

UDWQ POTW Nutrient Removal Cost Impact Study: Analysis of Orem City Water Reclamation 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 evaluations of Orem City Water Reclamation Facility (OCWRF) 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 Ditch (OD)
- Activated Sludge (AS)
- Membrane Bioreactor (MBR)
- Trickling Filter (TF)
- Hybrid Process (Trickling Filter/Solids Contact (TF/SC) or Trickling Filter/Activated Sludge (TF/AS))

OCWRF is currently operating a trickling filter and an oxidation ditch process in parallel. However, they are making modifications to the facility, which will expand the oxidation ditches and decommission the trickling filters; hence, OCWRF will fit 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 ⁽¹⁾	Base condition ⁽¹⁾

Note: ⁽¹⁾ Includes ammonia limits as per the current UPDES Permit

1. Facility Overview

OCWRF has an average annual design flow of 13.6 million gallons per day (mgd) and currently receives an average annual flow of approximately 8.3 mgd. The existing facility operates a trickling filter and an oxidation ditch process in parallel; however, the plant is currently undergoing upgrades and expansion to meet the increasing demands for sewer services, and to satisfy the required discharge limits. The upgrades include primary clarifier capacity expansion, addition of a new oxidation ditch with anaerobic and anoxic zones, addition of anaerobic zones to the existing oxidation ditches, expansion of secondary clarifiers, addition of a new UV disinfection system, improved solids handling and decommissioning the existing trickling filter process. The secondary solids generated from the oxidation ditches will be thickened using dissolved air floatation thickeners. Both primary and secondary solids will be stabilized using two-phase thermophilic and mesophilic anaerobic digestion and mechanically dewatered using belt filter presses before being used for land application. The process flow schematic of the new facility is presented in Figure 1 and an aerial photo of the existing facility is shown in Figure 2. All major new unit processes are summarized in Table 2.

