UDWQ POTW Nutrient Removal Cost Impact Study: Analysis of a "Model" Lagoon System

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COPIES: Lagoons

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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 a "model" lagoon to meet the four tiers of nutrient standards presented in Table 1. The "model" lagoon is a generic representation of a typical small capacity lagoon POTW in the state of Utah.

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

The average design capacity of the twenty-seven small lagoons in Utah is 0.55 million gallons per day (mgd) and their current annual average influent flow is 0.28 mgd. Most of the lagoons are designed to treat TSS and BOD and has an effluent limit of 45 mg/L TSS and BOD on their effluent stream. A generic process flow diagram of the "model" lagoon is presented in Figure 1, and a list of all the lagoon facilities in Utah with their design capacities is provided in Table 2.

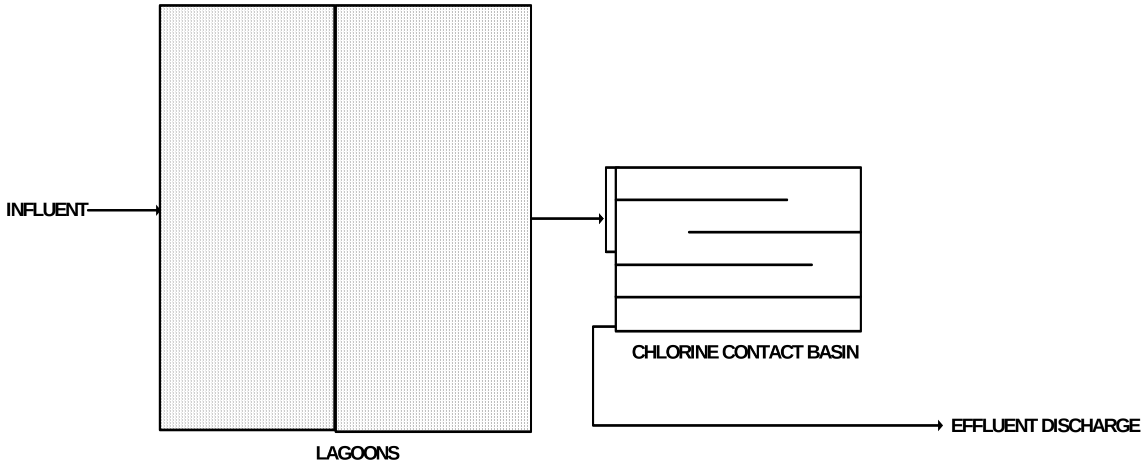

Figure 1
Process Flow Diagram

TABLE 2

List of Lagoon POTWs in Utah

POTW	Design Capacity, mgd
Bear River	0.06
Castle Dale	0.702
Corrine	0.07
Duchesne	0.42
Eureka	0.2
Ferron	0.465
Grantsville	0.76
Green River	0.331
Henefer	0.5
Huntington	0.4
Kamas	2
Lakepoint	0.51
Logan	19.1
Monticello	0.32
Morgan	0.51
Mt. Green	0.25
Neola	Not Available
Perry	Not Available
Plain City	0.75
Richmond	Not Available
Salem	0.98
Santaquin	Not Available
Spring City	0.11
Springdale	0.76
Stansbury Park	1.00
Wellsville	0.67
Wendover	0.34

2. Nutrient Removal Alternatives Development, Screening and Selection

The nutrient removal alternatives developed for the lagoons consider biological and chemical phosphorus removal approaches as well as activated sludge configurations for biological nutrient control. The processes that were modeled and described in subsequent sections are considered proven methods for meeting the nutrient limits. There may be ways to further optimize the suggested methods that are not captured here.

The lagoons are primarily designed to remove TSS and BOD only. To meet the different Tiers of nutrient standards, more conventional chemical and biological treatment processes will be required. Phosphorus can be removed using chemical or biological treatment processes, while nitrogen removal will require a biological process. Keeping this in mind, it was decided to keep the lagoon and add additional infrastructure for Tiers 2 and 1, and build an entirely new mechanical treatment process for Tier 2N and Tier 1N.

