

MOVING WASTEWATER TREATMENT FACILITIES TO RESOURCE RECOVERY FACILITIES

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ABSTRACT

Utilities across the globe are recognizing the opportunity to move to more sustainable entities by focusing on the recovery of water, nutrient and energy resources from wastewater. The primary drivers include regulatory pressure, economics and a recognition that business-as-usual operation is unsustainable. The Metropolitan Wastewater Reclamation District of Denver, Colorado (USA) has taken its first major steps toward resource recovery at its R.W. Hite facility. These steps include innovative sidestream enhanced biological phosphorus removal and deammonification to reduce energy, chemical usage and balance carbon while improving water quality in its receiving waters. These initial steps have set the stage for Denver to move to full recovery systems in the near future.

INTRODUCTION

Globally, there is a trend to move water and wastewater utilities to more sustainable environmental systems. Traditionally, treatment of wastewater has followed a "linear" approach whereby wastewater is collected, transported, treated, and disposed into environmental receptors. The new paradigm, however, is "circular" in which all waste streams are seen as value streams because the resources present in the wastewaters are recovered and returned to the community for beneficial reuse. The sustainable wastewater treatment plant is a "factory" for producing beneficial products recovered from the matrix of substances dissolved and carried by wastewater streams. This concept defines the "Utility of the Future."

The recovery of resources from wastewaters involves four fundamental principles. First and foremost is the recovery of water for reuse within and around the local community. This offsets demands created by agricultural and urban irrigation, and is a viable supplement to water supplies in regions of water-scarcity through indirect potable reuse (reservoir and aquifer storage) and ultimately direct potable reuse (eliminating all environmental buffers). Studies project that the global demand for accessible

water (which constitutes only about 1% of all global water) will exceed supply by more than 40% by 2030 based on current water usage rates in all economic sectors, even without considering the potential impacts of climate change (McKinsey Company, 2009) Though recovery of water from wastewater does not offer a complete solution, it is indeed integral to the world's total resource management strategy in the coming decades.

Since the early 1970s, the global production of energy (in oil equivalents) has doubled, with much of the growth being in developing countries (IEA, 2012). Despite this expansion, energy demand, similar to water, is exceeding supply globally and this gap is predicted to be as much as 40% by 2030. Here again, energy recovery from wastewater, though not able to close this gap on its own, must be integral to the total energy solution. It is a well-known fact that the amount of energy embedded in domestic wastewater is an order of magnitude more than that required to operate a conventional treatment facility (Shizas and Bagley, 2004; Tchobanoglous and Leverenz, 2009). Traditionally, treatment facilities have captured some of this energy by combusting biogas produced from anaerobic digestion to generate thermal and electrical energy. A number of recent developments in digestion technology intensification (sludge pre-treatment, co-digestion, multi-phased digestion, etc.) have advanced energy recovery efficiencies to where facilities can operate at or near "energy neutral." In addition, generation of electrical energy using microbial electrochemical cell technologies to support the neutrality objectives are rapidly advancing though likely still a decade away from commercial viability. Furthermore, some utilities are pursuing the recovery of thermal energy from the heat present in the effluent to offset on-site thermal demands or to market to a local power utility.

Third, nutrients, specifically nitrogen and phosphorus, are in abundance in raw wastewater and have been shown to be a source of environmental degradation of receiving waters and other public health concerns. These nutrients are available for recovery for use in agricultural fertilizers to offset commercial fertilizer production. Currently, emphasis remains on phosphorus recovery due to its relative process simplicity coupled with a growing awareness of finite global phosphate supplies and the implications that has

on global food production. Current studies indicate global phosphate reserves could be depleted in 370 years based on 2010 production levels (USGS, 2011). The majority of phosphorus loss is via erosion and crop losses, and about 15% is lost via wastewater discharges and biosolids disposal. Thus, phosphorus recovery from waste streams could reduce the amount of phosphate that is being mined (WEF Special Publication, 2014).

Cost-competitive technologies for the recovery of nitrogen, however, remains elusive. The current rate of global nitrogen fertilizer production exceeds 100 million metric tons/yr (FAO, 2007), and drivers for offsetting nitrogen in fertilizers remain weak, particularly in light of the current (though not likely to be long-term) cost-favorability of fossil fuels used in the widely employed and efficient Haber-Bosch process. Nonetheless, there are many countries where nitrogen demand exceeds supply. At the current global population level, the total human excretion of nitrogen is equivalent to about one quarter of the nitrogen content of the total artificial nitrogen fertilizer produced globally (WEF Special Publication, 2014). Here again, recovery of nitrogen from wastewaters can help reduce the total amount of nitrogen that is commercially produced.

