UDWQ POTW Nutrient Removal Cost Impact Study: Analysis of Ashley Valley Water Reclamation Facility

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COPIES: Ashley 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 analysis of Ashley Valley Water Reclamation Facility (AVWRF) 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 AVWRF 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

AVWRF has a design flow of 7 million gallons per day (mgd) and currently receives an average annual influent flow of approximately 2.5 mgd. The facility operates a nitrifying extended aeration process using oxidation ditches with surface aeration, along with pre-anoxic zones. Secondary effluent is disinfected by ultra-violet radiation and aerated prior to discharge to receiving streams. Wasted solids are held in aerobic holding tanks and mechanically dewatered using belt presses before being disposed of or beneficially used. A process flow diagram 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.

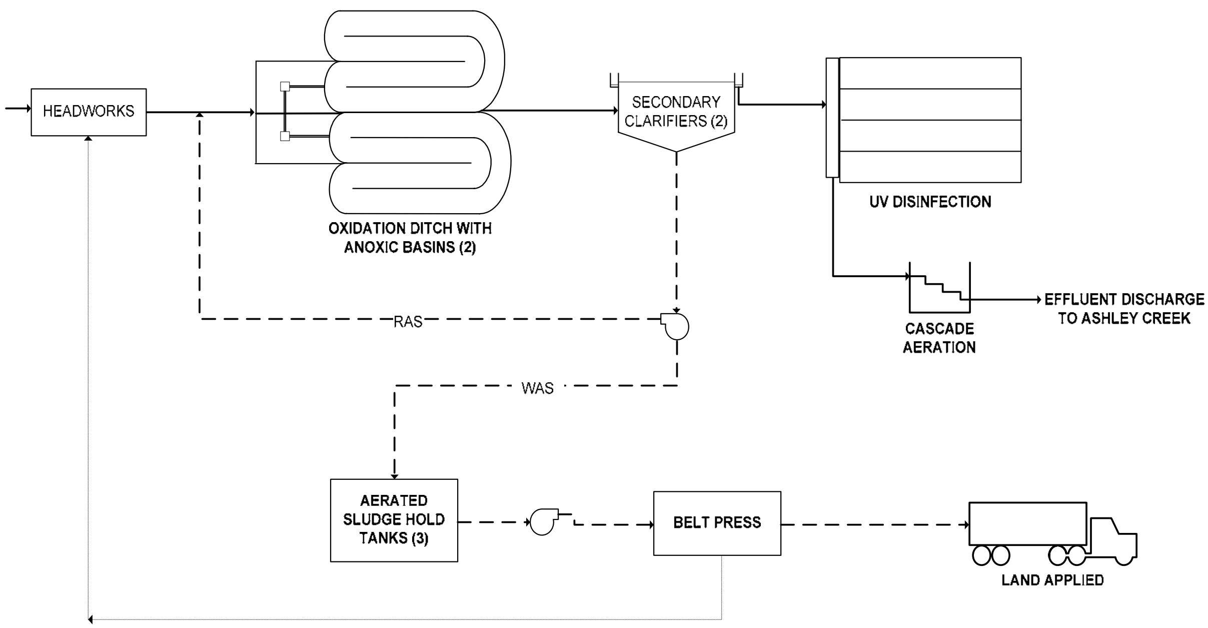

FIGURE 1
Process Flow Diagram

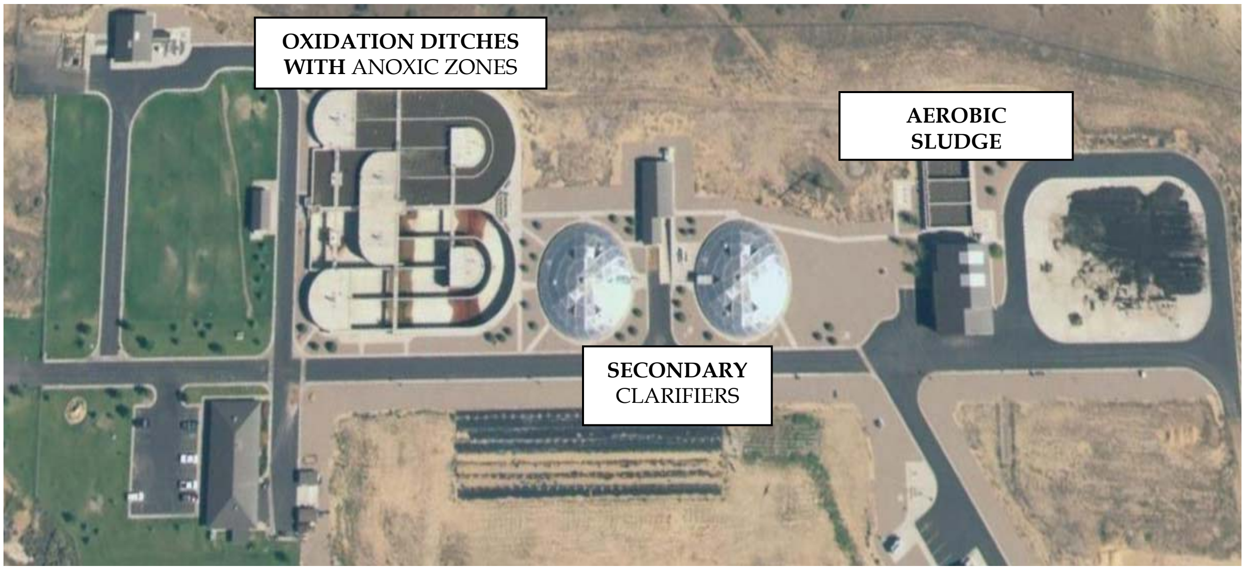

FIGURE 2
Aerial View of the Facility

TABLE 2
Summary of Major Unit Processes

Unit Process	Number of Units	Size, Each	Details
Anoxic basins	2	0.3 MG	----
Oxidation ditch	2	2.35 MG	With slow speed surface aerators
Secondary clarifiers	2	95-ft diameter, 15-ft SWD	Circular, covered clarifiers
Aerated sludge holding tanks	3	72,000 gal	With rotary positive displacement air blowers
Sludge dewatering	1	1 meter	Belt filter press

2. Nutrient Removal Alternatives Development, Screening and Selection