Data Evaluation and Modeling of Upgrades

The selected progression of upgrades conceived for meeting the different tiers of nutrient control for a lagoon facility was analyzed using the following four steps:

- Step 1. Review and summarize the information obtained from the Utah Division of Water Quality
- Step 2. Develop and calibrate a base model of the existing POTW using the summarized data
- Step 3. Using the design flow and load, build upon the base model by modifying it to include unit process additions for the different tiers of nutrient control and use model outputs to determine unit process sizing and operating requirements
- Step 4. Summarize model output for the capital and O&M cost development.

The information received from the Division of Water Quality on all small lagoons was evaluated to (a) develop, and validate the base process model, (b) size facilities to conserve the POTW's current rated capacity, and (c) project operating costs from 2009 through 2029. If data was not available, assumptions were made. Table 2 provides a summary of information used as the model input conditions for the "model" lagoon. See process modeling protocol (Attachment B) for additional information.

TABLE 3
Summary of Input Conditions for Small Lagoons

Input Parameter	2009[(1)]	2029[(2)]	Design[(3)]
Flow, mgd	0.28	0.38	0.55
BOD, lb/day	584 (250 mg/L)	793 (250 mg/L)	1,147 (250 mg/L)
TSS, lb/day	561 (240 mg/L)	761 (240 mg/L)	1,102 (240 mg/L)
TKN, lb/day	91 (40 mg/L)	124 (40 mg/L)	179 (40 mg/L)
TP, lb/day	12 (5 mg/L)	16 (5 mg/L)	23 (5 mg/L)

(1) Historic flow conditions. Data on loads were assumed.
(2) The flow and loads were calculated assuming an annual growth rate of 1.6%
(3) Reported design capacity of the lagoon. The design loads were maintained same as current loads

The main sizing and operating design criteria that were important for capturing the costs associated with the selected upgrade approach for lagoon facilities are summarized in Table 4.

TABLE 4
Main Unit Process Sizing and Operating Design Parameters

Design Parameter (Nutrient Tier)	Value
Target metal:PO_4-P molar Ratio to the secondary clarifier and filters (All Tiers)	2:1, 7:1
Metal-salt storage (Tier 2N)	5 days
Metal-salt storage (Tier 1, Tier 1 and Tier 1N)	14 days
Mixed-Liquor return pumping ratio as a percent of influent Flow (Tier 2N and Tier 1N)	100% to 150%
Granular filter loading rate (Tier 1 and Tier 1N)	5 gpm/ft^2 (1)

(1) 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 2.

Tier 2 Phosphorus (A)

The nutrient limit of this alternative is 1.0 mg/L total phosphorus. The "model" lagoon can achieve the 1.0 mg/L total phosphorus by adding a secondary clarifier which would receive the effluent from the lagoons. A metal-salt feed point would be implemented ahead of the clarifier for chemical phosphorus removal. A process flow diagram for this treatment approach is presented in Figure 2.

