UDWQ POTW Nutrient Removal Cost Impact Study: Analysis of South Valley 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 evaluation of South Valley Water Reclamation Facility (SVWRF) 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 Processes (Trickling Filter/Solids Contact (TF/SC) or Trickling Filter/Activated Sludge (TF/AS))

SVWRF is currently undergoing expansion and upgrades to accommodate more stringent wastewater treatment. Thus, while originally based on the oxidation ditch technology, SVWRF now fits into the Activated Sludge 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

SVWRF has a design flow of 57.5 million gallons per day (mgd) and currently receives an average annual influent flow of approximately 31.7 mgd. The facility has a nitrifying extended aeration process using closed loop reactors, but is currently upgrading to operate an anaerobic/anoxic/aerobic process with a diffused aeration system to treat its influent wastewater. Secondary effluent is disinfected by ultra-violet radiation and aerated prior to discharge. Wasted secondary solids are thickened by dissolved air floatation thickeners and mechanically dewatered using belt filter press to approximately 14% solids. The facility has the option of disposing the dewatered cake to a landfill or produce dry pellets for land application using a thermal dryer. A process flow diagram is presented in Figure 1 and an aerial photo of the POTW is shown in Figure 2. The major existing unit processes are listed in Table 2.

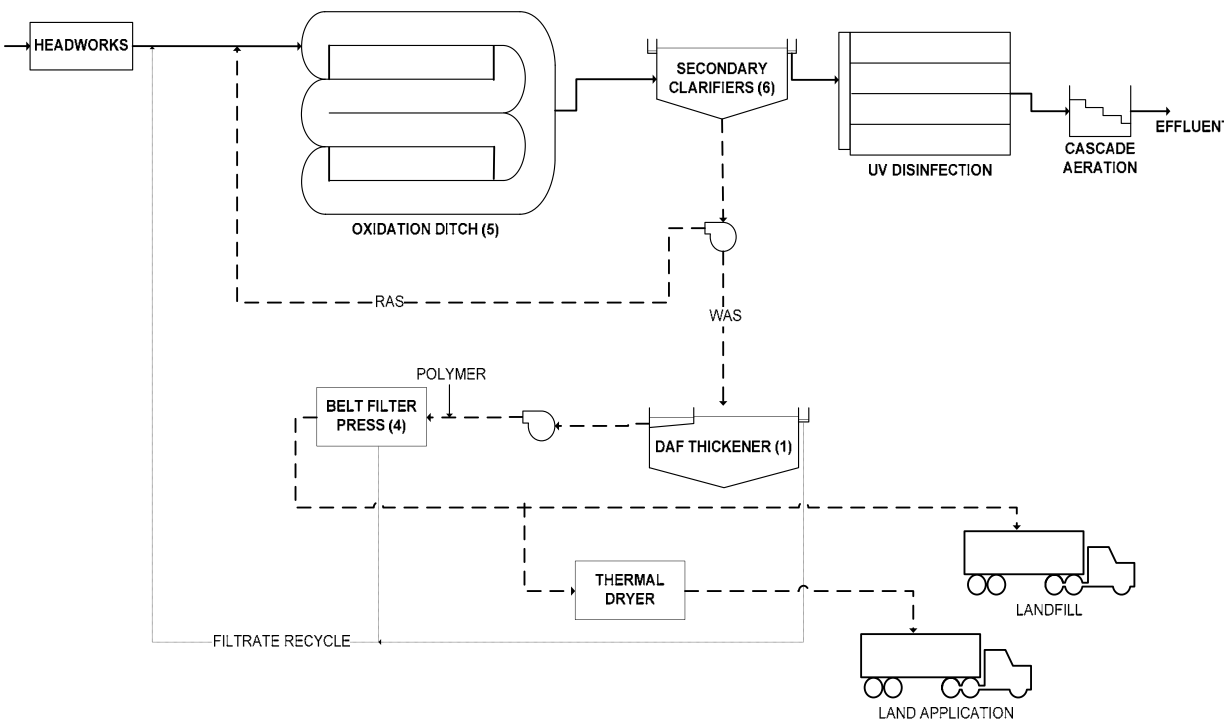

FIGURE 1
Process Flow Diagram

FIGURE 2
Aerial View of the Facility

TABLE 2
Summary of Major Unit Processes

Treatment step	Number of Units	Size, each	Details
Oxidation Ditches	5	6.63 MG, 15.4-ft SWD	Diffused-aeration
Secondary Clarifiers	6	150-ft diameter, 13-ft SWD	Stamford Baffles, Spiral Collection
Dissolved Air Floatation Thickening	2	60-ft diameter	1 Duty + 1 Standby
Belt Filter Press	4	2 meter width	Achieves 14% solids
Thermal Dryer	2	----	----

2. Nutrient Removal Alternatives Development

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 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.