A nutrient removal alternatives matrix was prepared to capture an array of viable approaches for OD facilities (See Attachment A). This matrix considers biological and chemical phosphorus removal approaches as well as different activated sludge configurations for nitrogen control. The alternatives matrix illustrates that there are several strategies for controlling nutrient limits. The processes that were modeled and described in 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.

AVWRF currently has (2) oxidation ditches and (2) secondary clarifiers. A goal of this project was to make maximum use of existing infrastructure in the upgrade approaches selected for meeting the various tiers of nutrient limits. Upgrades were added to the system models added as required to meet increasingly stringent discharge limits. Figure 3 shows the basic 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, the existing anoxic basins were modified to operate as anaerobic basins to achieve enhanced biological phosphorus removal. A metal-salt addition system was added upstream of the secondary clarifiers as a back up to the biological phosphorus uptake process.

B. To go from Tier 2 to Tier 2N, an anaerobic selector was added upstream of the existing oxidation ditch process for biological nutrient removal. The metal-salt facility upstream of the secondary clarifiers added in Tier 2 was retained and operated as a back up to biological phosphorus removal.

C. To go from Tier 2 to Tier 1 phosphorus control, a deep bed granular media filtration system was installed downstream of the secondary clarifiers to remove particulate phosphorus from the liquid stream. Metal-salt was added upstream of the filters to enhance soluble phosphorus removal.