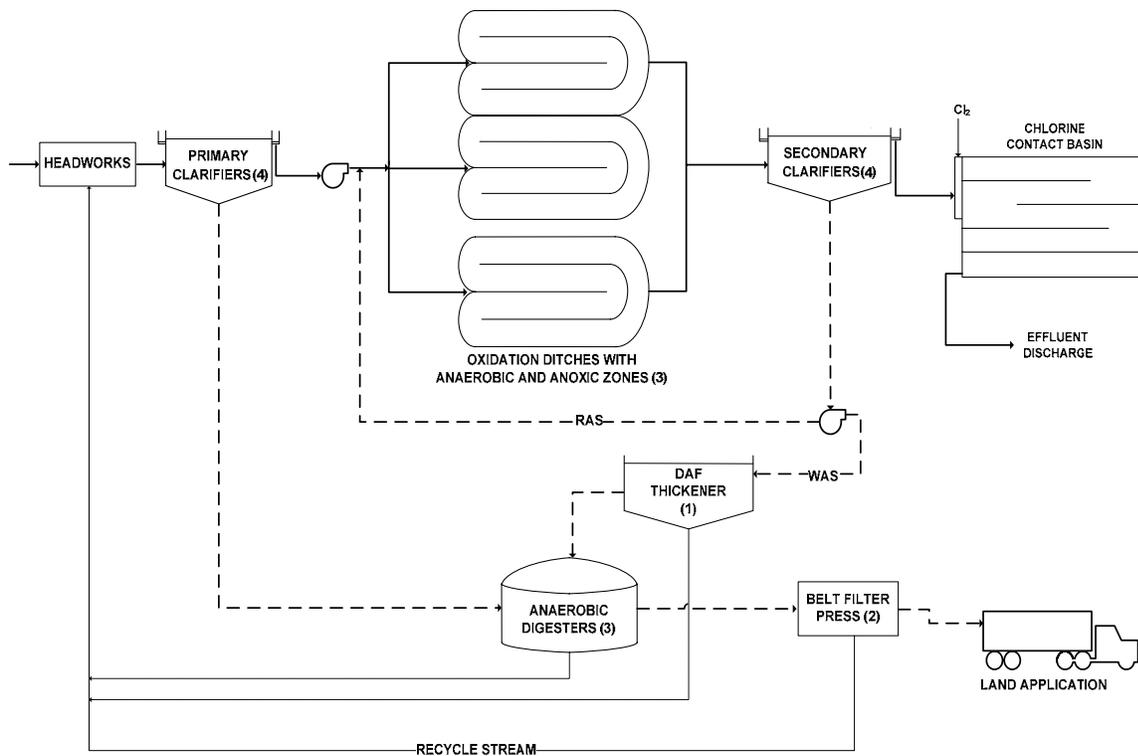


FIGURE 1
Process Flow Diagram of OCWRF

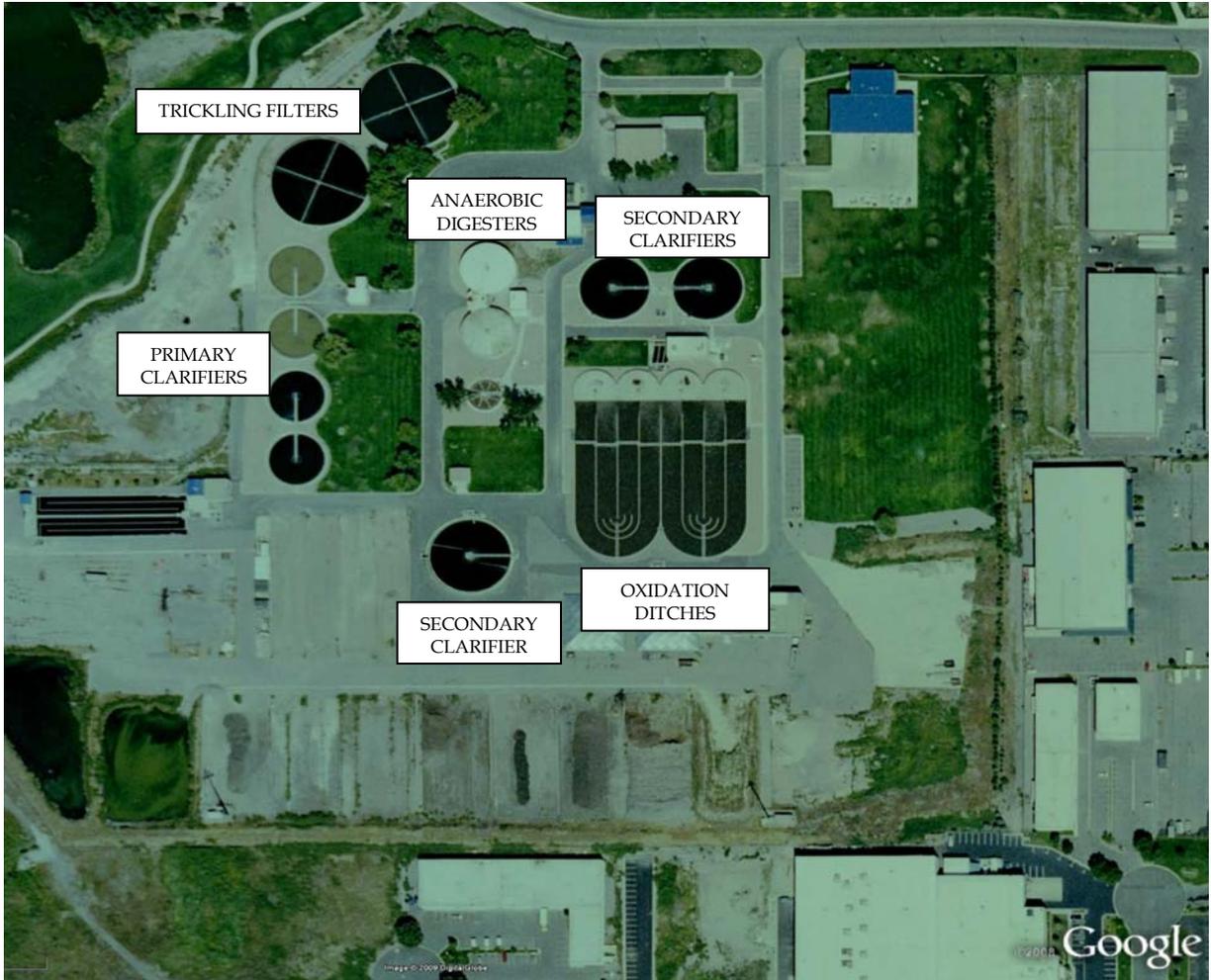


FIGURE 2
Aerial View of OCWRF

TABLE 2

Summary of Major Unit Processes

Treatment step	Number of Units	Size, each	Details
Primary Clarifiers	4	75-ft diameter, 8.5-ft SWD	Round clarifiers
Oxidation Ditches	3	3.8 MG, 15-ft SWD	With surface and diffused aerators
Secondary Clarifiers	4	100-ft diameter (2), 120-ft diameter (2)	Round clarifiers
Sludge Thickening	1	60-ft diameter	Dissolved air floatation
Anaerobic Digestion	3	0.695 MG (2) 1.0 MG (1)	One thermophilic and two mesophilic anaerobic digesters operating in series
Sludge Dewatering	2	2.2 meter	Belt filter presses