Finally, the chemical content of wastewaters opens the door to a wide array of opportunities to generate products from the wastewater such as industrial chemicals, bioplastics (with fermentation of sludges serving as feedstock for intracellular polyhydroxylaklanoate production) and biofuels (from algae cultivated in treated wastewater effluents). These can result in new revenue streams for the utility while offsetting conventional products produced from finite natural resources.

CURRENT TRENDS

For a utility to become a Utility of the Future, recovery of resources must be at its forefront. But it is unrealistic to assume that all who manage these facilities will choose resource recovery solely on a basis of environmental stewardship. For most utilities, particularly those in the public arena, pragmatically, the choice to engage in resource recovery means that clear drivers must be present to justify the investment of funds (be they public or private).

Drivers differ regionally across the globe. In North America, the stringent regulations on effluent consents is by far the dominate driver for utilities choosing to engage in nutrient recovery. Without these regulations, it is difficult for utilities to justify either phosphorus or nitrogen recovery schemes. In Europe, however, phosphorus recovery specifically is driven more by EU initiatives for sustainability. Australia, though embracing

resource recovery, currently has only one phosphorus recovery facility. Offsetting the rising prices for purchased power is the primary driver that utilities across North American and Europe use to justify investing in energy recovery systems.

Investments in water reclamation and reuse is almost solely in response to water scarcity. In Australia, water recycling infrastructure has grown significantly in the past 20 years. Much of this is the response to nearly a decade of intense droughts, but also due to changes in how the customers view the true value of water (as evidenced by the growth in water recycling in New South Wales and Victoria). In Europe, water recycling has been widely practiced for more than a half century for environmental flow, agriculture and saltwater intrusion barriers. In North America, water reuse has been sporadic and focused almost entirely in those local geographies where water scarcity has become a dominant issue. In Asia and the Middle East, water recycling is a dominant practice, ranging from agriculture (e.g., 90% of Israel's water management program and 35% of India's program) to direct potable reuse schemes (e.g., Singapore).

There is evidence, then, that transitioning to a resource recovery paradigm for treating wastewater is a positive global trend. Further advancing this trend requires individual utilities at all scales to make the conscious choice to engage. This means drafting a road map toward their specific recovery future, and implementing calculated, incremental steps. Such is the case with the Metro Wastewater Reclamation District (MWRD) of Denver, Colorado, USA. The following describes how the MWRD has taken its initial incremental, yet monumental steps toward becoming a leader in the resource recovery arena on its road to becoming the Utility of the Future at its Robert W. Hite Treatment Facility (RWHTF).

THE ROBERT W. HITE FACILITY DESCRIPTION

Metro's RWHTF is rated for 830 ML/d (220 MGD), providing treatment for a total of 49 entities in the Denver metropolitan region including 22 member municipalities and 27 specific connectors. The facility consists of two batteries of primary and secondary biological nutrient removal plants. The North Complex is rated for approximately ten percent more capacity than the South Complex and operates as a Modified Ludzack-Ettinger (MLE) process. The South Complex operates as a 3-Stage bio-P/nitrification/denitrification process. Solids are anaerobically digested and the Class B biosolids dewatered and land applied locally. Figure 1 shows an aerial of the site.

ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL (EBPR)

Metro's goal for its EBPR upgrades was founded on meeting the imminent effluent phosphorus consent of 1.0 mg/L as TP as an annual median being imposed by new regulation. This consent is anticipated to be further reduced to less than 0.1 mg/L TP in the near future. Therefore, the EBPR treatment goals are first and foremost to minimize, to the extent practical, tertiary upgrades that will likely be required in the future to comply with the regulatory framework. Additionally, the EBPR process will result in eliminating the current chemical phosphorus removal process, significantly reducing operating costs. This presented an excellent opportunity to take an important incremental step toward recovery of phosphorus (as struvite) in a subsequent recovery-specific process.

