UDWQ POTW Nutrient Removal Cost Impact Study: Analysis of Magna Water Company

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COPIES: Magna Water Company

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In partial fulfillment of the Utah Division of Water Quality *Publicly Owned Treatment Works (POTW) Nutrient Removal Cost Impacts Study,* this Technical Memorandum (TM) summarizes the process, financial and environmental evaluation of the Magna Water Company (MWC) 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 MWC 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 average annual flow rate of 3.3 million gallons per day (mgd) and currently receives an average annual influent flow of approximately 2.3 mgd. The facility operates an oxidation ditch process. Residual secondary solids from the process are dewatered using Huber presses and air dried in sludge drying beds before being disposed of in a landfill. A process flow diagram of the existing facility is presented in Figure 1 and an aerial photo is shown in Figure 2. The major unit processes are summarized in Table 2.

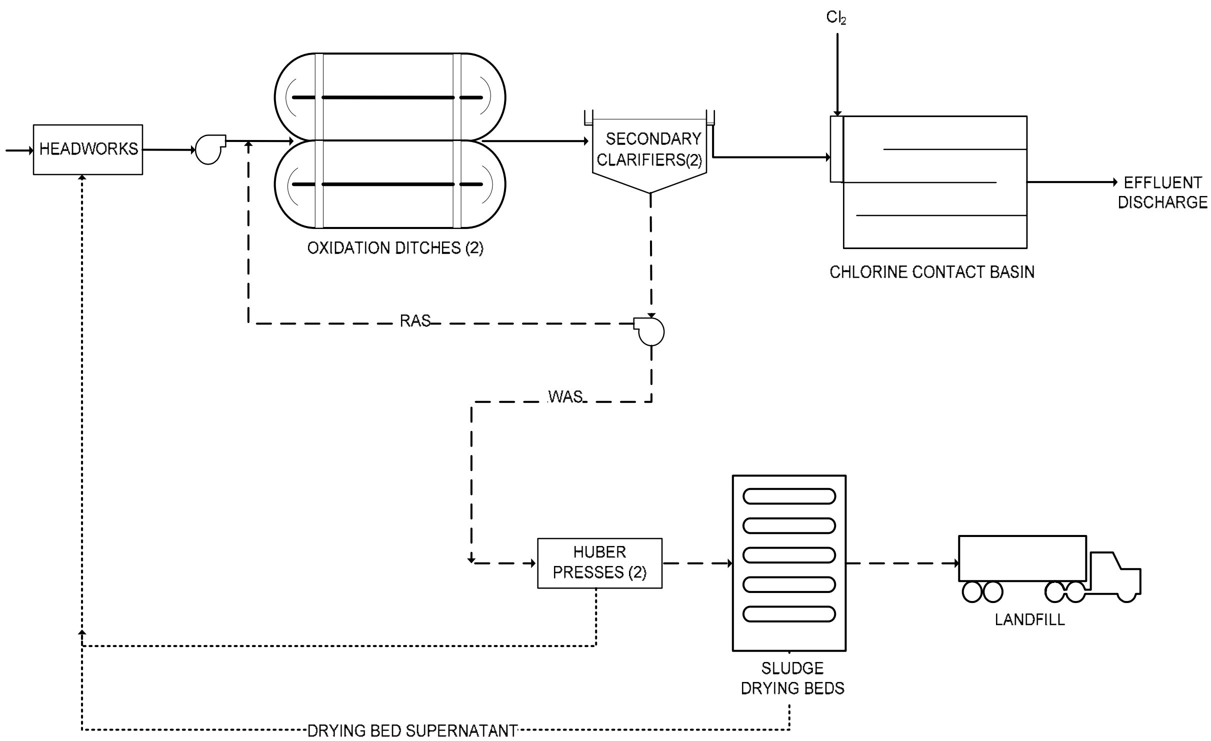

FIGURE 1
Process Flow Diagram

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	1.7 MG	----
Secondary clarifiers	2	75-ft diameter, 14-ft SWD	Round
Solids dewatering	2	----	Huber press
Solids drying	----	----	Sludge drying beds. Achieves 12.5% solids

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 are 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.

MWC operates two (2) oxidation ditches and two (2) secondary clarifiers; hence, it was proposed to work with the existing treatment system to the extent possible and add upgrades as required to meet the various tiers of nutrient limits. Figure 3 shows the selected upgrade approach used between each tier of nutrient control with the following bullet points A through D describing each upgrade step:

A. From Tier 3 (existing process) to Tier 2 phosphorus control, an anaerobic selector was added upstream of the existing oxidation ditches for enhanced biological phosphorus removal. Metal-salt addition was implemented as a back-up to the biological process at the secondary clarifiers.