2. Nutrient Removal Alternatives Development, Screening and Selection

A nutrient removal alternatives matrix was prepared 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 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.

OCWRF is in the process of upgrading to three (3) oxidation ditches with specific anaerobic and anoxic zones that are capable of achieving biological nutrient removal. This being the case, it was proposed to optimize the use of the new facility and make suitable additions as required to meet the different tiers of nutrient control. Figure 3 shows the selected upgrade approach used between each tier of nutrient control with the bullet points A through D (below) describing each upgrade step:

- A. From Tier 3 (existing process) to Tier 2 phosphorus control, a metal-salt addition was implemented at the secondary clarifiers as a back-up to enhanced biological phosphorus removal occurring in the oxidation ditches.
- B. To go from Tier 2 to Tier 2N, no additional process modification was required.
- C. To go from Tier 2 to Tier 1 level of phosphorus control, deep bed granular media filters and an intermediate pump station were added to the facility with an additional metal-salt feed point before the filters.

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

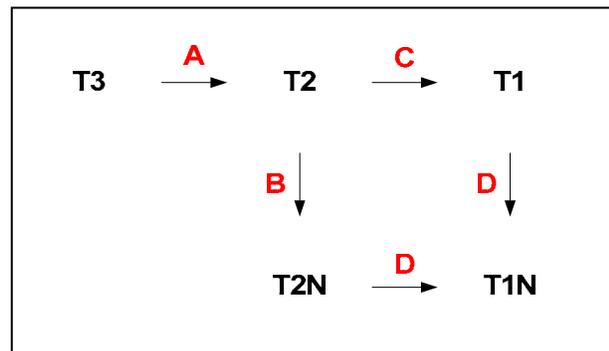


FIGURE 3
Upgrades Scheme for Meeting Increasingly More Stringent Nutrient Control

Data Evaluation and Modeling of Upgrades

The selected progression of upgrades conceived for meeting the different tiers of nutrient control for OCWRF 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 from OCWRF per the initial data request and the new design criteria 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 (Attachment B) for additional information.

TABLE 3
Summary of Input Conditions

Input Parameter	2009 ⁽¹⁾	2029 ⁽²⁾	Design ⁽³⁾
Flow, mgd	8.34	10	16.5
BOD, lb/day	20,133 (289 mg/L)	24,103 (289 mg/L)	48,163 (350 mg/L)
TSS, lb/day	17,593 (250 mg/L)	20,850 (250 mg/L)	48,163 (350 mg/L)
TKN, lb/day	2,919 (42 mg/L)	3,486 (42 mg/L)	5,780 (42 mg/L)
TP, lb/day	345 (5 mg/L)	417 (5 mg/L)	688 (5 mg/L)

⁽¹⁾ Historic conditions 2008

⁽²⁾ Assumed based on increase in population provided by the POTW

⁽³⁾ Design maximum month capacity of the POTW (assumed 1.2 times the design annual average flow)

The main sizing and operating design criteria that are associated with the system upgrades for OCWRF are summarized in Table 4.

TABLE 4
Main Unit Process Sizing and Operating Design Parameters

Design Parameter (Nutrient Tier)	Value
Influent design temperature	14 deg C
Target metal:PO ₄ -P molar Ratio (All Tiers)	2:1, 7:1 ⁽¹⁾
Metal salt storage (T2 and T2N)	5 days
Metal salt storage (T1 and T1N)	14 days
Nitrification Safety Factor (T2N and T1N)	2 ⁽³⁾
SVI (All Tiers)	180
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. Filter doses are for Tier 1 and 1N only

⁽²⁾ Hydraulic loading rate at peak hourly flow

⁽³⁾ SRT in the BNR process adjusted to maintain nitrification safety factor of 2

3. Nutrient Upgrade Approaches

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

Tier 2 - Phosphorus (A)

This Tier has an effluent limit of 1.0 mg/L total phosphorus. With the new upgrades, OCWRF would be able to achieve this limit without any process modifications. However, a metal-salt feed system was added upstream of the secondary clarifiers to serve as a back-up to the biological phosphorus removal process. A process flow diagram for this alternative is presented in Figure 4 with the upgrade indicated in red.