D. To add nitrogen removal to Tier 1, the upgrade approaches identified for Tier 2N and Tier 1 was combined.

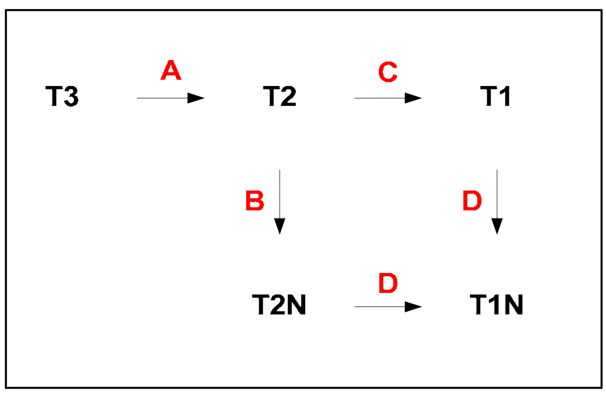

FIGURE 3
Upgrades Scheme for Meeting Increasingly More Stringent Nutrient Control

Data Evaluation and Modeling of Upgrades

The selected progression of upgrades conceived for meeting the different tiers of nutrient control for AVWRF 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.

No data was received from AVWRF. Therefore, the design criteria and data submitted by the POTW to the State Department of Water Quality was summarized and 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	2.50	4.00	7.00
BOD, lb/day	3,128 (150 mg/L)	5,004 (150 mg/L)	8,757 (150 mg/L)
TSS, lb/day	4,691 (225 mg/L)	7,506 (225 mg/L)	8,757 (150 mg/L)
TKN, lb/day	626 (30 mg/L)	1,000 (30 mg/L)	1,752 (30 mg/L)
TP, lb/day	125 (6 mg/L)	200 (6 mg/L)	350 (6 mg/L)

(1) Historic conditions for the year 2007-2009

(2) 2029 flow and loads projected by the POTW

(3) Design average capacity of the POTW

The main sizing and operating design criteria that were associated with the system upgrade for AVWRF are summarized in Table 4.

TABLE 4
Main Unit Process Sizing and Operating Design Parameters

Design Parameter (Nutrient Tier)	Value
Influent design temperature	10 deg C
Target metal:PO_4-P molar Ratio (All tiers)	2:1, 7:1 (1)
Metal salt storage (All tiers)	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 polishing filter, respectively. Filter doses were for Tiers 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 2.0

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 the Tier 2 alternatives is 1.0 mg/L total phosphorus. AVWRF can achieve this limit biologically by modifying the existing anoxic basins to anaerobic basins. This was achieved by turning off the existing nitrate recycle pumps. A metal-salt feed pumps and storage system were installed as back-up to the biological system ahead of the secondary clarifiers. The process flow diagram for this alternative is shown as Figure 4.

