LOW COST NUTRIENT REMOVAL in Montana

a 2016 report on 11 wastewater treatment plants

THE WATER PLANET COMPANY

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Montana's experience disproves the conventional belief that new infrastructure is required for wastewater treatment plants to significantly reduce nutrients in their effluent.

An investment in wastewater operator training and technical support is sustainably improving the quality of the waters of the State of Montana. The combined efforts and expertise of Montana regulators and municipal wastewater treatment plant operators has given renewed evidence to support the position that operational optimization is an extremely potent and effective alternative to massive capital improvement projects.

The clever use of existing treatment equipment has reduced the wastewater discharge of nutrients by as much as ninety percent. Before and after results from 11 of the 27 participating communities in the Montana Department of Environmental Quality's four year training and technical support effort are summarized below. Total-nitrogen was reduced by an average 59% and total-phosphorus by 33% at facilities not designed to remove nutrients. To achieve similar results through conventional improvements, the cost to each community would typically be several million dollars.

In order to realize the results presented above, Montana expended approximately $1,100 per treatment facility to provide free classroom training and $5,000 for in-plant technical guidance. Since 2012, DEQ has employed an operations consultant to train 70 wastewater treatment plant personnel and make 38 wastewater treatment plant site visits. Montana DEQ and the consultant provided extensive follow-up support in the form of emails and telephone calls.

Montana's experience demonstrates that educated, supported and empowered wastewater operators can remove nutrients using infrastructure not designed to do so.

MONTANA POTW	Effluent Total Nitrogen			Effluent Total Phosphorus		
	BEFORE (mg/L)	AFTER (mg/L)	PERCENT REDUCTION	BEFORE (mg/L)	AFTER (mg/L)	PERCENT REDUCTION
BNR PLANTS						
Columbia Falls	10	7	32%	2.5	0.3	87%
East Helena	20	10	48%	NR	NR	NA
Helena	7	5	31%	2.9	2.0	32%
Manhattan	10	8	21%	1.5	0.4	73%
NON BNR PLANTS						
Big Sky	25	14	46%	1.3	1.4	-8%
Chinook	26	3	88%	2.8	0.30	89%
Conrad	35	5	85%	2.1	0.13	94%
Hamilton	7	3	54%	5.5	4.0	28%
Hardin	18	4	78%	2.1	2.4	-14%
Libby	32	21	34%	4.6	3.0	35%
Lolo	28	21	25%	4.6	4.4	5%

None of the treatment facilities spent more than $10,000 on new equipment, most of which was for instrumentation.

Different people respond to training differently. Because some operators are more receptive to technical support than others, some plants got a lot more out of Montana’s support than others. Slightly more than one-third of the 27 participating communities realized improvements; the remainder did not, or have not yet. Several of the participants were first introduced to the concept earlier this year and may not see the results of their optimization efforts for some time.

Some reasons plants failed to improve nutrient removal follow: three plants are already removing nitrogen to less than 8 mg/L and phosphorus to less than 0.5 mg/L, one plant had made a prior commitment to a facility upgrade, and three of the facilities are so new that plant staff are not yet familiar enough with operations to effectively experiment.

Classroom training. A two-day training program provides plant personnel with tools (detailed knowledge of the biochemistry of nutrient cycles) to optimize nitrogen and phosphorus removal in their wastewater treatment facilities. Following a day of training, participants are given the opportunity to describe their treatment facilities to fellow operators to generate ideas on how they might be operated differently to optimize nutrient removal. The training program was developed by Grant Weaver of The Water Planet Company and Greg Kidd of Northeast Water & Wastewater Training Associates, Inc. Greg and Grant conducted the training during the late spring of 2012 and 2013. Grant led the classroom presentations with DEQ support in 2014 and 2015.

Without the encouragement of their regulators, many municipal operators are unlikely to experiment with changes in day-to-day operation of their facilities.

In-plant technical support. During half-day site visits, a technical team comprised of Water Planet's Grant Weaver and one or more Montana DEQ personnel (most frequently, Bill Bahr, Dave Frickey, and Paul LaVigne) met with plant staff to discuss operations, tour the plant, review data, and brainstorm opportunities for optimizing nutrient removal. It has been plant personnel's decision to accept or refuse guidance. Most, in large part due to the state's interest in having them experiment, chose to make process changes.