B. To add nitrogen removal to Tier 2, no additional process modifications were required.

C. To go from Tier 2 to Tier 1 phosphorus control, deep bed granular media filters were added after the secondary clarifiers, along with a second metal-salt feed point before them for chemical phosphorus polishing.

D. To add nitrogen control to Tier 1, the upgrade approach taken in Tier 2 was adapted. In addition, an anoxic zone was added after the anaerobic zone as described in B, for biological nutrient removal (BNR). These two zones were followed by the existing oxidation ditches. Deep bed granular media filters were installed for chemical phosphorus polishing as described in the previous upgrade step.

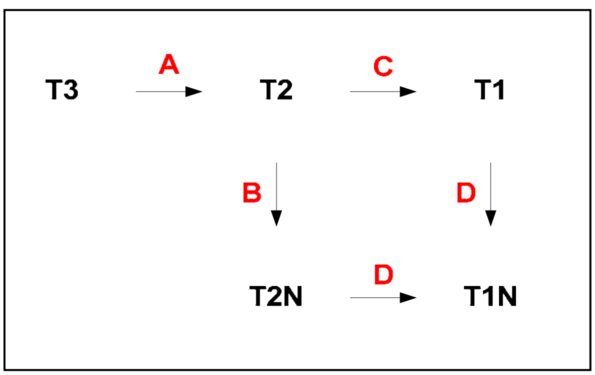

FIGURE 3
Upgrades Scheme for Meeting Increasingly More Stringent Nutrient Control

Data Evaluation and Modeling of Upgrades

The selected progression of the upgrades conceived for meeting the different tiers of nutrient control for MWC 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 MWC 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(1)	2029(2)	Design(3)
Flow, mgd	2.30	3.60	6.60
BOD, lb/day	2,228 (116 mg/L)	3,483 (116 mg/L)	6,385 (116 mg/L)
TSS, lb/day	2,110 (110 mg/L)	3,303 (110 mg/L)	5,200 (88 mg/L)
TKN, lb/day	575 (30 mg/L)	901 (30 mg/L)	1,651 (30 mg/L)
TP, lb/day	115 (6 mg/L)	180 (6 mg/L)	330 (6 mg/L)

(1) Historic conditions 2007-2008
(2) Flow 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 MWC 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
Fraction of anaerobic volume (T2 and T1)	15%
Fraction of anoxic volume (T2N and T1N)	30%
Mixed-Liquor return pumping ratio as a percent of influent Flow (T2N and T1N)	100%
Nitrification Safety Factor (T2N and T1N)	2(3)
SVI (T2N and T1N)	180
Granular filter loading rate (T1)	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 sections 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. MWC was able to achieve this phosphorus goal by introducing an anaerobic selector upstream of the existing oxidation ditches for enhanced biological phosphorus removal. A metal-salt addition system was also implemented at the secondary clarifiers to be used only as a back-up for biological phosphorus removal. A process flow diagram for this alternative is presented in Figure 4.