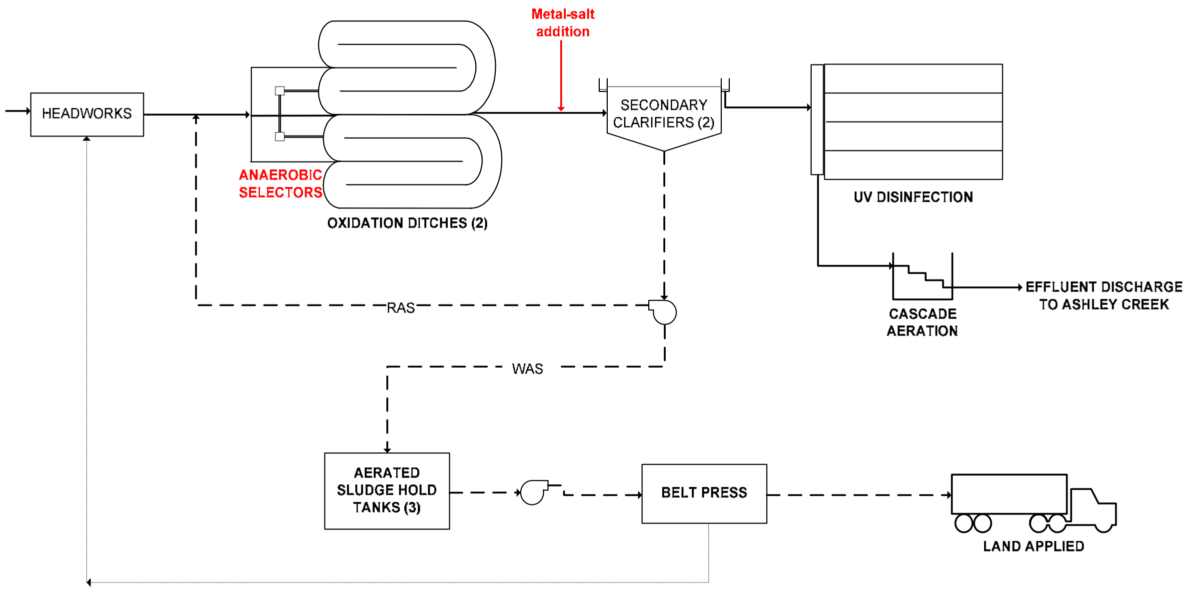

FIGURE 4
Modifications to POTW for Tier 2 Nutrient Control

Tier 2N – Phosphorus & Nitrogen (B)

The upgrade approach taken for Tier 2 phosphorus limits was modified to accommodate the 20 mg/L total nitrogen limit of this Tier. This was achieved by adding an external anaerobic selector to the existing oxidation ditch secondary treatment. A separate basin was constructed upstream of the oxidation ditches to provide the anaerobic environment. This basin included submersible or vertical-shaft mixers to ensure a completely mixed environment. The metal salt feed and storage system proposed for Tier 2 was retained as a back-up to the biological system upstream of the secondary clarifiers. The process flow diagram for this alternative is shown as Figure 5.

