UDWQ POTW Nutrient Removal Cost Impact Study: Analysis of Tooele Wastewater Reuse Facility

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COPIES: Tooele Wastewater Reuse 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 Tooele Wastewater Reuse Facility (TWRF) 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))

The TWRF 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 [1]	Base condition [1]

Note: [1] Includes ammonia limits as per the current UPDES Permit

1. Facility Overview

This facility is designed for an annual average flow of 3.4 million gallons per day (mgd) and currently receives an average annual influent flow of approximately 1.8 mgd. The facility operates an oxidation ditch process with anaerobic selectors upstream of it. The filtered and disinfected effluent from the facility is discharged into storage ponds and reused. Residual secondary solids are gravity thickened and dewatered using belt presses before being used or disposed. TWRF has a lime stabilization process for generating Class A biosolids. A process flow diagram of the existing facility 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.

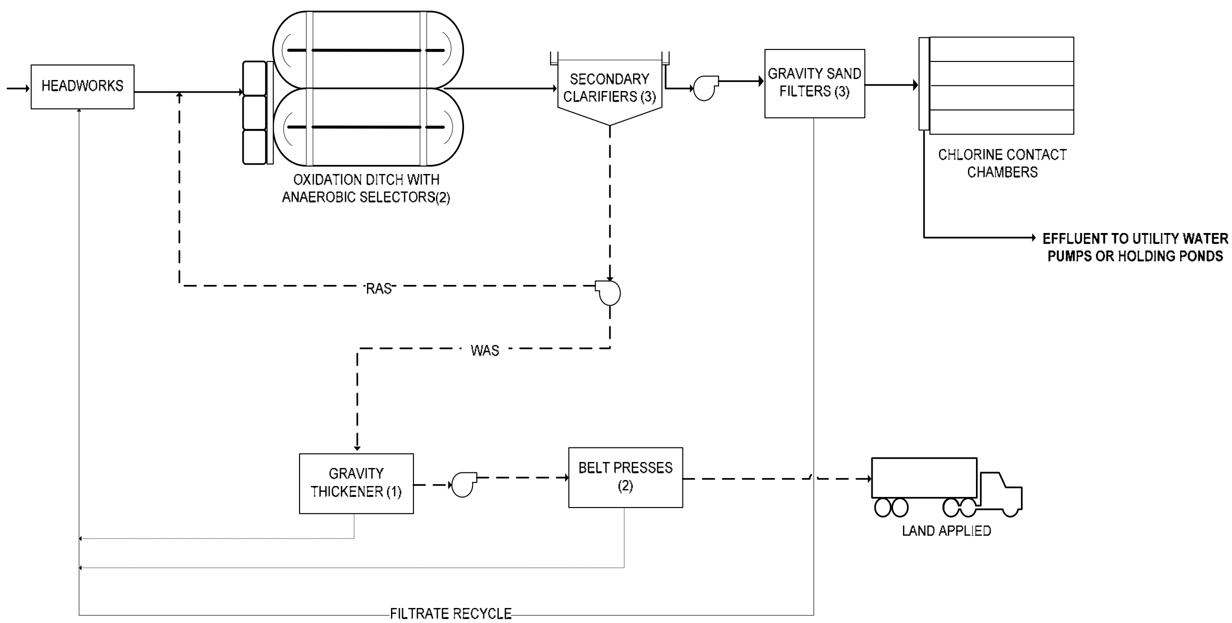

FIGURE 1
Process Flow Diagram

FIGURE 2
Aerial View of the Facility

TABLE 2
Summary of Major Unit Processes

Unit Process	Number of Units	Size, Each	Details
Oxidation ditch	2	1.225 MG, 12-ft SWD	Kruger configuration
Secondary clarifiers	3	Two at 60-ft diameter, 12-ft SWD One at 60-ft diameter, 14-ft SWD	Round clarifiers
Filtration	3	430-ft^2	Traveling bridge sand filters
WAS thickening	1	0.065 MG	Gravity thickening
Sludge dewatering	2	1.2 meter	Belt presses

2. Nutrient Removal Alternatives Development, Screening and Selection

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.