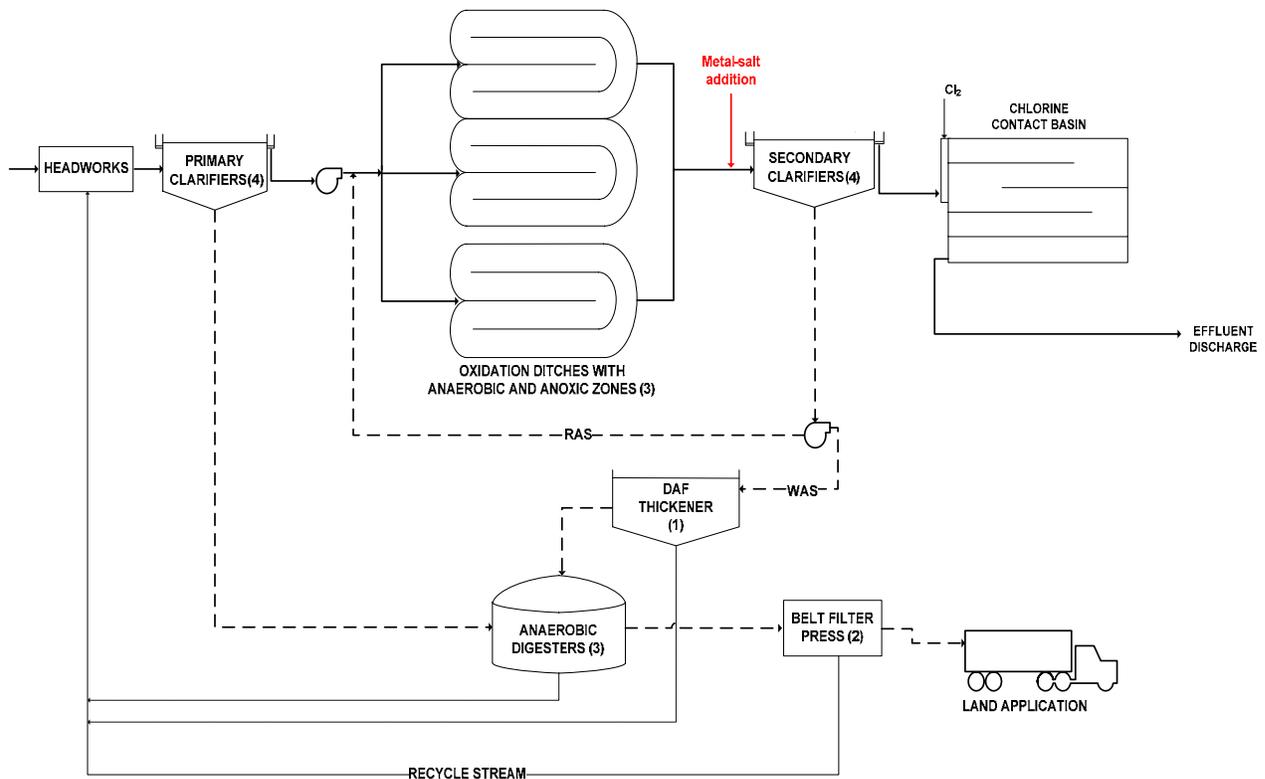


FIGURE 4
Modifications to POTW for Tier 2 Nutrient Control

Tier 2N - Phosphorus & Nitrogen (B)

The effluent limits for this Tier is 1 mg/L total phosphorus and 20 mg/L total nitrogen. The single metal-salt feed point approach identified in Tier 2 would not require any adjustment to achieve the total nitrogen removal in addition to phosphorus. As per process modeling, the modified oxidation ditch process would be able to exhibit sufficient biological nitrogen removal to meet this limit. Therefore, the process flow diagram for this approach is the same as presented in Figure 4.