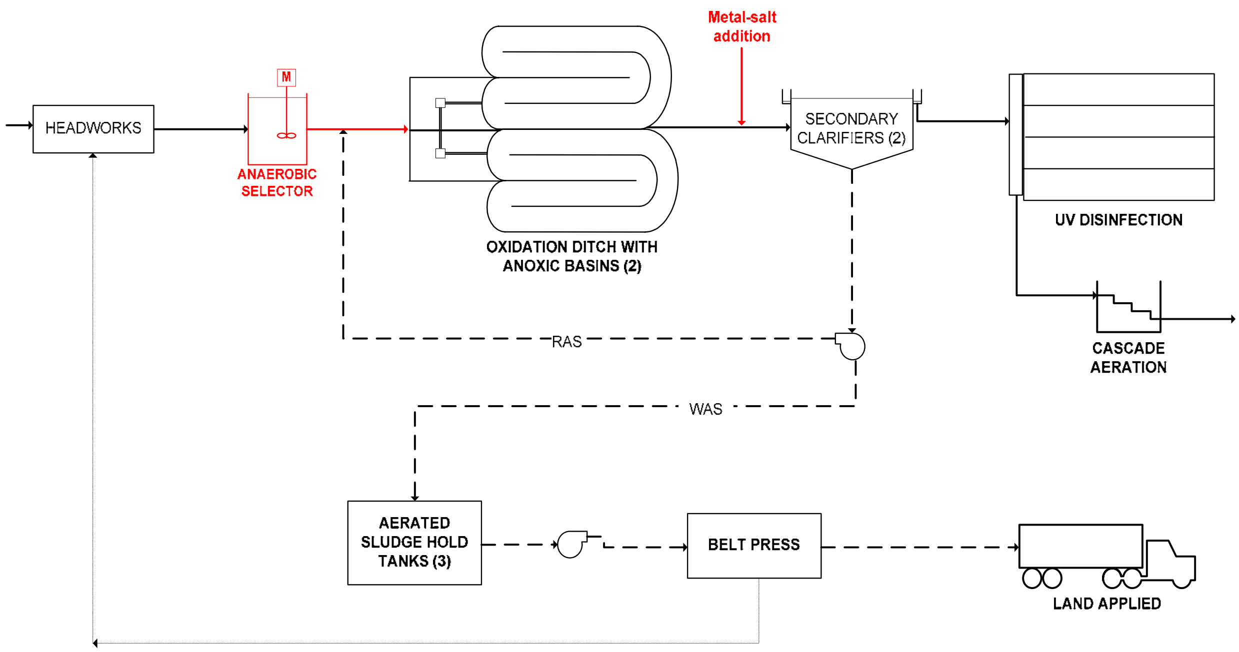

FIGURE 5
Modifications to POTW for Tier 2N Nutrient Control

Tier 1 Phosphorus (C)

This alternative builds upon the Tier 2 approach for phosphorus control; however, to meet 0.1 mg/L total phosphorus, metal-salt was used continuously at the secondary clarifiers. In addition, deep bed granular media filters were installed after the secondary clarifiers with a second metal-salt feed point upstream for chemical phosphorus polishing. A new pump station was also required to lift the secondary effluent to the filters. A process flow diagram of this approach is provided in Figure 6.

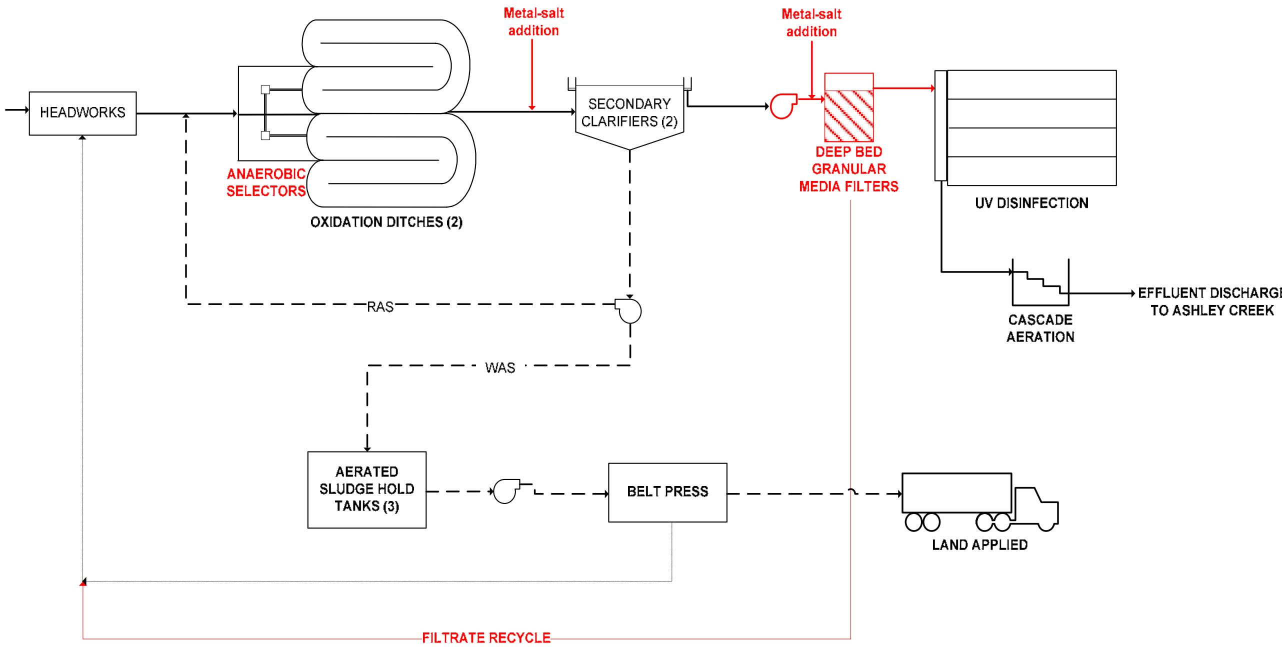

FIGURE 6
Modifications to POTW for Tier 1 Nutrient Control

Tier 1N Phosphorus & Nitrogen (D)

The effluent limit for this alternative is 0.1 mg/L total phosphorus and 10 mg/L total nitrogen. This approach maintains the existing oxidation ditch basins with the external anaerobic volume as specified for Tier 2N. Deep bed granular media filters were installed after the clarifiers with an additional metal-salt feed point upstream for chemical phosphorus polishing as specified in Tier 1. A process flow diagram of this approach is provided in Figure 7.