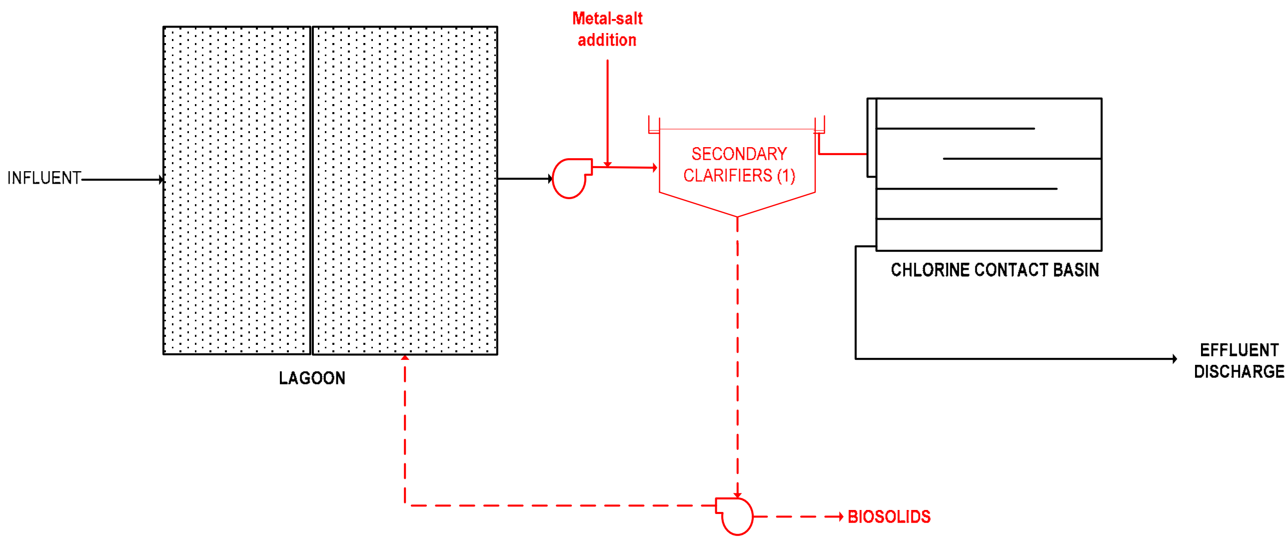

FIGURE 2
Modifications to POTW for Tier 2 Nutrient Control

Tier 2N – Phosphorus & Nitrogen (B)

To meet the 1.0 mg/L total phosphorus and 20 mg/L total nitrogen limit of this Tier, the existing lagoon treatment plant would be abandoned and a new mechanical treatment facility would be built to replace it. The new mechanical facility would have influent pump station, headworks and a biological nutrient removal process complete with engineered anaerobic, anoxic and aerobic zones and a mixed liquor recirculation system for efficient biological phosphorus and nitrogen removal. New secondary clarifiers would be installed with a metal-salt feed facility ahead of it that would serve as a back-up to the biological phosphorus removal process. The effluent would be disinfected using an UV disinfection system, before being discharged to the receiving streams. The secondary residual solids would be dewatered by implementing a mechanical dewatering system. A process flow diagram for this treatment approach is presented in Figure 3.

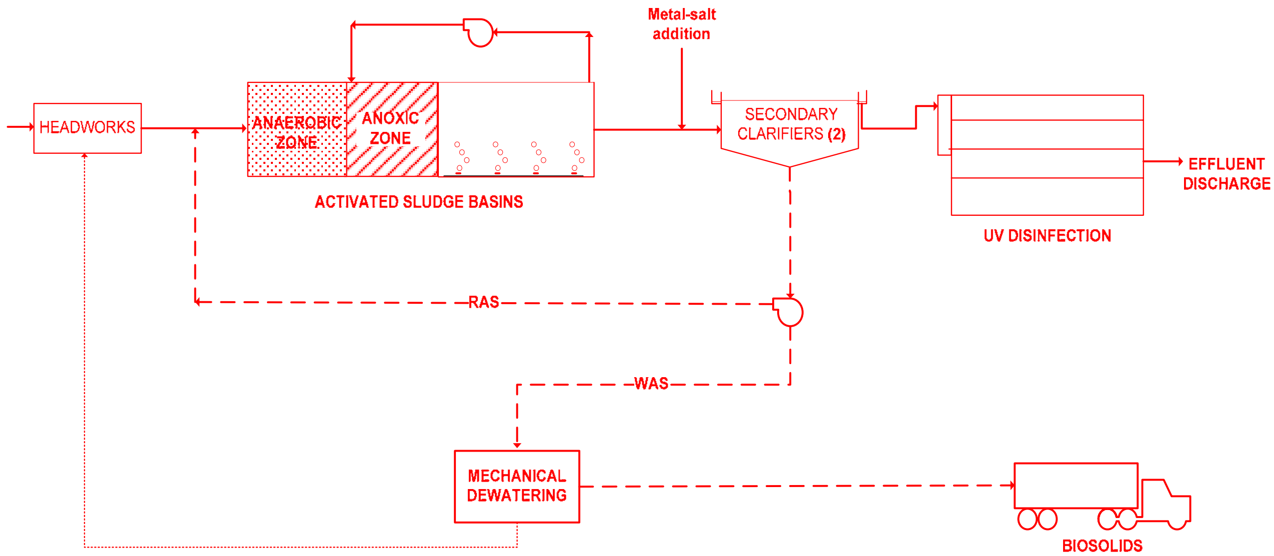

FIGURE 3
Modifications to POTW for Tier 2N Nutrient Control

Tier 1 Phosphorus (C)

This alternative builds upon the Tier 2 approach for phosphorus control. Phosphorus would be chemically removed by adding metal-salt to the secondary clarifiers and ahead of new deep bed granular media filters to achieve the 0.1 mg/L TP limit. Settled secondary effluent would be pumped to the new granular media filters for chemical phosphorus polishing. A process flow diagram for this treatment approach is presented in Figure 4.