SVWRF is a large POTW with five (5) oxidation ditches and six (6) secondary clarifiers. The ditches are being configured to accommodate anaerobic/anoxic/aerobic zones with nitrified recycle pumps. With these infrastructure and mode of operation, the facility should be able to achieve sufficient biological nutrient removal. This being the case, it was decided to work with the existing facility to the extent possible, and then add upgrades as required. 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) to Tier 2 phosphorus control, no process modifications or upgrades were necessary. However, a metal-salt addition point was added at the secondary clarifier as a back up to biological phosphorus uptake process in the existing ditches.

B. To add nitrogen control to Tier 2, no additional process modification was required.

C. To go from Tier 2 to Tier 1 phosphorus control, deep bed granular media filters and an intermediate pump station was added to the facility with an additional metal-salt feed point upstream of the filters.

D. To add nitrogen control to Tier 1, no additional process modification was required.

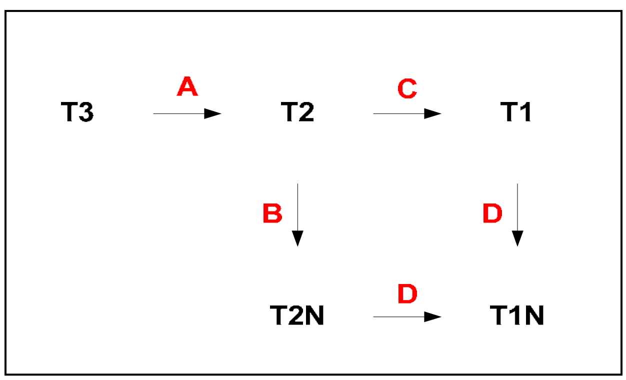

FIGURE 3
Upgrades Scheme for Meeting Increasingly More Stringent Nutrient Control

Data Evaluation, Initial Modeling, and Calibration

The selected progression of upgrades conceived for meeting the different tiers of nutrient control for SVWRF 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 SVWRF 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 (Attachment B) for additional information.

TABLE 3

Summary of Input Conditions

Input Parameter	2009	2029	Design
Flow, mgd	31.7	40.6	57.5
BOD, lb/day	47,944 (181 mg/L)	71,335 (210 mg/L)	95,860 (200 mg/L)
TSS, lb/day	64,027 (240 mg/L)	85,000 (250 mg/L)	95,860 (200 mg/L)
TKN, lb/day	9,758 (37 mg/L)	12,535 (37 mg/L)	14,180 (30 mg/L)
TP, lb/day	1,606 (5 mg/L)	1,690 (5 mg/L)	2,399 (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 SVWRF 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 (All Tiers)	14 days
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.

(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 the Tier 2 alternative is 1.0 mg/L total phosphorus. As per process modeling, SVWRF can achieve this limit without any modifications to the recently upgraded process with specific anaerobic, anoxic and aerobic zones. However, a metal-salt feed point was installed as a back-up to the biological system, upstream of the secondary clarifiers to be operated only as required for chemical phosphorus removal. The overall process flow diagram for this alternative is shown in Figure 4 with the upgrades indicated in red.