In brief, the objective of the plant visits has been to identify opportunities for the creation of optimal biological habitats for nitrogen and phosphorus removal bacteria. These habitats contain aerobic conditions for ammonia-nitrogen conversion to nitrate and the uptake of orthophosphate by phosphate accumulating organisms (PAOs), nutrient rich anoxic conditions for the conversion of nitrate-nitrogen to nitrogen gas, and anaerobic (fermentative) conditions for the generation of volatile fatty acids (VFAs) and the subsequent uptake of VFAs by PAOs.

In making specific recommendations the team seeks to nudge operators out of their comfort zones while providing early wins to empower further, more aggressive process changes. When experiments fail to provide the desired results, or when setbacks occur, remote support is generously provided and operators are supported in whatever correction they choose to pursue.

Remote support. Following every site visit, consultant Grant Weaver sends a report on the visit to plant staff and DEQ. The consultant provides plant personnel with ongoing telephone and email support. DEQ staff make periodic visits and also provide ongoing remote support by telephone and email to the extent desired by plant personnel.

As Montana DEQ Program Manager Paul LaVigne says;

"Basically, we are training the operators to hide their O&M manuals in a dark corner somewhere and start operating their systems differently than what they were originally designed for – along with some specific education and guidance."

Chinook, Montana

Following two days of classroom training in 2012, plant supervisor Eric Miller and staff (Cory Fox and Larry Miller) experimented with cycling the one in-service rotor on Chinook's 0.5 MGD oxidation ditch. Prior to the class, plant staff had established the practice of using one rotor during the winter and a different rotor in summer. After discussing their operations with the trainers (Grant Weaver of The Water Planet Company, and Greg Kidd of Northeast Training), Montana DEQ staff, and the other operators in attendance, Chinook's operators began cycling their one in-service aeration rotor on and off. Aeration was kept on long enough to provide sufficiently aerobic conditions to maintain complete ammonia removal and turned off long enough to create anoxic conditions to support denitrification.

Nitrate-N was reduced to 5 mg/L and, as a result, Chinook's effluent total-N dropped from 26 to 15 mg/L. Buoyed by the success, an in-line ORP probe was installed and connected to the plant's SCADA. Both rotors remain off until the ORP reaches -210 mV at which time one is turned on and continues operating until the ORP rises to +210 mV, when the one in-service rotor shuts off.

Effluent total-N now averages 3 mg/L, an 88% drop from its pre-optimization totals. To maintain the outstanding total nitrogen removal, plant staff track the daily average DO reading in an effort to keep it close to a target value of approximately 1 mg/L.

The technical team's first site visit was made in 2015 after nitrogen removal had already been optimized. Water Planet and Montana DEQ staff worked with plant staff to modify operations to maintain nitrogen removal while providing biological phosphorus removal. After one failed trial involving the conversion of the aerobic sludge digester to a fermenter, plant staff turned off one of the oxidation ditch's two in-line mixers so when the one in-service rotor cycles off, only one of the two submersible mixers operates. With minimal mixing, sludge settles and creates fermentative conditions where volatile fatty acids (VFAs) are produced and "eaten" by the phosphate accumulating organisms (PAOs). The PAOs are energized, and ortho-phosphorus is temporarily released and then bio-accumulated by the energized PAOs during aeration. Daily operation of both mixers for a 10-15 minute period keeps the deposition from becoming problematic.

Effluent total-P now averages 0.3 mg/L. Prior to optimization it was greater than 2.8 mg/L.

Chinook's plant was not originally designed to remove nitrogen or phosphorus. Other than process changes, plant staff have invested $8,000 in new ORP probes and SCADA control.

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Conrad, Montana

Following two days of classroom training in 2012, operator Keith Thaut experimented with turning aeration off for increasing periods of time at the 0.5 MGD extended aeration activated sludge facility. The air on and off cycles were established by using a hand-held spectrophotometer to measure ammonia. Enough air was provided to keep ammonia down to 0.5 mg/L while long cycles of air being off were established to create anoxic conditions for nitrate removal. Additionally, over a two-year period the mixed liquor concentration was increased from 1500 to 5000 mg/L.