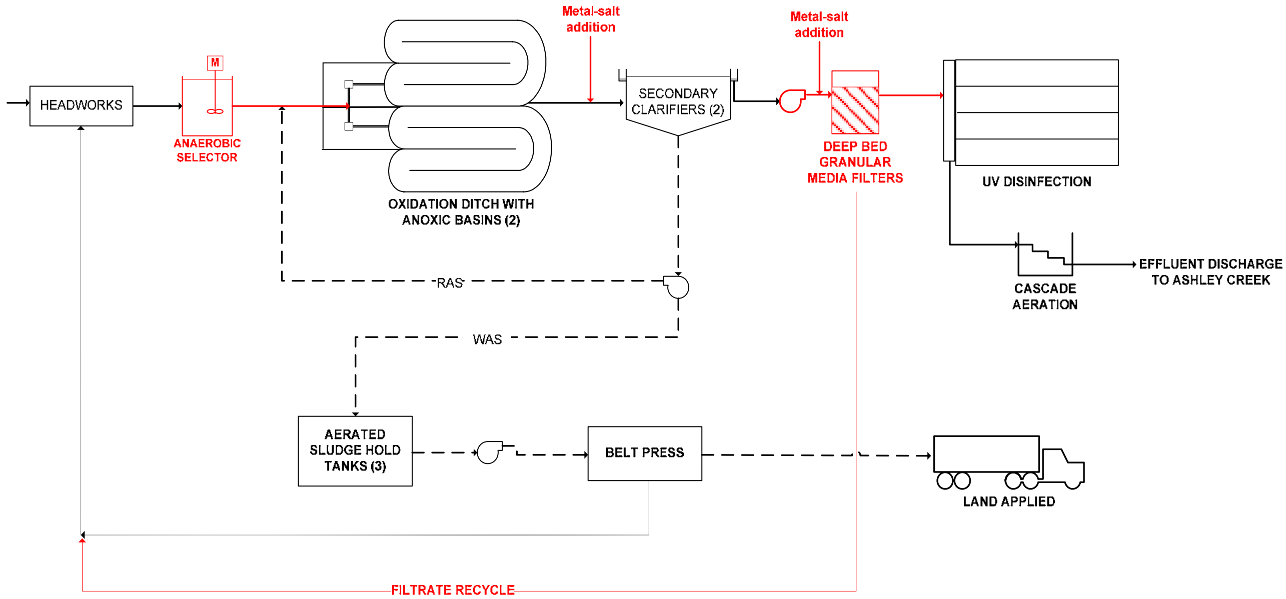

FIGURE 7
Modifications to POTW for Tier 1N Nutrient Control

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 Tier 1, the existing anoxic basins were converted to anaerobic basins and a metal-salt storage facility and feed pumps were installed at the secondary clarifiers. For Tier 2N and Tier 1N, an external anaerobic tank was constructed ahead of the oxidation ditches. Tier 1 and 1N also required the installation of deep bed granular media filters and metal-salt storage facility and feed pumps upstream of the filters with a secondary effluent pump station.

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	
Anaerobic selector		X		X
Secondary effluent pump station			X	X
Deep bed granular media filters			X	X

The capital cost estimates shown in Table 6 were generated for the facility upgrades summarized in Table 5. These estimates were prepared in accordance with the guidelines of the Association for the Advancement of Cost Engineering (AACE) International and defined as a Class 4 estimate. The expected accuracy range for the estimates shown in Table 6 is -30%/+50%.