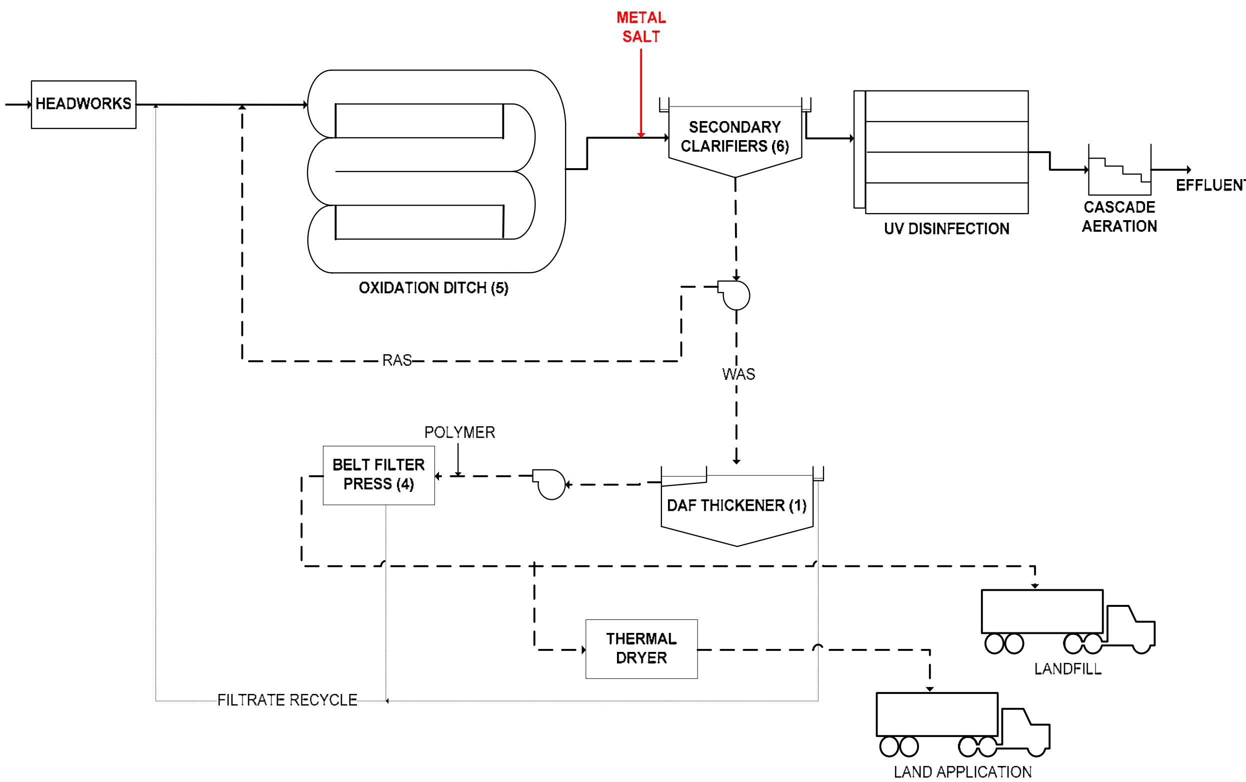

FIGURE 4
Modifications to POTW for Tier 2 Nutrient Control

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 modifications proposed for Tier 2 were capable of meeting these effluent limits with no additional upgrades. Therefore, the overall process flow diagram would be similar to Figure 4.

Tier 1 –Phosphorus (C)

The effluent limit for this alternative is 0.1 mg/L total phosphorus. The approach for this Tier builds upon the upgrades proposed for Tier 2 with the addition of a deep bed granular media filter system with a metal-salt feed point upstream of it. Metal-salt was fed to the secondary clarifiers and upstream of the filter system to ensure contact with soluble phosphorus. According to process modeling, the secondary clarifiers were not overloaded at the design condition and therefore did not warrant tertiary clarifiers upstream of the filter system. A secondary effluent pump station may be required to lift the secondary effluent to the filters, depending on the existing hydraulic profile. The basic process schematic for this alternative is presented as Figure 5.