EBPR Process Description

The innovative EBPR process design was developed by the Metro process staff. It involves a dedicated anaerobic phosphorus accumulating organism (PAO) growth reactor (using a repurposed existing tank) acting on a sidestream of Return Activated Sludge, fed with volatile fatty acids generated by fermenting primary sludge in a dedicated fermenter and from gravity thickeners. The reactor is designed to maximize phosphorus release. To prove performance under a variety of

operational conditions, the Metro District conducted a full-scale pilot at the North plant (illustrated in Figure 2) of the process from November 2011 to June of 2012. The pilot demonstrated that two of four existing centrate nitrification/denitrification sidestream reactors could be converted to the sidestream EBPR process. The pilot showed that the plant average effluent TP concentration of less than 0.6 mg-P/L was readily achievable (Carson, 2012). The pilot performance results are shown in Figure 3. Positioning the anaerobic volume for the Bio-P process as a sidestream preserves aeration capacity in the existing MLE bioreactors necessary for optimal phosphorus uptake without decreasing nitrogen removal efficiency, and, eliminating any need for supplemental carbon necessary for achieving higher TN removal efficiencies under future regulations.

Fermentation of primary sludge for the balanced production of VFAs is key to the performance of the EBPR. Two fermentation facilities were retrofitted: utilizing primary sludge gravity thickeners with controlling sludge blanket depth and HRT, and a sludge holding tank to receive pumped primary sludge and with controlled HRT. The baseline design criteria for the sidestream EBPR are shown in Table 1. Final detailed design of the sidestream EBPR system was completed in January of 2016 with construction scheduled to be completed in late 2017.



Figure 1: RWHTF Aerial: North and South Treatment Plants

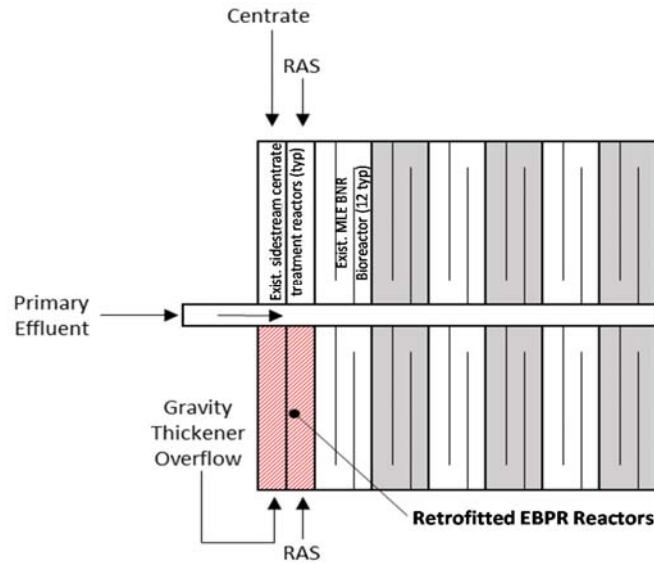


Figure 2. EBPR Pilot Process Configuration at North Secondary Complex (Adapted from Carson, 2012)