Tier 1 - Low Phosphorus (C)

This alternative builds upon the Tier 2 approach for phosphorus control to meet 0.1 mg/L total phosphorus limit. The settled effluent from the secondary clarifiers was pumped to new deep bed granular media filters. A second feed point for metal-salt addition was introduced upstream of these filters. The metal-salt feed point at the secondary clarifiers was retained and operated as required. A process flow diagram of this approach is provided in Figure 5.

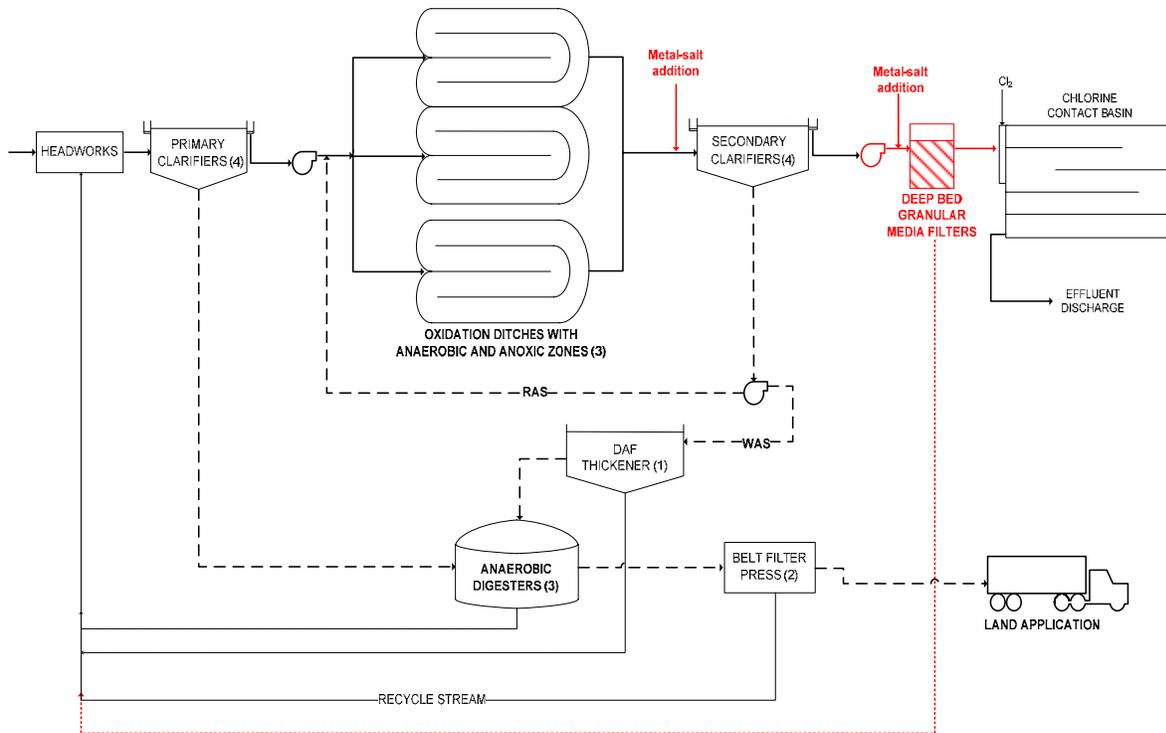


FIGURE 5
Modifications to POTW for Tier 1 Nutrient Control

Tier 1N - Phosphorus & Nitrogen (D)

The process modeling efforts show that the addition of a granular media filtration system proposed in Tier 1 would be capable of achieving the nutrient limits specified for this Tier. The oxidation ditch process would be able to meet 10 mg/L total nitrogen limit; therefore, the process flow diagram for this approach would be the same as presented in Figure 5.

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

This section summarizes the cost-impact results from the 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, metal-salt storage facility and new feed pumps were required upstream of the secondary clarifiers. For Tier 1 and 1N, a secondary effluent pump station was installed to lift the secondary effluent to the new deep bed granular media filters. A new metal-salt feed system was added upstream of the filters to provide chemical phosphorus polishing.