TWRF has two (2) oxidation ditches with anaerobic selectors, three (3) secondary clarifiers, sand traveling bridge filters and the capability of reusing their effluent. With the existing infrastructure, the facility is already achieving some biological nutrient removal. This being the case, it was decided to make use of the existing infrastructure and add upgrades as required. Figure 3 shows the selected upgrade approach used between each tier of nutrient standard with the following bullet points A through D describing each upgrade step:

A. From Tier 3 (existing) to Tier 2 phosphorus control, a metal-salt addition system was initiated at the secondary clarifiers to be used only as a backup to biological phosphorus removal occurring in the oxidation ditch process with anaerobic selectors.

B. To add nitrogen control from Tier 2 to Tier 2N, no additional process modifications were required.

C. To go from Tier 2 to Tier 1 level of phosphorus control, the existing sand traveling bridge filters were replaced with deep bed granular media filters with a second metal-salt feed point upstream of these filters for chemical phosphorus polishing.

D. For Tier 1N, the upgrades from Tier 2N and Tier 1 were combined.

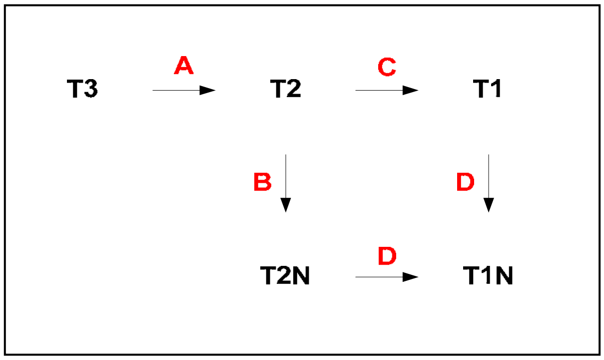

FIGURE 3
Upgrades Scheme for Meeting Increasingly More Stringent Nutrient Control

Data Evaluation and Modeling of Upgrades

The selected progression of upgrades conceived for meeting the different tiers of nutrient control for TWRF 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 TWRF per the initial data request and per follow-up emails 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. Note that TWRF projected their 2029 flows and loads to be same as the plant design capacity. It was decided to cap the flow and load at the design capacity in order to avoid accounting for modifications for capacity adjustments rather than for changes in nutrient limits.

TABLE 3
Summary of Input Conditions

Input Parameter	2009(1)	2029(2)	Design(3)
Flow, mgd	1.80	2.80	3.40
BOD, lb/day	3634 (242 mg/L)	5604 (240 mg/L)	6815 (240 mg/L)
TSS, lb/day	3257 (217 mg/L)	5838 (250 mg/L)	7089 (250 mg/L)
TKN, lb/day	681 (45 mg/L)	934 (40 mg/L)	1134 (40 mg/L)
TP, lb/day	130 (8.65 mg/L)	202 (8.65 mg/L)	245 (8.65 mg/L)

(1) Historic conditions for the year 2007-2009
(2) 2029 flow and loads projected to conserve the plant design capacity
(3) Design average capacity of the POTW

The main sizing and operating design criteria that were associated with the system upgrade for TWRF 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 Factors	2.0(3)
Granular filter loading rate (T1 and T1N)	5 gpm/ft^2 (2)

(1)Target dosing ratio at the secondary clarifiers and upstream of gravity filter, respectively. Filter doses were for Tier 1 and 1N only

(2)Hydraulic loading rate at peak hourly flow

(3) SRT in the BNR process adjusted to maintain a nitrification safety factor of 2.0

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 alternative is 1.0 mg/L total phosphorus. As per operational data received and per process modeling, TWRF already has the ability to achieve this limit with its existing infrastructure and mode of operation. However, a metal-salt addition system was implemented at the secondary clarifiers as a backup to enhanced biological phosphorus uptake by the oxidation ditch process with anaerobic selectors. A process flow diagram for this treatment approach is presented in Figure 4 with the upgrades indicated in red.