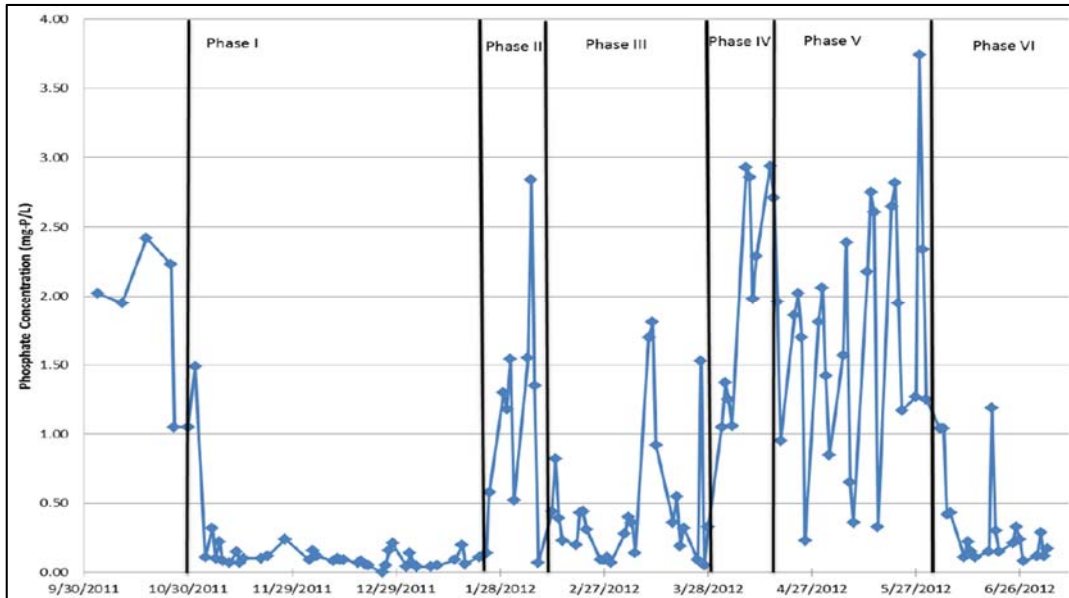


Figure 3. Effluent Phosphate Concentrations (Carson, 2012)

Phase 1: Steady State – constant blanket depths in thickeners; Phase 2: Dynamic – variable blanket depths in thickeners

Phase 3: EBPR in combination with PACl for filament control; Phase 4: VFA from fermentation of RAS only

Phase 5: Variable phosphorus loadings from centrate; Phase 6: Same as Phase 1.

Table 1. Sidestream EBPR Reactor Design Criteria

Parameter	Pilot	Final Design
No. of EBPR Reactors	2	2
Total anaerobic volume	5,140 m ³	5,140 m ³
Gravity Thickener Overflow (VFA Source)	20.03 ML/d	18.9 – 26.08 ML/d
RAS design flow	75.6 – 90.7 ML/d	75.6 – 196.6 ML/d
EBPR Reactor HRT	1.1 – 1.3 hours	0.6 – 1.3 hours
EBPR Reactor SRT	1.0 days	0.4 days

Unintended Consequences of EBPR

During the EBPR pilot, the District observed the following negative impacts:

- Excessive struvite precipitation and deposition in anaerobic digesters, increasing significantly costs associated with maintenance and chemicals needed to remove struvite;
- Reduced dewatering performance: efficiency reduced by about 4 percent with concomitant increase in polymer and ferric chloride use, and increased solids hauling;
- The return load of phosphorus in the centrate sidestream increased substantially affecting final effluent phosphorus levels.

ENERGY AND NUTRIENT MANAGEMENT: DEAMMONIFICATION (DMX)

The centrate return stream from the dewatering of anaerobically digested sludge at the RWHTF constitutes between 20 to 25 percent of the total ammonia load treated in the secondary facilities. With upcoming limits on both phosphorus and nitrogen, and the recognition that managing energy consumption to reduce operational costs it became clear to Metro that the sidestream nitrogen load on the plant must be reduced. Metro determined that an anammox process would be its choice for reducing the recycled nitrogen loads.

While DMX is not required to comply with the anticipated imminent 15 mg-N/L of TIN consent,

and a future of 2.01 mg/L as TN as part of the new regulatory framework, the DMX process provides reliable ammonia removal on the centrate stream. Model simulations (data not shown) from studies completed in 2013 predicted that DMX will reduce the effluent TIN to within 1.0 to 2.0 mg-TIN/L (HDR Engineering, 2014). At the same time, energy consumption will be reduced significantly due to the reduction in aeration demand from the reduction in ammonia.

Preparing the Nitrogen Management Process

Similar to the EBPR, the Metro District evaluated the feasibility of DMX technology by conducting a pilot of Kruger's ANITA™Mox technology from September 2012 to March 2013. The study was conducted in four phases intending to understand the required volumetric and surface area loading rates and operational stability. The study demonstrated an ammonia oxidation rate of 80 to 85 percent is obtainable, while eliminating between 70 to 80 percent of the TIN. The influent ammonia concentration during the pilot ranged from 800 to 1200 mg/L, with the effluent TIN consistently between 200 and 250 mg/L. Figure 4 shows the performance efficiency during the pilot. As shown in Figure 5, the pilot study demonstrated that the design loading rate of 3 g-N/m²/d could be sustained and that a volumetric loading rate (VLR) of 1 kg-N/m³/d was feasible for full scale design.