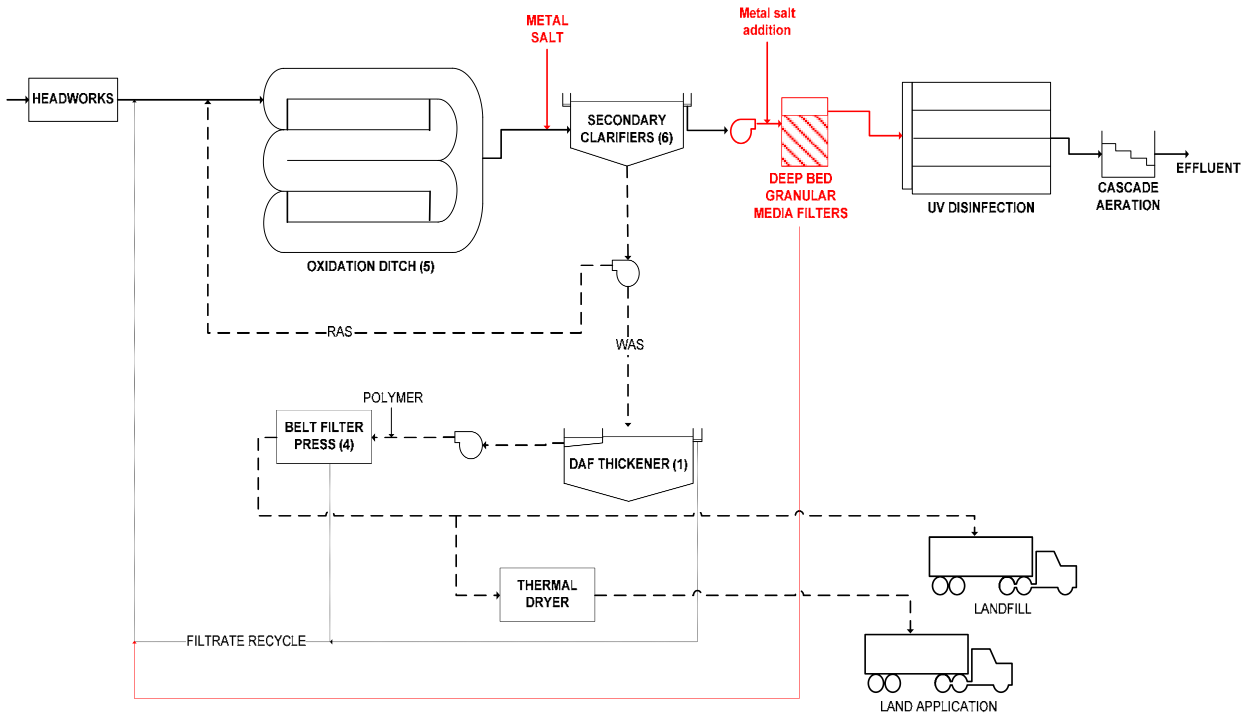

FIGURE 5
Modifications to POTW for Tier 1 Nutrient Goal

Tier 1N – Phosphorus & Nitrogen (D)

The effluent limit for this alternative is 0.1 mg/L total phosphorus and 10 mg/L total nitrogen. Process modeling efforts show that the filtration system proposed for Tier 1 was capable of achieving the Tier 1N effluent requirements. Therefore, Tier 1N would 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 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 components that were identified as facility upgrades for meeting each tier of nutrient control. For Tier 2 and Tier 2N, metal-salt storage facility and new feed pumps were required and for Tier 1 and 1N, a secondary effluent pump station was installed to lift the secondary effluent to a new deep bed granular media filtration system. A second metal-salt feed point with storage facilities and pumps were added upstream of the filters for chemical phosphorus polishing.

TABLE 5
Major Facility Upgrade Summary

Processes	Tier 2	Tier 2N	Tier 1	Tier 1N
Metal salt feed & storage system	X	X	X	X
Secondary effluent pump station			X	X
Deep bed granular media filtration system			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	$0.89	$0.89	$3.68	$3.68
Secondary effluent pump station	$0	$0	$11.85	$11.85
Deep bed granular media filtration system	$0	$0	$68.22	$68.22
TOTAL TIER COST	**$0.89**	**$0.89**	**$83.75**	**$83.75**

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 either provided by the POTW or assumed based on the average costs in the State of Utah used to estimate the O&M costs are presented 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 tipping fee	$20/wet ton
Biosolids hauling cost	$8/wet ton
Round trip hauling distance (1)	60 miles
Alum	$480/ton
Polymer	$0.96/lb
Power	$0.06/kwh

(1) SVWRF sends a third of the biosolids produced to landfill, either at Salt Lake County or at Wasatch Regional. Since the hauling distance to Salt Lake County and to Wasatch Regional is different, an average distance was assumed

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	$0.25	$0.32	$0.25	$0.32
Metal-salt	$0.01	$0.01	$0.01	$0.01	$1.70	$2.47	$1.70	$2.47
Polymer	$0.00	$0.00	$0.00	$0.00	$0.01	$0.01	$0.01	$0.01
Power	$0.00	$0.00	$0.00	$0.00	$0.17	$0.22	$0.17	$0.22
Total O&M	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$2.13**	**$3.02**	**$2.13**	**$3.02**

Note: $ Million (US) in December 2009.