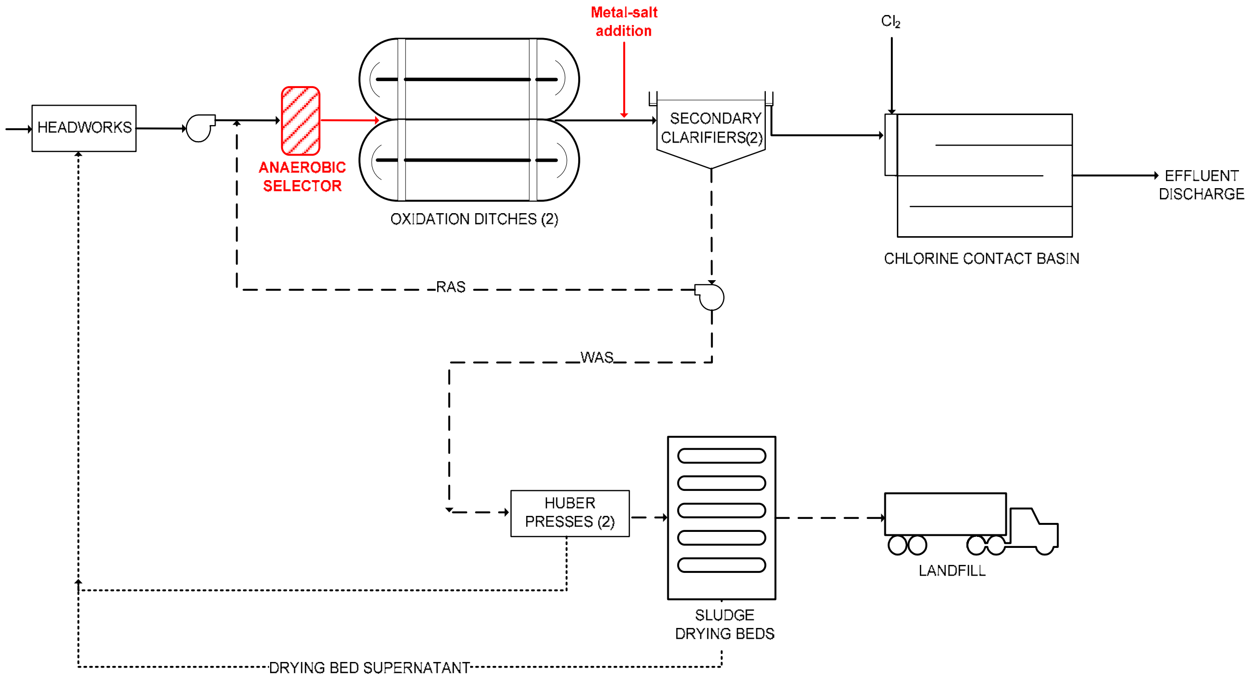

FIGURE 4
Modifications to POTW for Tier 2 Nutrient Control

Tier 2N – Phosphorus & Nitrogen (B)

The upgrade approach taken for Tier 2 phosphorus limits was able to meet the nutrient limits of this Tier. Therefore no additional process modification was required for this alternative and the process flow diagram would remain the same as Figure 4.

Tier 1 Phosphorus (C)

This alternative builds upon the Tier 2 approach for phosphorus control. Apart from the upgrades described in Tier 2, the settled effluent from the secondary clarifiers was pumped to new deep bed granular media filters with a second metal-salt addition system upstream of it. With a complete enhanced biological phosphorus removal process, metal-salt consumption at the secondary clarifiers and upstream of the filters was required to polish down phosphorus to the 0.1 mg/L level after biological uptake of phosphorus in the modified oxidation ditch process. A process flow diagram of this approach is provided in Figure 5.