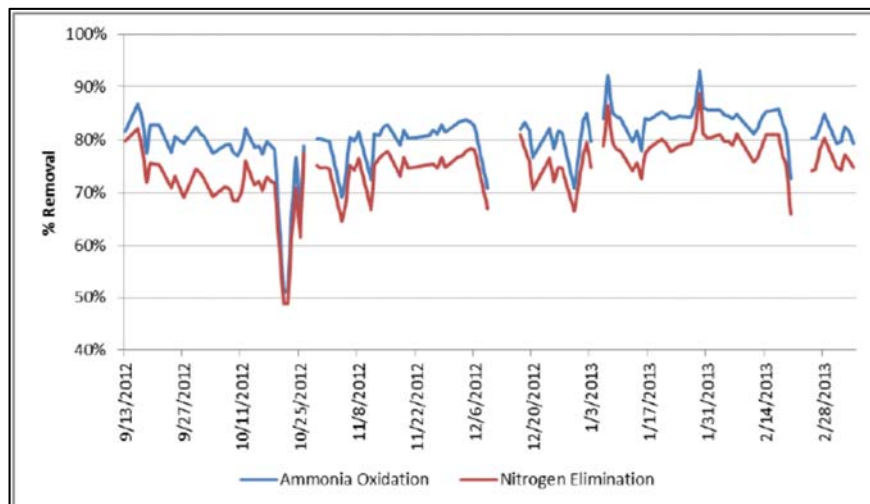


Figure 4. Ammonia Oxidation and Nitrogen Removal Using DMX Technology

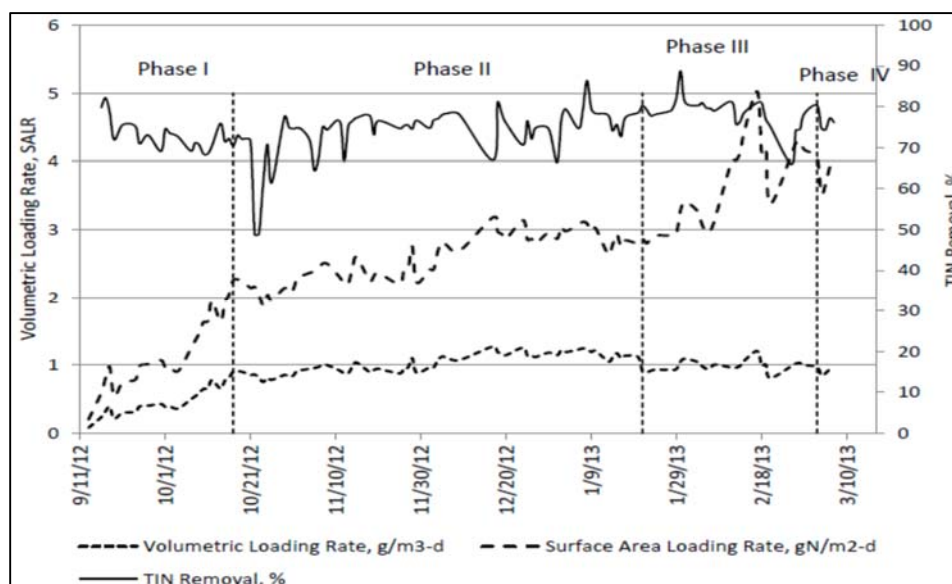


Figure 5. TIN Removal, Volumetric Loading Rate, and Surface Area Loading Rate for DMX

Deammonification Full-Scale Design

The DMX design criteria is shown in Table 2. The installation consists of converting two existing centrate treatment reactors and is illustrated in the site plan of Figure 5. Final design of the DMX

reactor was completed in December 2015 and installation and commissioning is scheduled for late 2016.

Table 2: Baseline DMX Reactor Design Criteria

Parameter	Units	Value
Reactor Dimensions (Each of 2)	m	19.89 L x 16.62 W x 6.33 (SWD)
Total Reactor Volume (All Trains)	m ³	4,180
Average Flow	ML/d	3.40
HRT, Average Flow	days	1.2
NH ₄ -N Average	mg/L	1,200
TKN, Average	mg/L	1,300
Alkalinity, Average (as CaCO ₃)	mg/L	3,900
Temperature, max	°C	40
Temperature, min	°C	30
Fill of Biofilm Carriers, All Reactors	%	36.5%
Total Effective Surface Area	m ²	1,229,910
AOR, Design Flow	kg-O ₂ /hr	332
Total Standard O ₂ Transfer Efficiency at 6.33 m SWD	%	20.6

NEXT INCREMENTAL STEPS TOWARD RESOURCE RECOVERY

Phosphorus

With the installation of both the EBPR and the Deammonification facilities, MWRD is now poised to take the next significant step toward full resource recovery facility operation: phosphorus recovery. In 2015, MWRD completed an internal technical and economic evaluation on phosphorus recovery technologies and determined that

phosphorus recovery was favorable (technically, economically and socially) in light of the total amount of struvite product that can be recovered and marketed as a potential revenue stream for the District. The recovery facility is likely to enter into preliminary design phases during FY2016-17, with final design and procurement of recovery reactors immediately following. Figure 6 is the overall Process Flow Diagram for the RWHTF inclusive of the EBPR, DMX, and future P-Recovery facilities.