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

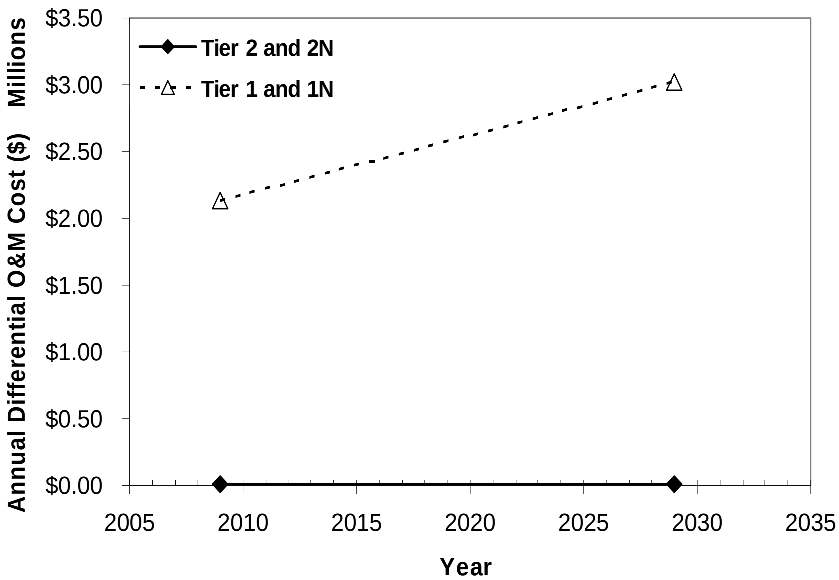

FIGURE 6
Impact of Nutrient Control on O&M Costs over 20 year evaluation period

5. Financial Impacts

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

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	2,013,267	2,013,267
Nitrogen Removal (pounds)[2]	-	meets limit	-	meets limit
Net Present Value of Removal Costs[3]	**$ 1,022,808**	**$ 1,022,808**	**$ 122,911,445**	**$ 122,911,445**
NPV: Phosphorus Allocation	1,022,808	1,022,808	122,911,445	122,911,445
NPV: Nitrogen Allocation[4]		-		-
TP Cost per Pound[5]	**NA**	**NA**	**$ 61.05**	**$ 61.05**
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 w as assumed that the nitrogen cost allocation w as the incremental difference betw een 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 SVWRF 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	$ 895,000	$ 895,000	$ 83,751,000	$ 83,751,000
Estimated Annual Debt Service[1]	$ 71,800	$ 71,800	$ 6,720,400	$ 6,720,400
Incremental Operating Cost[2]	7,400	7,400	2,177,800	2,177,800
Total Annual Cost Increase	$ 79,200	$ 79,200	$ 8,898,200	$ 8,898,200
Number of ERUs	110,800	110,800	110,800	110,800
Annual Cost Increase per ERU	$0.71	$0.71	$80.31	$80.31
Monthly Cost Increase per ERU[3]	**$0.06**	**$0.06**	**$6.69**	**$6.69**
Current Average Monthly Bill[4]	$15.25	$15.25	$15.25	$15.25
Projected Average Monthly Bill[5]	**$15.31**	**$15.31**	**$21.94**	**$21.94**
Percent Increase	**0.4%**	**0.4%**	**43.9%**	**43.9%**

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 SVWRF 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]	$ 43,000	$ 43,000	$ 43,000	$ 43,000
Affordability Threshold (% of MAGI)[3]	1.4%	1.4%	1.4%	1.4%
Monthly Affordability Criterion	**$50.17**	**$50.17**	**$50.17**	**$50.17**
Projected Average Monthly Bill	$15.31	$15.31	$21.94	$21.94
Meets State's Affordability Criterion?	Yes	Yes	Yes	Yes
Estimated Bill as % of State Criterion	**31%**	**31%**	**44%**	**44%**

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, disposal and energy consumption

As per the data received from SVWRF and per process modeling of the base condition (Tier 3), SVWRF 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 9 summarizes the annual reduction in nutrient loads in SVWRF 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 9

Estimated Environmental Benefits of Nutrient Control

	Tier 2	Tier 2N	Tier 1	Tier 1N
Total phosphorus removed, lb/year	0	0	86,850	86,850
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 SVWRF 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**
SVWRF	----	49.51	1.00	10.00	1.0	N/A	1.0	10.0	0.10	N/A	0.10	10
Jordan River at 7800S	4994170	240.74	0.08	1.69	----	----	----	----	----	----	----	----
Combined Concentration			**0.24**	**3.11**	**0.24**	**N/A**	**0.24**	**3.11**	**0.09**	**N/A**	**0.09**	**3.11**

The process upgrades established to meet the four tiers of nutrient standards would 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		30,000	30,000	7,090,000	7,090,000
Polymers, lb/year		0	0	9850	9850
Biosolids Management:					
Biosolids produced, ton/year		0	0	980	980
Average yearly hauling distance[(1)]		0	0	900	900
Particulate emissions from hauling trucks, lb/year [(2)]		0	0	50	50
Tailpipe emissions from hauling trucks, lb/year[(3)]		0	0	115	115
CO_2 emissions from hauling trucks lb/year[(4)]		0	0	11420	11420
Energy Consumption:					
Annual energy consumption, kwh		0	0	175,000	175,000
Air pollutant emissions, lb/year [(5)]					
	CO_2	0	0	157,700	157,700
	NOx	0	0	245	245
	SOx	0	0	210	210
	CO	0	0	10	10
	VOC	0	0	1	1
	PM_{10}	0	0	3	3
	$PM_{2.5}$	0	0	2	2

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 an average daily hauling distance of 60 miles for a third of the biosolids generated.

[(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)*.