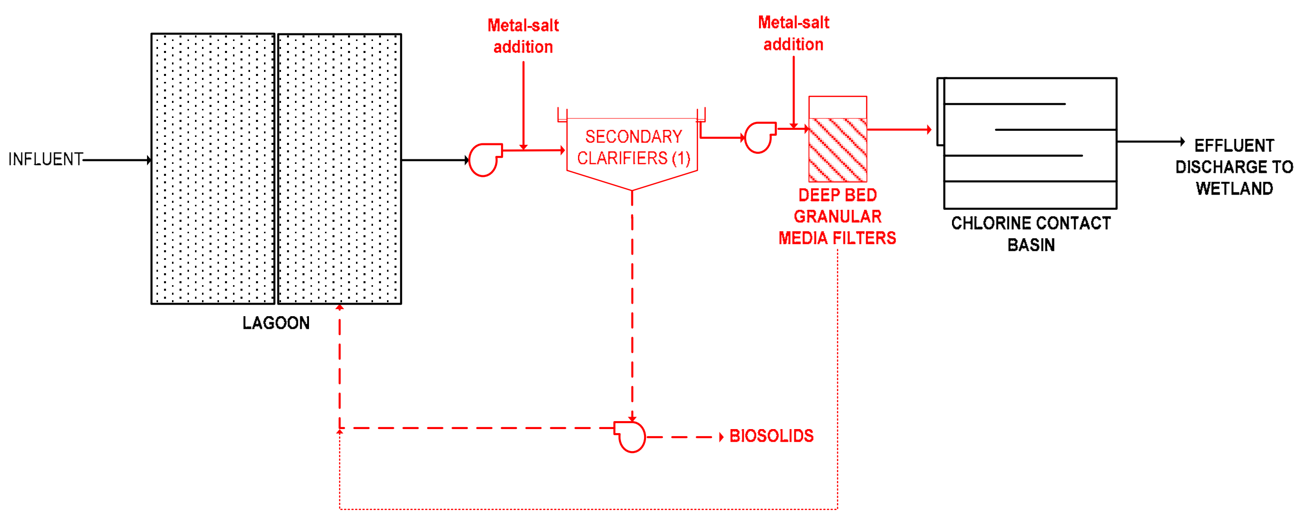

FIGURE 4
Modifications to POTW for Tier 1 Nutrient Control

Tier 1N Phosphorus & Nitrogen (D)

This approach builds on a combination of the Tier 1 and Tier 2N. Total phosphorus and nitrogen would be removed biologically as described for Tier 2N using a new mechanical treatment facility and phosphorus would be chemically polished down to 0.1 mg/L via the filtration method described in Tier 1. A process schematic of this approach is presented in Figure 5.