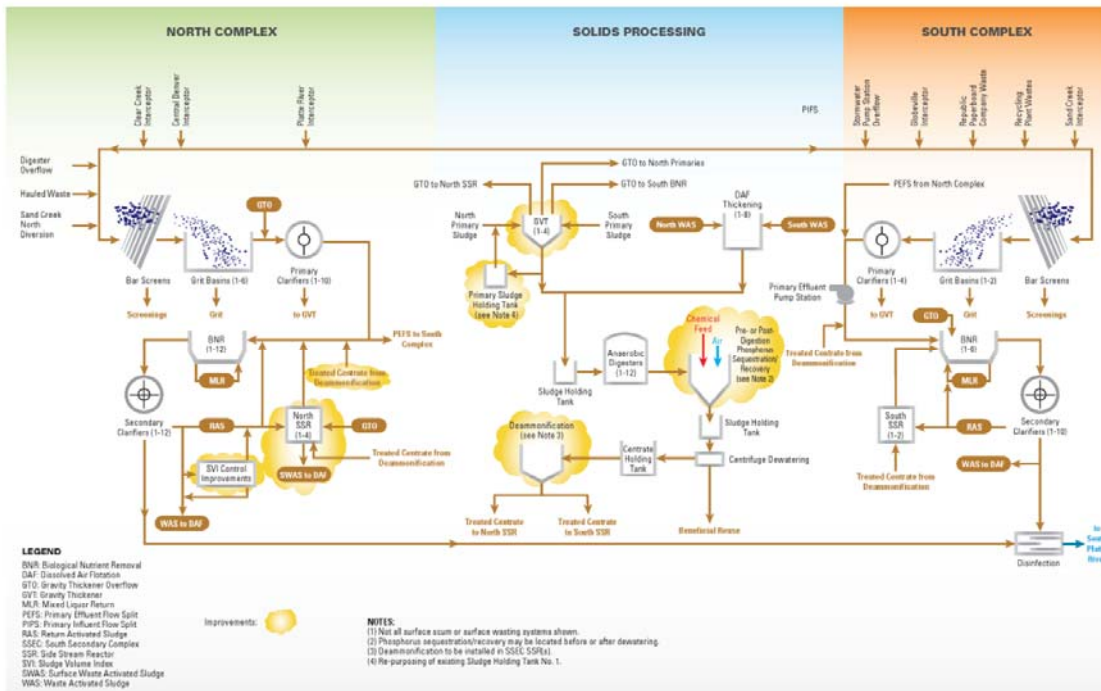


Figure 6: Plant-wide Process Flow Diagram showing EBPR, DMX and P-Recovery Improvements

Heat

The opportunity exists with MWRD to explore the feasibility of recovery of thermal energy from the influent and effluent wastewaters. Influent wastewater temperatures pose the opportunity to recover heat for use as supplemental heating for commercial buildings in the downtown business district. Similarly, effluent heat recovery can be implemented to provide supplemental thermal energy for facilities on the RWHTF while addressing the temperature of the treated effluent and questions surrounding long term sensitivities these temperatures may have on aquatic life sustainability in the receiving waters.

Water

The Metro District already provides 114 ML/d (30 MGD) of treated effluent to Denver Water for further treatment for local reuse. It is anticipated that the growth of reuse in the next decade will continue as demand for reuse in the Denver area increases. Metro is poised to be the lead agency in meeting these demands.

CONCLUSIONS

The Metropolitan Water Reclamation District of Denver, Colorado, USA, has determined to be a leader in resource recovery and has taken its first significant steps toward being a Utility of the Future. These steps are the successful implementation of an innovative Enhanced Biological Phosphorus Removal process in conjunction with Deammonification to manage

nutrients in the wastewaters it treats. Though drivers for these installations are influenced significantly by regulatory frameworks, the Metro District has seized the opportunity to use these requirements as the launch pad for a long term program of full recovery of water, nutrient, and energy resources.

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