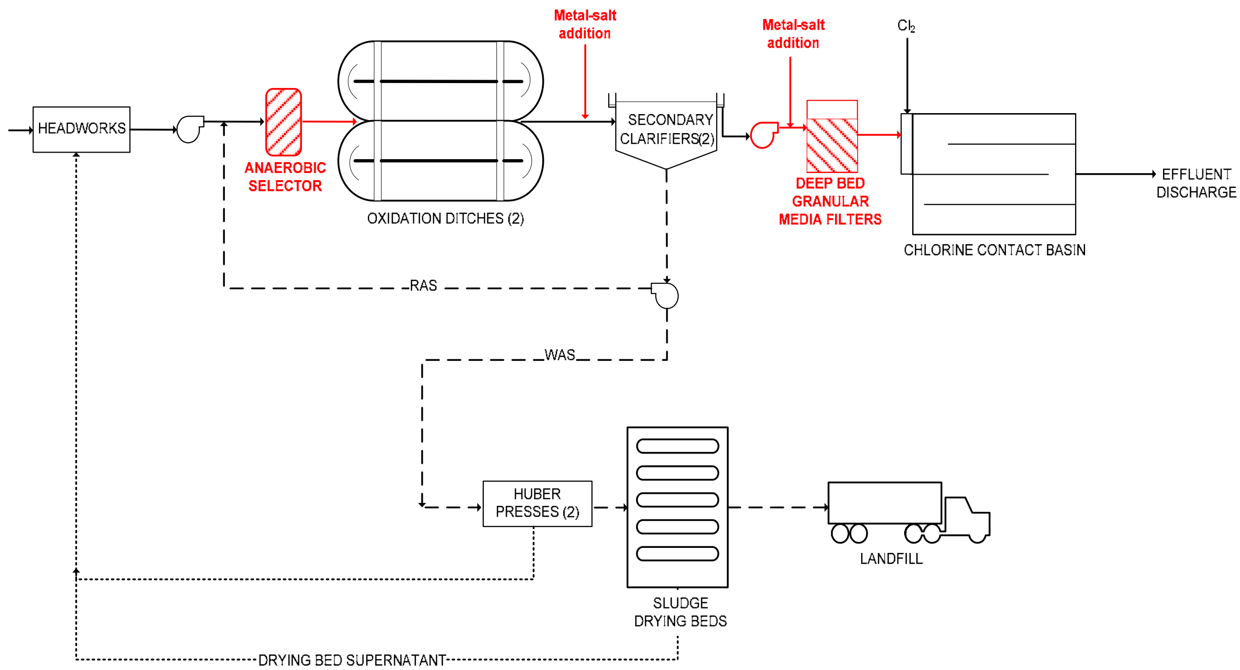

FIGURE 5
Modifications to POTW for Tier 1 Nutrient Control

Tier 1N Phosphorus & Nitrogen (D)

To meet the nutrient limits for this Tier, the upgrade approaches taken for Tier 2N and Tier 1 were combined. An anaerobic selector followed by an anoxic selector was added upstream of the existing oxidation ditches for BNR. Mixed liquor recycle pumps were installed to recycle the nitrified mixed liquor from the oxidation ditches to the anoxic selector. With a complete BNR process, metal-salt consumption at the secondary clarifiers and upstream of the filters was required only to polish down phosphorus to the 0.1 mg/L after enhanced biological phosphorus uptake. A process flow diagram for this alternative is presented in Figure 6.

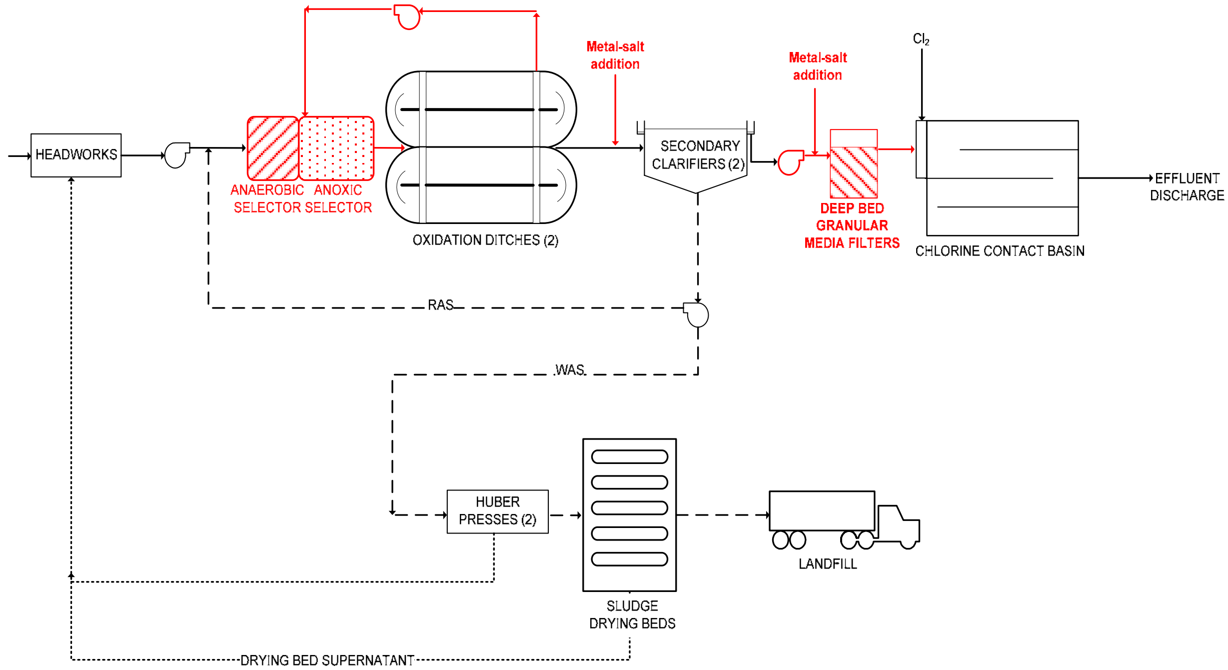

FIGURE 6
Modifications to POTW for Tier 1N Nutrient Control

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 facility upgrade components identified for meeting each tier of nutrient control. For Tier 2 and 2N, an anaerobic selector with mixers, metal-salt storage facility and new metal-salt feed pumps at the secondary clarifiers were required. To go to Tier 1, deep bed granular media filters along with an additional metal-salt storage facility and feed pumps upstream of the filters were required. For Tier 1N, an anoxic basin with mixers and mixed liquor recycle system was required along with anaerobic selector. Some modification was needed to the flow distribution structures to the modified oxidation ditches. Tier 1N additionally included an intermediate pump station and deep bed granular media filters with metal-salt feed facility as described for Tier 1.