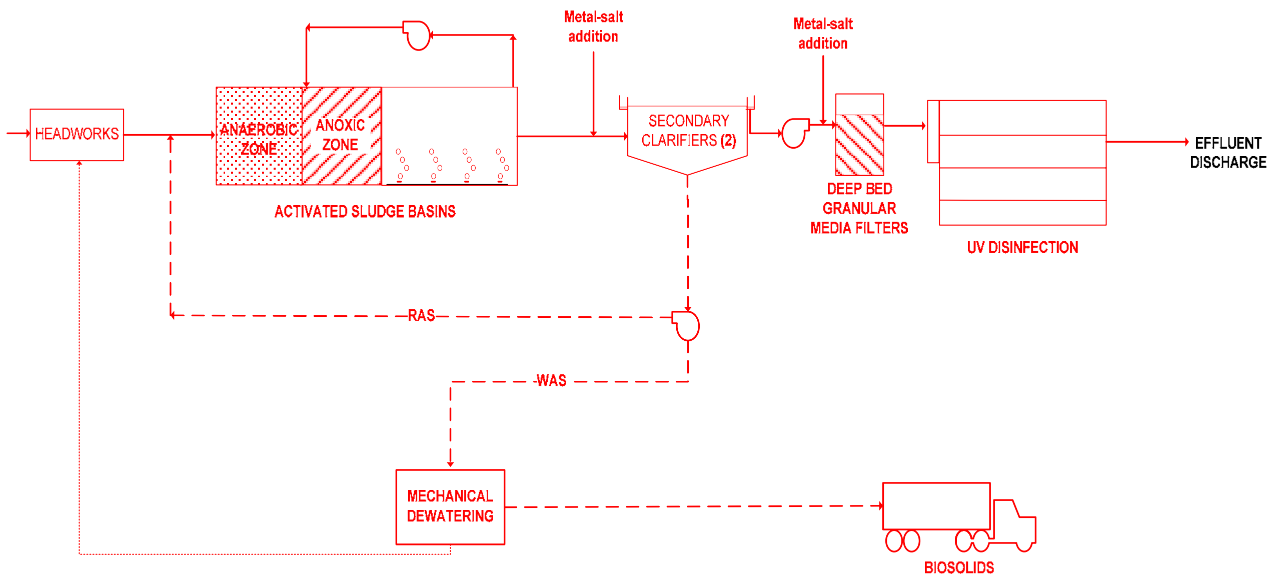

FIGURE 5
Modifications to POTW for Tier 1N Nutrient Control

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

Table 5 presents a summary of the major facility upgrade components identified for meeting each tier of nutrient control.

For Tier 2, a lift station and a secondary clarifier with a metal-salt feed facility would be required. To go to Tier 2N, a mechanical treatment facility, complete with influent pump station, headworks, biological nutrient removal process, secondary clarifiers, mechanical dewatering facility and a UV disinfection system would be required. For Tier 1, in addition to the facilities proposed for Tier 2, a new deep bed granular media filtration system with a secondary effluent pump station would be required. For Tier 1N, deep bed granular media filtration system would be added to the facilities proposed for Tier 2N.

TABLE 5

Major Facility Upgrade Summary

Processes	Tier 2	Tier 2N	Tier 1	Tier 1N
Influent Pump Station		X		X
Headworks		X		X
Metal-Salt Feed Facility		X		X
Anaerobic Basin with mixers		X		X
Anoxic Basin with Mixers		X		X
Aerobic Basin		X		X
NRCY Pumps		X		X
Flow Split Structure		X		X
Blower Building		X		X
Secondary Clarifiers	X	X	X	X
RAS/WAS Pumps		X		X
Piping Modifications	X	X	X	X
UV Disinfection		X		X
Dewatering System		X		X
Electrical Substation	X	X	X	X
Secondary Effluent Pumps			X	X
Deep Bed Granular Media Filters			X	X
Miscellaneous	X	X	X	X

The capital cost estimates shown in Table 6 were generated for the facility upgrades summarized in Table 5 for the “model” lagoon. 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 and 8 is -30%/+50%.

TABLE 6
Capital Cost Estimates

Unit Process Facility	Tier 2	Tier 2N	Tier 1	Tier 1N
Influent Pump Station	$0	$169,293	$0	$169,293
Headworks	$0	$241,847	$0	$241,847
Metal-Salt Feed Facility	$386,955	$241,847	$507,878	$507,878
Anaerobic Basin with mixers	$0	$386,955	$0	$386,955
Anoxic Basin with Mixers	$0	$628,801	$0	$798,094
Aerobic Basin	$0	$1,088,310	$0	$1,088,310
Nitrate Recycle Pumps	$0	$145,108	$0	$145,108
Flow Split Structure	$0	$193,477	$0	$193,477
Blower Building (1300 scfm = 75 Hp)	$0	$338,585	$0	$338,585
Secondary Clarifiers	$507,878	$1,354,341	$507,878	$1,354,341
RAS/WAS Pumps	$0	$145,108	$0	$145,108
Piping Modifications	$72,554	$120,923	$72,554	$120,923
UV Disinfection	$0	$332,539	$0	$332,539
Dewatering System	$0	$604,617	$0	$604,617
Electrical Substation	$60,462	$266,031	$60,462	$370,025
Secondary Effluent Pumps	$0	$0	$846,463	$846,463
Deep Bed Filters	$0	$0	$2,418,466	$2,418,466
Backwash Pumps	$0	$0	$483,693	$483,693
Mudwell and Pumps	$0	$0	$169,293	$169,293
Miscellaneous	$84,646	$96,739	$84,646	$96,739
TOTAL TIER COST	**$1,112,494**	**$6,354,520**	**$5,151,333**	**$10,811,752**