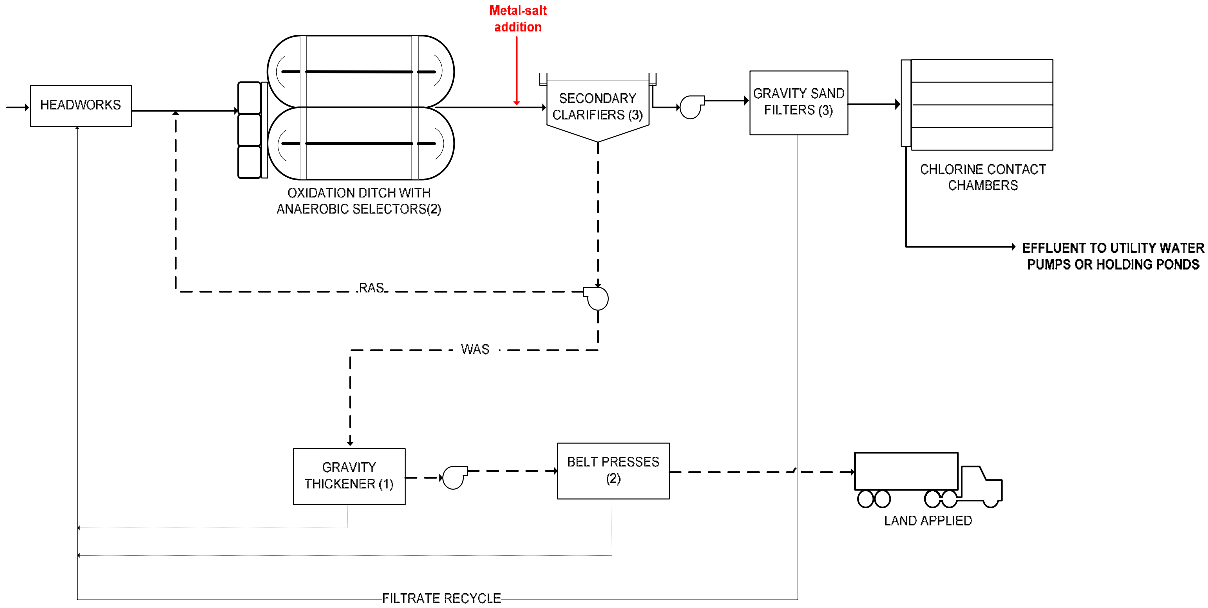

FIGURE 4
Modifications to POTW for Tier 2 Nutrient Control

Tier 2N – Phosphorus & Nitrogen (B)

Similar to Tier 2, Tier 2N required the single metal-salt feed point at the secondary clarifiers to achieve 2N levels of nitrogen and phosphorus control. The existing oxidation ditch process at the POTW is already exhibiting sufficient biological nutrient removal to meet the 20 mg/L total nitrogen limit specified for this Tier. Therefore, the process flow diagram for this approach would be the same as presented in Figure 4.

Tier 1 Phosphorus (C)

This alternative builds upon the Tier 2 approach for phosphorus control; however, to meet 0.1 mg/L TP, metal-salt was used regularly. The existing sand traveling bridge filters were replaced by deep bed granular media filters with a second metal-salt feed point upstream of the filters for chemical phosphorus polishing. A process flow diagram of this approach is provided in Figure 5.