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
Flow split structure and piping modifications	X	X	X	X
Anaerobic basin with mixers	X	X	X	X
Anoxic basin with mixers				X
Mixed liquor recycle system				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 and storage facility	$0.31	$0.31	$0.75	$0.75
Flow split structure and piping modifications	$0.48	$0.48	$0.48	$0.53
Anaerobic basin with mixers	$1.45	$1.45	$1.45	$1.45
Anoxic basin with mixers	$0.00	$0.00	$0.00	$2.54
Mixed liquor recycle system	$0.00	$0.00	$0.00	$0.31
Secondary effluent pump station	$0.00	$0.00	$3.14	$3.14
Deep bed granular media filters	$0.00	$0.00	$12.53	$12.53
TOTAL TIER COST	**$2.24**	**$2.24**	**$18.35**	**$21.25**

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 either provided by the POTW or assumed based on the average costs in the State of Utah, and are presented in Table 7. A straight line interpolation was used to estimate the differential cost for the two years. O&M costs for each upgrade included the following components:

- Biosolids management: hauling , use, and disposal
- Chemical consumption costs: metal-salt, and, polymer

- Power costs for the major mechanized process equipment: aeration, intermediate pumping, mixed-liquor return pumping, and reactor mixing

TABLE 7
Operating and Maintenance Unit Costs

Parameter	Value
Biosolids handling	$18.05/wet ton
Round trip hauling distance[1]	8 miles
Ferric Chloride	$1000/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 7.

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	$0.004	$0.007	$0.004	$0.007	$0.025	$0.041	$0.028	$0.044
Metal-salt	$0.001	$0.002	$0.001	$0.002	$0.170	$0.299	$0.172	$0.300
Polymer	$0.000	$0.000	$0.000	$0.000	$0.002	$0.003	$0.002	$0.003
Power	$0.015	$0.017	$0.015	$0.017	$0.037	$0.050	$0.063	$0.075
Total O&M	**$0.020**	**$0.026**	**$0.020**	**$0.026**	**$0.234**	**$0.393**	**$0.265**	**$0.422**

Note: $ Million (US) in December 2009
Costs shown are the annual differential costs relative to the base line O&M cost of the POTW