TABLE 5
Major Facility Upgrade Summary

Processes	Tier 2	Tier 2N	Tier 1	Tier 1N
Metal-salt feed and storage facility	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 pumps and storage facility	\$0.40	\$0.40	\$0.97	\$0.97
Secondary effluent pump station	\$0	\$0	\$6.19	\$6.19
Deep bed granular media filtration system	\$0	\$0	\$24.79	\$24.79
TOTAL TIER COST	\$0.40	\$0.40	\$31.95	\$31.95

December 2009 US Dollars

Incremental O&M costs associated with meeting each tier of nutrient standard were generated for the years 2009 and 2029. As no data was provided by the POTW, the unit costs were assumed based on the average costs in the State of Utah, and are presented in Table 7. A round trip hauling distance was also assumed and is stated in Table 7. A straight line interpolation was used to estimate the differential cost for the two years. O&M cost estimates for each upgrade included the following components:

- Biosolids management: hauling , use, and disposal
- Chemical consumption costs: metal-salt, and, polymer
- Power costs for the major mechanized process equipment: secondary effluent pumps, and backwash pumps

TABLE 7
Operating and Maintenance Unit Costs

Parameter	Value
Biosolids handling	\$16/wet ton
Round trip hauling distance ⁽¹⁾	90 miles
Alum	\$480/ton
Polymer	\$1/lb
Power	\$0.06/kwh

⁽¹⁾ Provided by the POTW

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	0.001	0.011	0.001	0.011	\$0.033	\$0.041	\$0.033	\$0.041
Metal-salt	0.002	0.002	0.002	0.002	\$0.227	\$0.255	\$0.227	\$0.255
Polymer	0.000	0.001	0.000	0.001	\$0.004	\$0.005	\$0.004	\$0.005
Power	0.000	0.000	0.000	0.000	\$0.084	\$0.104	\$0.084	\$0.104
Total O&M	\$0.003	\$0.014	\$0.003	\$0.014	\$0.348	\$0.405	\$0.348	\$0.405

Note: \$ Million (US) in December 2009.

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

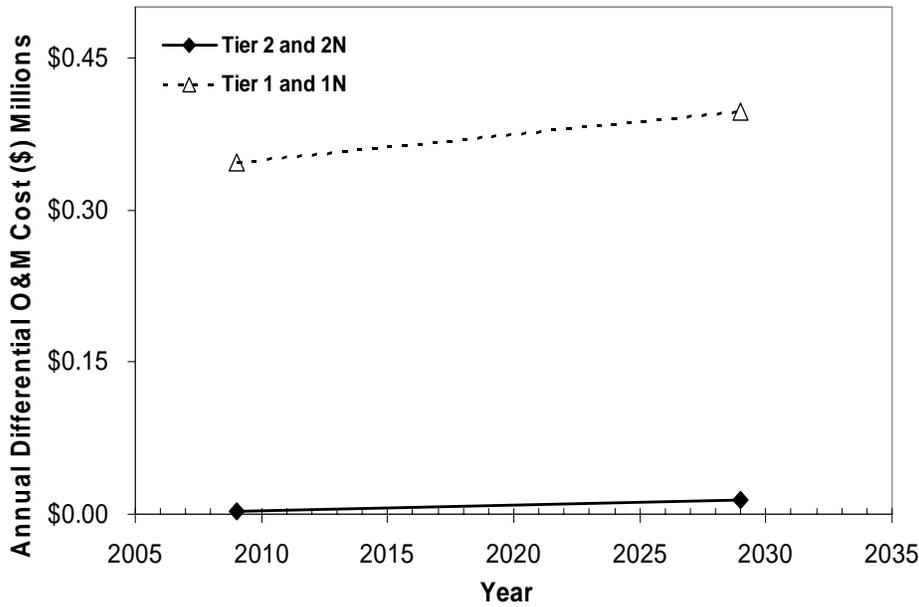


FIGURE 6
Impact of Nutrient Control on O&M Costs over 20 year evaluation period

5. Financial Impacts

This section presents the estimated financial impacts that would result from the implementation of nutrient discharge standards for OCWRF. 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 OCWRF.

TABLE 9

<i>Nutrient Removal: 20-Year Life Cycle Cost per Pound¹</i>				
	Tier 2	Tier 2N	Tier 1	Tier 1N
Phosphorus Removal (pounds) ²	meets limit	meets limit	504,975	504,975
Nitrogen Removal (pounds) ²	-	meets limit	-	meets limit
Net Present Value of Removal Costs³	\$ 540,770	\$ 540,770	\$ 37,551,159	\$ 37,551,159
NPV: Phosphorus Allocation	540,770	540,770	37,551,159	37,551,159
NPV: Nitrogen Allocation ⁴		-		-
TP Cost per Pound⁵	NA	NA	\$ 74.36	\$ 74.36
TN Cost per Pound⁵		NA		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 customers served by the POTW. The financial impact is 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 OCWRF are presented in Table 10.