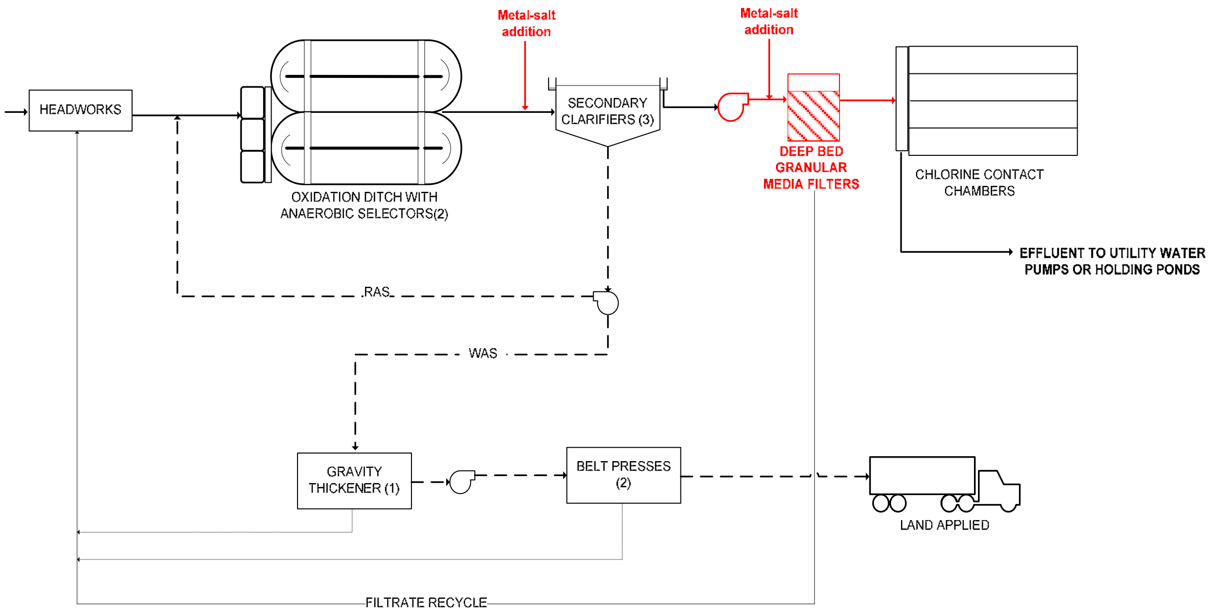

FIGURE 5
Modifications to POTW for Tier 1 Nutrient Control

Tier 1N Phosphorus & Nitrogen (D)

The process modeling indicates that the modifications proposed in Tier 1 were sufficient for achieving nutrient control for Tier 1N. This Tier would therefore be identical to Tier 1 and the process flow diagram would be the same as Figure 5.

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

This section summarizes 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 components identified for facility upgrade for meeting each tier of nutrient control. For Tier 2 and Tier 2N, metal-salt storage facility and new metal-salt feed pumps were installed at the secondary clarifiers. For Tier 1 and 1N, in addition to the metal-salt feed system at the secondary clarifiers, the existing traveling bridge filters were replaced by deep bed granular media filters and a metal-salt storage facility and new feed pumps upstream of the filters.

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

Unit Process Facility	Tier 2	Tier 2N	Tier 1	Tier 1N
Metal-salt feed pumps and storage facility	$145,108	$145,108	$483,693	$483,693
Secondary effluent pump station	$0	$0	$1,958,958	$1,958,958
Deep bed granular media filtration system	$0	$0	$7,956,753	$7,956,753
TOTAL TIER COST	**$145,108**	**$145,108**	**$10,399,404**	**$10,399,404**

December 2009 US Dollars

Incremental O&M costs associated with meeting each tier of nutrient standard were generated for the years 2009 and 2029. These costs were derived from the unit costs provided by the POTW as presented in Table 7. If unit costs were not provided, they were assumed based on the average costs in the State of Utah. 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:

- 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
Ferric Chloride	$1000/ton
Polymer	$1/lb
Power	$0.06/kwh
Biosolids hauling	$7/wet ton
Biosolids tipping fee	$8/wet ton
Round trip hauling distance (1)	0

(1) The biosolids hauling distance is negligible for this facility, as it is hauled across the street.

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	$0	$0	$0	$14,250	$19,720	$14,250	$19,720
Metal-salt	$1,500	$2,355	$1,500	$2,355	$273,750	$383,250	$273,750	$383,250
Polymer	$0	$0	$0	$0	$1,700	$2,350	$1,700	$2,350
Power	$900	$1,445	$900	$1,445	$27,900	$40,480	$27,900	$40,480
Total O&M	**$2,400**	**$3,800**	**$2,400**	**$3,800**	**$317,600**	**$445,800**	**$317,600**	**$445,800**

Note: $ (US) in December 2009.