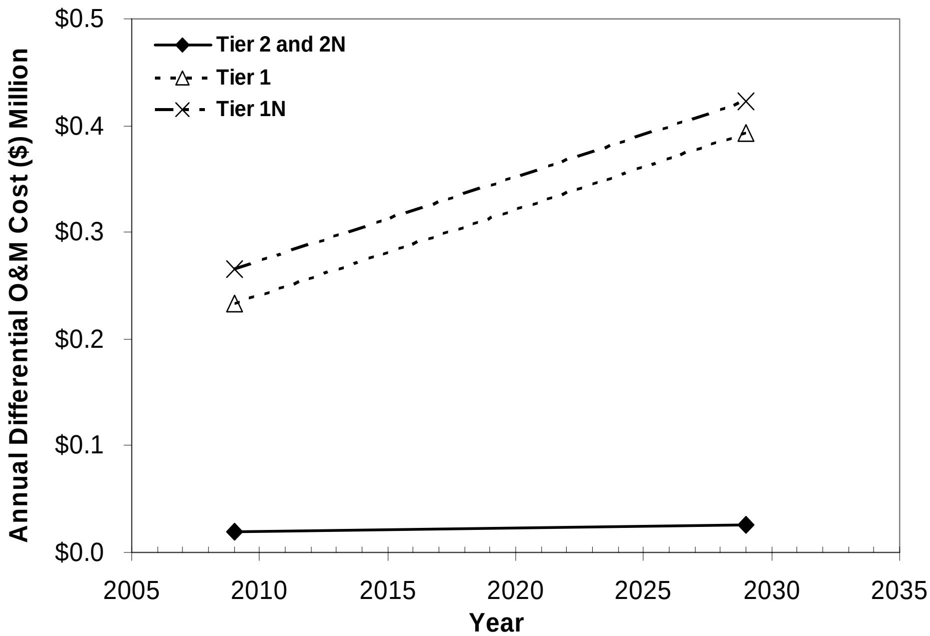

FIGURE 7
Impact of Nutrient Control on O&M Costs over 20 year evaluation period

5. Financial Impacts

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

TABLE 9

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

	Tier 2	Tier 2N	Tier 1	Tier 1N
Phosphorus Removal (pounds)[2]	415,611	415,611	579,112	579,112
Nitrogen Removal (pounds)[2]	-	meets limit	-	1,816,677
Net Present Value of Removal Costs[3]	**$ 2,597,529**	**$ 2,597,529**	**$ 23,102,915**	**$ 26,470,192**
NPV: Phosphorus Allocation	2,597,529	2,597,529	23,102,915	23,102,915
NPV: Nitrogen Allocation[4]		-		3,367,277
TP Cost per Pound[5]	**$ 6.25**	**$ 6.25**	**$ 39.89**	**$ 39.89**
TN Cost per Pound[5]		**NA**		**$ 1.85**

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 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 MWC are presented in Table 10.

TABLE 10

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

	Tier 2	Tier 2N	Tier 1	Tier 1N
Initial Capital Expenditure	$ 2,249,000	$ 2,249,000	$ 18,356,000	$ 21,258,000
Estimated Annual Debt Service[1]	$ 180,500	$ 180,500	$ 1,472,900	$ 1,705,800
Incremental Operating Cost[2]	20,200	20,200	241,100	272,900
Total Annual Cost Increase	$ 200,700	$ 200,700	$ 1,714,000	$ 1,978,700
Number of ERUs	8,400	8,400	8,400	8,400
Annual Cost Increase per ERU	$23.89	$23.89	$204.05	$235.56
Monthly Cost Increase per ERU[3]	**$1.99**	**$1.99**	**$17.00**	**$19.63**
Current Average Monthly Bill[4]	$17.03	$17.03	$17.03	$17.03
Projected Average Monthly Bill[5]	**$19.02**	**$19.02**	**$34.03**	**$36.66**
Percent Increase	**11.7%**	**11.7%**	**99.8%**	**115.3%**

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 MWC 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]	$ 34,200	$ 34,200	$ 34,200	$ 34,200
Affordability Threshold (% of MAGI)[3]	1.4%	1.4%	1.4%	1.4%
Monthly Affordability Criterion	**$39.90**	**$39.90**	**$39.90**	**$39.90**
Projected Average Monthly Bill	$19.02	$19.02	$34.03	$36.66
Meets State's Affordability Criterion?	Yes	Yes	Yes	Yes
Estimated Bill as % of State Criterion	**48%**	**48%**	**85%**	**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, disposal and energy consumption

As per the data received from MWC and per process modeling of the base condition (Tier 3), MWC is able to achieve an effluent total nitrogen concentration of 20 mg/L and some biological phosphorus removal. Table 12 summarizes the annual reduction in nutrient loads in MWC 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 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	16,540	16,540	22,840	22,840
Total nitrogen removed, lb/year	----	0	----	70,020

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 MWC to the receiving water body 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**
MWC	----	3.568	3.40	20.0	1.0	N/A	1.0	20.0	0.10	N/A	0.10	10
Kersey Ck	4991650	2.31	0.23	2.99	----	----	----	----	----	----	----	----
Combined Concentration			2.15	13.32	0.69	N/A	0.70	13.32	0.15		0.15	7.25

The process upgrades established to meet the four tiers of nutrient standards 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. Process modifications to meet the total nitrogen limits would also result in increased energy consumption and biosolids productions. 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 a differential value 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		2,000	2,000	339,500	345,000
Polymers, lb/year		0	0	1450	1800
Biosolids Management:					
Biosolids produced, ton/year		1	1	180	190
Average yearly hauling distance(1)		0	0	65	70
Particulate emissions from hauling trucks, lb/year (2)		0	0	4	4
Tailpipe emissions from hauling trucks, lb/year(3)		0	0	8	9
CO_2 emissions from hauling trucks lb/year(4)		0	0	830	890
Energy Consumption:					
Annual energy consumption, kwh		665	665	606,630	905,930
Air pollutant emissions, lb/year (5)					
	CO_2	218,609	218,609	547,180	817,149
	NOx	339	339	849	1,268
	SOx	291	291	728	1,087
	CO	16	16	40	59
	VOC	2	2	5	7
	PM_{10}	5	5	12	18
	$PM_{2.5}$	2	2	6	9

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

(1) Based on a round trip hauling distance of 8 miles to the landfill and, on the assumption that the facility uses 22 ton trucks for hauling biosolids to the landfill.

(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)*.