TABLE 6
Capital Cost Estimates ($ Million)

Unit Process Facility	Tier 2	Tier 2N	Tier 1	Tier 1N
Metal-salt feed and storage facility	$0.314	$0.314	$0.774	$0.774
Flow split structure and piping modifications	$0	$0.580	$0	$0.580
Anaerobic selector	$0	$1.427	$0	$1.427
Secondary effluent pump station	$0	$0	$3.168	$3.168
Deep bed granular media filters	$0	$0	$13.156	$13.156
TOTAL TIER COST	**$0.314**	**$2.321**	**$17.098**	**$19.105**

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 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. 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, secondary effluent pumps and backwash pumps

TABLE 7
Operating and Maintenance Unit Costs

Parameter	Value
Biosolids hauling	$8/wet ton
Biosolids tipping fee	$6/wet ton
Roundtrip hauling distance	50 miles
Alum	$480/ton
Polymer	$1/lb
Power	$0.06/kwh

Increased O&M relative to the current O&M cost (Tier 3) are presented in Table 8 and shown graphically in Figure 6.

TABLE 8
Estimated Impact of Nutrient Control on O&M Costs

	Tier 2		Tier 2N		Tier 1		Tier 1N	
	2009	**2029**	**2009**	**2029**	**2009**	**2029**	**2009**	**2029**
Biosolids	$0.001	$0.004	$0.004	$0.006	$0.019	$0.030	$0.021	$0.033
Metal-salt	$0.001	$0.001	$0.001	$0.001	$0.102	$0.175	$0.111	$0.186
Polymer	$0.000	$0.000	$0.000	$0.001	$0.002	$0.003	$0.002	$0.004
Power	$0.001	$0.001	$0.009	$0.010	$0.023	$0.037	$0.033	$0.046
Total O&M	**$0.003**	**$0.006**	**$0.014**	**$0.018**	**$0.146**	**$0.246**	**$0.167**	**$0.269**