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

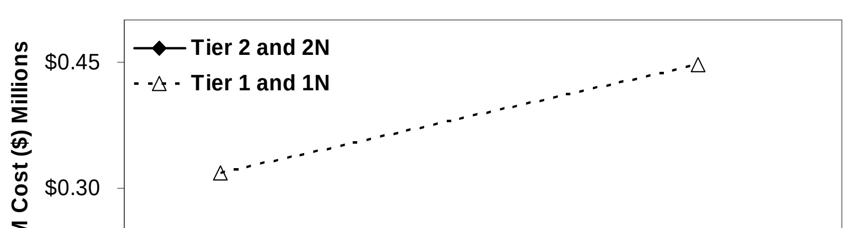

FIGURE 6
Impact of Nutrient Control on O&M Costs over 20 year evaluation period

5. Financial Impacts

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

TABLE 9

Nutrient Removal: 20-Year Life Cycle Cost per Pound [1]

	Tier 2	Tier 2N	Tier 1	Tier 1N
Phosphorus Removal (pounds)[2]	meets limit	meets limit	127,457	127,457
Nitrogen Removal (pounds)[2]	-	meets limit	-	meets limit
Net Present Value of Removal Costs[3]	**$ 192,017**	**$ 192,017**	**$ 16,201,066**	**$ 16,201,066**
NPV: Phosphorus Allocation	192,017	192,017	16,201,066	16,201,066
NPV: Nitrogen Allocation[4]		-		-
TP Cost per Pound[5]	**NA**	**NA**	**$ 127.11**	**$ 127.11**
TN Cost per Pound[5]		**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 TWRF 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	$ 145,000	$ 145,000	$ 10,399,000	$ 10,399,000
Estimated Annual Debt Service[1]	$ 11,600	$ 11,600	$ 834,400	$ 834,400
Incremental Operating Cost[2]	2,500	2,500	324,100	324,100
Total Annual Cost Increase	$ 14,100	$ 14,100	$ 1,158,500	$ 1,158,500
Number of ERUs	6,760	6,760	6,760	6,760
Annual Cost Increase per ERU	$2.09	$2.09	$171.38	$171.38
Monthly Cost Increase per ERU[3]	**$0.17**	**$0.17**	**$14.28**	**$14.28**
Current Average Monthly Bill[4]	$23.71	$23.71	$23.71	$23.71
Projected Average Monthly Bill[5]	**$23.88**	**$23.88**	**$37.99**	**$37.99**
Percent Increase	**0.7%**	**0.7%**	**60.2%**	**60.2%**

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) w ithin 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 TWWTP 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]	$ 42,900	$ 42,900	$ 42,900	$ 42,900
Affordability Threshold (% of MAGI)[3]	1.4%	1.4%	1.4%	1.4%
Monthly Affordability Criterion	**$50.05**	**$50.05**	**$50.05**	**$50.05**
Projected Average Monthly Bill	$23.88	$23.88	$37.99	$37.99
Meets State's Affordability Criterion?	Yes	Yes	Yes	Yes
Estimated Bill as % of State Criterion	**48%**	**48%**	**76%**	**76%**

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 TWRF and per process modeling of the base condition (Tier 3), TWRF 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 TWRF 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	4,935	4,935
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.

Attempts were also made to summarize the impact of effluent load reductions on receiving streams or 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 requirements. 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.

For TWRF, no STORET data was found upstream to the POTW discharge point. Thus, total phosphorus and total nitrogen concentration discharged by TWRF for baseline condition (Tier 3) and for each Tier of nutrient standard was not estimated.

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 13 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 13
Estimated Environmental Impacts of Nutrient Control

	Tier 2	Tier 2N	Tier 1	Tier 1N
Chemical Use:				
Metal-salt use, lb/year	3,000	3,000	547,500	547,500
Polymers, lb/year	0	0	1,680	1,680
Biosolids Management:				
Biosolids produced, ton/year	0	0	170	170
Average yearly hauling Distance, miles(1)	0	0	0	0
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	17	17	303,000	303,000
Air pollutant emissions, lb/year (5)				
CO_2	15	15	273,285	273,285
NOx	0	0	424	424
SOx	0	0	363	363
CO	0	0	20	20
VOC	0	0	3	3
PM_{10}	0	0	6	6
$PM_{2.5}$	0	0	3	3

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

(1) TWRF hauls their biosolids across the street from the facility. Thus, hauling distance and emissions due to hauling is assumed to be negligible.

(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)*.