Note: $ Million (US) in December 2009

Incremental O&M costs associated with meeting each tier of nutrient standard were generated for the year 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 over a 20-year period. O&M costs for each alternative 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: aeration, secondary effluent pumps, backwash pumps, filtration system and dewatering units

TABLE 7

Operating and Maintenance Unit Costs

Parameter	Value
Biosolids hauling	$8/wet ton
Biosolids tipping fee	$6/wet ton
Hauling distance	20 miles
Alum	$480/ton
Polymer	$1/lb
Power	$0.06/kwh

The estimated net impact of nutrient control on 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	$1,168	$2,336	$8,760	$11,680	$2,920	$5,840	$10,512	$13,432
Metal-salt	$14,892	$20,148	$72	$960	$30,660	$43,800	$14,975	$22,743
Polymer	$602	$1,205	$4,825	$6,581	$1,506	$3,373	$5,938	$7,733
Power	$12,775	$17,885	$89,425	$97,090	$25,550	$38,325	$94,535	$102,200
Total O&M	**$29,437**	**$41,574**	**$103,082**	**$116,311**	**$60,636**	**$91,338**	**$125,960**	**$146,108**

Note: $ Million (US) in December 2009

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

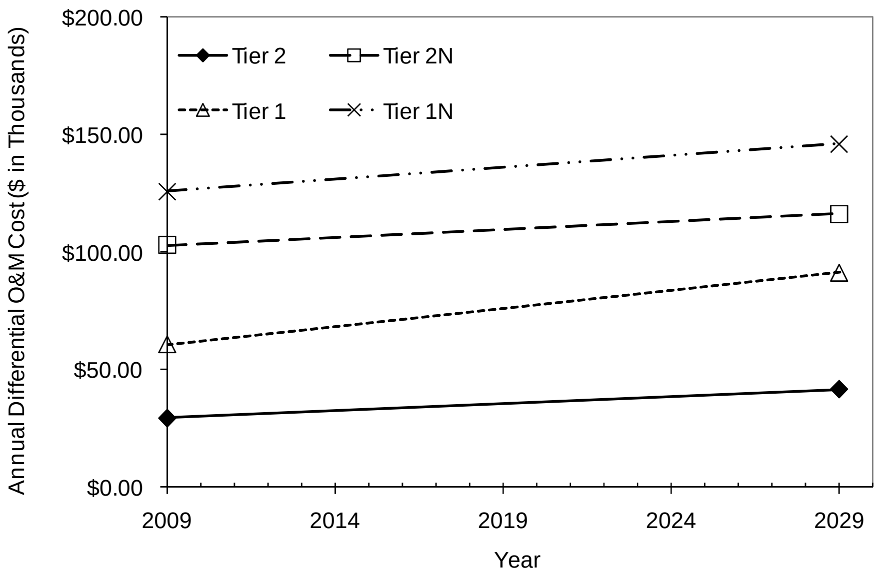

FIGURE 6
Impact of Nutrient Control on O&M Costs over 20 year evaluation period for small lagoon facilities

5. Financial Impacts

This section presents the estimated economic impacts that will result from the implementation of nutrient discharge standards for the State of Utah. Financial impacts are summarized for the smaller lagoon facilities 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 Tasks 7 and 8.

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 alternative that is prescribed to meet one of the State’s proposed 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 is developed in current (2009) dollars, and discounted to yield the net present value (NPV).

The NPV is divided by the resulting 20-year nutrient reduction for each tier, resulting in a cost per pound estimate for nutrient removal. This calculation represents an appropriate matching of costs with benefits over the same time period. Table 9 presents the results of the life cycle cost analysis for the “model” lagoon facility.

TABLE 9

Nutrient Removal: 20-Year Life Cycle Cost per Pound

	Tier 2	Tier 2N	Tier 1	Tier 1N
Phosphorus Removal (pounds)[1]	81,012	81,012	99,240	99,240
Nitrogen Removal (pounds)[1]	-	405,059	-	607,589
Net Present Value of Removal Costs[2]	**$ 1,651,674**	**$ 8,029,370**	**$ 6,304,581**	**$ 12,887,269**
NPV: Phosphorus Allocation	1,651,674	1,651,674	6,304,581	6,304,581
NPV: Nitrogen Allocation[3]		6,377,696		6,582,687
TP Cost per Pound[4]	**$ 20.39**	**$ 20.39**	**$ 63.53**	**$ 63.53**
TN Cost per Pound[4]		**$ 15.75**		**$ 10.83**

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

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

3 - 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

4 - 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 "model" lagoon are presented in Table 10.