TABLE 10

<i>Projected Monthly Bill Impact per Equivalent Residential Unit (ERU) for Treatment Alternatives</i>				
	Tier 2	Tier 2N	Tier 1	Tier 1N
Initial Capital Expenditure	\$ 411,000	\$ 411,000	\$ 31,948,000	\$ 31,948,000
Estimated Annual Debt Service ¹	\$ 33,000	\$ 33,000	\$ 2,563,600	\$ 2,563,600
Incremental Operating Cost ²	3,600	3,600	349,400	349,400
Total Annual Cost Increase	\$ 36,600	\$ 36,600	\$ 2,913,000	\$ 2,913,000
Number of ERUs	21,000	21,000	21,000	21,000
Annual Cost Increase per ERU	\$1.74	\$1.74	\$138.71	\$138.71
Monthly Cost Increase per ERU³	\$0.15	\$0.15	\$11.56	\$11.56
Current Average Monthly Bill ⁴	\$24.88	\$24.88	\$24.88	\$24.88
Projected Average Monthly Bill⁵	\$25.03	\$25.03	\$36.44	\$36.44
Percent Increase	0.6%	0.6%	46.5%	46.5%
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 OCWRF is shown in Table 11.

TABLE 11

<i>Community Financial Impacts: Affordability of Treatment Alternatives</i>				
	Tier 2	Tier 2N	Tier 1	Tier 1N
Median Annual Gross Income (MAGI) ^{1,2}	\$ 34,000	\$ 34,000	\$ 34,000	\$ 34,000
Affordability Threshold (% of MAGI) ³	1.4%	1.4%	1.4%	1.4%
Monthly Affordability Criterion	\$39.67	\$39.67	\$39.67	\$39.67
Projected Average Monthly Bill	\$25.03	\$25.03	\$36.44	\$36.44
Meets State's Affordability Criterion?	Yes	Yes	Yes	Yes
Estimated Bill as % of State Criterion	63%	63%	92%	92%
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
- Changes in emissions from biosolids hauling and disposal and energy consumption

As per the data received from OCWRF and per process modeling of the base condition (Tier 3), OCWRF 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 OCWRF 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	0	0	22,850	22,850
Total nitrogen removed, lb/year	----	0	----	0

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 OCWRF 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)

STORET LOCATION	STORET ID	FLOW (cfs)	Tier 3		Tier 2		Tier 2N		Tier 1		Tier 1N	
			TP	TN	TP	TN	TP	TN	TP	TN	TP	TN
OCWRF	----	12.90	1.00	10.00	1.0	N/A	1.0	20.0	0.1	N/A	0.1	10.0
Powell Slough	4995260	4.54	1.69	2.65	----	----	----	----	----	----	----	----
Combined Concentration			1.18	8.09	1.18	N/A	1.18	8.09	0.52	N/A	0.52	8.09

The process upgrades established to meet the four tiers of nutrient standards would require increased energy consumptions, chemical usage and biosolids production. Regular metal-salt addition would be required 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	7,000	7,000	943,900	943,900
Polymers, lb/year	0	0	3,650	3,650
Biosolids Management:				
Biosolids produced, ton/year	1	1	350	350
Average daily hauling distance ⁽¹⁾	0	0	1400	1400
Particulate emissions from hauling trucks, lb/year ⁽²⁾	0	0	78	78
Tailpipe emissions from hauling trucks, lb/year ⁽³⁾	0	0	180	180
CO ₂ emissions from hauling trucks lb/year ⁽⁴⁾	0	0	17,800	17,800
Energy Consumption:				
Annual energy consumption, kwh	0	0	1,100,500	1,100,500
Air pollutant emissions, lb/year ⁽⁵⁾				
CO ₂	0	0	992,650	992,650
NO _x	0	0	1,540	1,540
SO _x	0	0	1,320	1,320
CO	0	0	70	70
VOC	0	0	10	10
PM ₁₀	0	0	22	22
PM _{2.5}	0	0	11	11

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

⁽¹⁾ Based on a round trip hauling distance of 90 miles for land application and, on the assumption that the facility uses 22 ton trucks for hauling biosolids.

⁽²⁾ Includes PM₁₀ 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⁾ CO₂ 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)*.