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

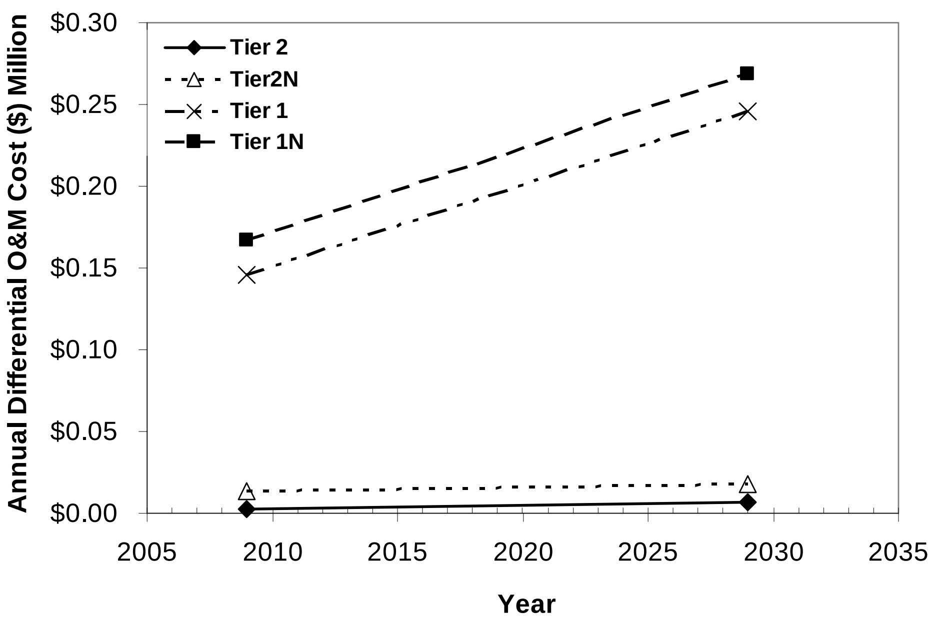

FIGURE 8
Impact of Nutrient Control on O&M Costs over 20 year evaluation period

5. Financial Impacts

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

TABLE 9

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

	Tier 2	Tier 2N	Tier 1	Tier 1N
Phosphorus Removal (pounds)[2]	643,544	643,544	823,765	823,765
Nitrogen Removal (pounds)[2]	-	600,737	-	2,603,192
Net Present Value of Removal Costs[3]	**$ 384,561**	**$ 3,717,541**	**$ 20,066,927**	**$ 22,410,707**
NPV: Phosphorus Allocation	384,561	384,561	20,066,927	20,066,927
NPV: Nitrogen Allocation[4]		3,332,981		2,343,780
TP Cost per Pound[5]	**$ 0.60**	**$ 0.60**	**$ 24.36**	**$ 24.36**
TN Cost per Pound[5]		**$ 5.55**		**$ 0.90**

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 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 AVWRF 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	$ 314,000	$ 2,322,000	$ 17,099,000	$ 19,106,000
Estimated Annual Debt Service[1]	$ 25,200	$ 186,300	$ 1,372,100	$ 1,533,100
Incremental Operating Cost[2]	2,700	21,700	151,100	172,300
Total Annual Cost Increase	$ 27,900	$ 208,000	$ 1,523,200	$ 1,705,400
Number of ERUs	5,380	5,380	5,380	5,380
Annual Cost Increase per ERU	$5.19	$38.66	$283.12	$316.99
Monthly Cost Increase per ERU[3]	**$0.43**	**$3.22**	**$23.59**	**$26.42**
Current Average Monthly Bill[4]	$22.25	$22.25	$22.25	$22.25
Projected Average Monthly Bill[5]	**$22.68**	**$25.47**	**$45.84**	**$48.67**
Percent Increase	**1.9%**	**14.5%**	**106.0%**	**118.7%**

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 AVWRF 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]	$ 54,600	$ 54,600	$ 54,600	$ 54,600
Affordability Threshold (% of MAGI)[3]	1.4%	1.4%	1.4%	1.4%
Monthly Affordability Criterion	**$63.70**	**$63.70**	**$63.70**	**$63.70**
Projected Average Monthly Bill	$22.68	$25.35	$45.84	$48.67
Meets State's Affordability Criterion?	Yes	Yes	Yes	Yes
Estimated Bill as % of State Criterion	**36%**	**40%**	**72%**	**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, disposal and energy consumption

As per the AVWRF data and per process modeling of the base condition (Tier 3), AVWRF is able to achieve some nutrient removal with its existing infrastructure, but not enough to meet the effluent limits of the specified Tiers of nutrient standards. Table 12 summarizes the annual reduction in nutrient loads in AVWRF 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	24,230	24,230	31,100	31,100
Total nitrogen removed, lb/year	----	20,780	----	96,890

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 AVWRF, no STORET data was found upstream to the POTW discharge point. Thus, total phosphorus and total nitrogen concentration discharged by AVWRF to the receiving waters 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. 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 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 a differential value 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	2,500	2,500	425,225	463,550
Polymers, lb/year	365	365	2,200	2,555
Biosolids Management:				
Biosolids produced, ton/year	4	40	205	230
Average yearly hauling distance(1)	0	90	465	525
Particulate emissions from hauling trucks, lb/year (2)	0	5	26	29
Tailpipe emissions from hauling trucks, lb/year(3)	0	11	59	67
CO_2 emissions from hauling trucks lb/year(4)	0	1,145	5,915	6,680
Energy Consumption:				
Annual energy consumption, kwh	600	151,475	382,155	543,850
Air pollutant emissions, lb/year (5)				
CO_2	460	136,630	344,704	490,553
NOx	1	212	535	761
SOx	1	182	459	653
CO	0	10	25	36
VOC	0	1	3	4
PM_{10}	0	3	8	11
$PM_{2.5}$	0	1	4	5

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 a 50 miles round trip hauling distance 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)*.