosphorus concentrations that could then be paired with the appropriate POTW records. It should be noted that the data obtained from STORET were not verified by sampling and possible anomalies and outliers could exist in historical data sets due to certain events or errors in measurement.

Table 13 shows the total phosphorus and total nitrogen concentration discharged by BCWT for baseline condition (Tier 3) and for each Tier of nutrient standard. The STORET ID from where historical water quality data were obtained is also presented in the Table.

TABLE 13
Estimates of Average TN and TP Concentrations for Baseline and Cumulative Treatments to Receiving Waters (mg/L)

			Tier 3		Tier 2		Tier 2N		Tier 1		Tier 1N	
STORET LOCATION	**STORET ID**	**FLOW (cfs)**	**TP**	**TN**	**TP**	**TN**	**TP**	**TN**	**TP**	**TN**	**TP**	**TN**
BCWT	----	2.17	3.00	20.00	1.0	N/A	1.0	10.0	0.1	N/A	0.1	10.0
Box Elder Creek	4901190	22.59	0.08	1.02	----	----	----	----	----	----	----	----
Combined Concentration			**0.34**	**2.68**	**0.16**	**N/A**	**0.16**	**2.68**	**0.08**	**N/A**	**0.08**	**1.81**

The process upgrades established to meet the four tiers of nutrient standards require increased energy consumptions, chemical usage and biosolids production. Metal-salt would need to be added to meet the more stringent phosphorus limits. This would result in increased chemical sludge generation and consequently increased biosolids production. Table 14 summarizes these environmental impacts of implementing the process upgrades to achieve the various tiers of nutrient control. The values shown are on an annual basis, for the current (2009) flow and load conditions, and indicate the differential relative to the base line condition.

TABLE 14
Estimated Environmental Impacts of Nutrient Control

		Tier 2	Tier 2N	Tier 1	Tier 1N
Chemical Use:					
Metal-salt use, lb/year		1,000	1,000	41,020	41,020
Polymers, lb/year		17	17	1,045	1,045
Biosolids Management:[(1)]					
Biosolids produced, ton/year		63	63	105	105
Particulate emissions from hauling trucks, lb/year [(2)]		0	0	0	0
Tailpipe emissions from hauling trucks, lb/year[(2)]		0	0	0	0
CO_2 emissions from hauling trucks lb/year[(4)]		0	0	0	0
Energy Consumption:					
Annual energy consumption, kwh		108,001	108,001	900,775	900,775
Air pollutant emissions, lb/year [(5)]					
	CO_2	97,417	97,417	812,499	812,499
	NOx	151	151	1,261	1,261
	SOx	130	130	1,081	1,081
	CO	7	7	59	59
	VOC	1	1	7	7
	PM_{10}	2	2	18	18
	$PM_{2.5}$	1	1	9	9

Note: Values shown are the annual differential values relative to the base line condition (Tier 3) of the POTW for the year 2009

(1) CCWTP composts all biosolids on site. Thus, hauling distance and emissions due to hauling is not applicable

(2) Includes PM_{10} and $PM_{2.5}$ emissions in pounds per year. The emission factors to estimate particulate emissions were derived using the equations from *AP-42, Fifth Edition, Vol. I, Section 13.2.1.: Paved Roads (11/2006)*.

(3) Tailpipe emissions in pounds per year resulting from diesel combustion of hauling trucks were based on *Emission standards Reference guide for Heavy-Duty and Nonroad Engines, EPA420-F-97-014 September 1997.* It was assumed that the trucks would meet the emission standards for 1998+.

(4) CO_2 emission factor in pounds per year for hauling trucks were derived from *Rosso and Chau, 2009, WEF Residuals and Biosolids Conference Proceedings.*

(5) Emission factors for electricity are based on EPA Clean Energy Power Profiler (http://www.epa.gov/cleanenergy/energy-and-you/how-clean.html) assuming PacifiCorp UT region commercial customer and *AP-42, Fifth Edition, Vol. I, Chapter 1, Section 1.1.: Bituminous and Sub bituminous coal Combustion (09/1998)*.