TABLE10

Projected Monthly Bill Impact per Equivalent Residential Unit (ERU) for Treatment Alternatives				
	Tier 2	**Tier 2N**	**Tier 1**	**Tier 1N**
Initial Capital Expenditure	$ 1,112,000	$ 6,355,000	$ 5,151,000	$ 10,812,000
Estimated Annual Debt Service[1]	$ 89,200	$ 509,900	$ 413,300	$ 867,600
Incremental Operating Cost[2]	30,100	103,800	62,200	127,000
Total Annual Cost Increase	$ 119,300	$ 613,700	$ 475,500	$ 994,600
Number of ERUs	1,760	1,760	1,760	1,760
Annual Cost Increase per ERU	$67.78	$348.69	$270.17	$565.11
Monthly Cost Increase per ERU[3]	**$5.65**	**$29.06**	**$22.51**	**$47.09**
Current Average Monthly Bill[4]	$18.36	$18.36	$18.36	$18.36
Projected Average Monthly Bill[5]	**$24.01**	**$47.42**	**$40.87**	**$65.45**
Percent Increase	**30.8%**	**158.3%**	**122.6%**	**256.5%**

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 "model" lagoon 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]	$ 37,700	$ 37,700	$ 37,700	$ 37,700
Affordability Threshold (% of MAGI)[3]	1.4%	1.4%	1.4%	1.4%
Monthly Affordability Criterion	**$43.98**	**$43.98**	**$43.98**	**$43.98**
Projected Average Monthly Bill	$24.01	$47.42	$40.87	$65.45
Meets State's Affordability Criterion?	Yes	No	Yes	No
Estimated Bill as % of State Criterion	**55%**	**108%**	**93%**	**149%**

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

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 DWQ and per process modeling, the "model" lagoon is able to achieve BOD and TSS removal, but no nutrients. Table 12 summarizes the annual reduction in nutrient loads in Logan's 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	3,410	3,410	4,180	4,180
Total nitrogen removed, lb/year	----	17,050	----	25,570

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

The process upgrades established to meet the four tiers of nutrient standards will require increased energy consumptions, chemical usage and biosolids production. Table 13 summarizes these environmental impacts of implementing the modifications and upgrades. The values shown are on an annual basis, for the current (2009) flow and load conditions. For Tier 2 and Tier 1, the impacts indicate a differential value relative to the base line condition (Tier 3), as process upgrades for these tiers are based on modification from Tier 3. Therefore, the impact is not significant. However, for Tier 2N and 1N, since a completely new mechanical plant is proposed, the impacts does not represent a differential value, as no comparison was done between the existing lagoon facility and the mechanical plant. The values shown are the environmental impacts for a new mechanical plant.

TABLE 13
Estimated Environmental Impacts of Nutrient Control

		Tier 2	Tier 2N	Tier 1	Tier 1N
Chemical Use:					
Metal-salt use, lb/year		62,000	300	127,750	62,400
Polymers, lb/year		0	2,925	0	3,600
Biosolids Management:					
Biosolids produced, ton/year		8	66	20	82
Average yearly hauling distance(1)		8	60	20	75
Particulate emissions from hauling trucks, lb/year (2)		0	3	1	4
Tailpipe emissions from hauling trucks, lb/year(3)		1	8	2	9
CO_2 emissions from hauling trucks lb/year(4)		100	765	240	945
Energy Consumption:					
Annual energy consumption, kwh		182,500	1,277,500	365,000	1,350,500
Air pollutant emissions, lb/year (5)					
	CO_2	164,615	1,152,305	329,230	1,218,151
	NOx	256	1,789	511	1,891
	SOx	219	1,533	438	1,621
	CO	12	84	24	89
	VOC	1	10	3	11
	PM_{10}	4	25	7	27
	$PM_{2.5}$	2	13	4	13

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 the assumption of 20 miles round trip hauling distance and that the facility uses 22 ton trucks for hauling biosolids.

(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)*.