Conrad's effluent total-N now averages 5 mg/L; before two days of training and staff efforts to reduce it, total-N averaged 35.

Two plant visits were made by DEQ and Water Planet in 2014 and 2015. To optimize phosphorus removal, the technical support team suggested turning off the air in the aerobic sludge holding pond and returning fermented sludge to the covered aeration basin.

As a side benefit to the recycling of sludge to the aeration basin, Conrad experienced a substantial reduction in dewatered sludge production during the summer of 2014. Approximately one-fifth as much sludge was produced as a result of bacteria breaking apart and becoming consumed in the two environments: aeration tank and digester. Much of the carbon is now broken down to carbon dioxide (CO_2) and released into the atmosphere instead of being removed as sludge.

The current mode of operation is as follows. During the summer Conrad operates the aeration tank so it receives air for 3 hours followed by 2 hours without aeration. During the winter and periods of -20° F weather, Conrad operates the aeration tank so that it receives air for 2 hours followed by 1½ hours without aeration. The sludge digester receives the same amount of aeration as the aeration tanks.

Conrad's total-phosphorus now averages less than 0.2 mg/L. Although not designed to do so, the facility is now effectively removing phosphorus biologically.

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Helena, Montana

Beginning with the first training class in 2012, Helena has sent 3-4 operators every year, more than any other facility. And, more site visits have been made to Helena than any other plant. Helena staff are fully engaged in the optimization effort.

Helena's 5.4 MGD Modified Ludzack-Ettinger (MLE) wastewater treatment plant has historically produced an effluent with excellent BOD & TSS numbers: less than 5 mg/L. At the onset of the optimization work, total nitrogen averaged a respectable 7 mg/L and total phosphorus averaged 3 mg/L. Total-N is now averaging 5 mg/L and total-P is averaging 2.0 mg/L.

The Helena staff continues to experiment with ways to optimize nutrient removal at the City's wastewater treatment plant. By being so actively involved, they have a high level of understanding of the process which will allow Helena to develop an extremely cost-effective long term nutrient removal strategy.

Plant staff routinely use ORP as a tool in making adjustments to the internal recycle pump rates. Dozens, if not hundreds of ORP readings have been collected. To increase organic loading on the plant bioreactors' anoxic zones for nitrate removal, plant staff are flushing (elutriating) the contents of the online primary clarifier during nighttime hours. To reduce floating solids in the bioreactors, plant staff have removed the troublesome scum baffles from all three of the plant's bioreactors. To lower the loading on the secondary clarifiers while retaining the same solids inventory in the bioreactors, plant staff has switched from two to three bioreactors; doing so provides the additional benefit of increasing the hydraulic retention time.

Currently, one of two primary clarifiers is in service. In an effort to solubilize waste to improve nitrate removal, but also to create fermentative conditions in the primary clarifier supporting phosphorus removal, plant water is used to flush solids (and solubilize BOD) in the primary clarifier. During the work day the primary sludge pump runs for 2 minutes on and 10 minutes off. No flush water is added during the day. After hours, plant water is run into the sludge wasting pipe for 5 minutes an hour to scour solids. No primary sludge is wasted overnight.

As a means of further improving total-P removal, plant staff have embraced the concept of extending the internal recycle pump outlet to the inlet end of the second anoxic zone. Doing so will convert the first anoxic zone to a fermentative zone so that volatile fatty acids (VFAs) produced in the primary clarifier will mix with the phosphate accumulating organisms (PAOs) contained in the RAS. The PAOs will eat the VFAs and temporarily release ortho-P in the fermentation zone. The PAOs will pass through the anoxic zone and will take in ortho-P in the first aeration zone (DO 3.0 mg/L).

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Hardin

With the support of DPW Director Russell Dill, Chief Operator John Stanich is experimenting with the operation of Hardin's 1.0 MGD oxidation ditch. Montana DEQ and Water Planet support personnel visited the facility twice in 2015; plant staff participated in classroom training in early 2015. Plant staff purchased an ORP probe for optimization work and are beginning to collect data for use in optimizing the process.

Plant effluent is clear; typical BOD is non-detect, and TSS is almost always less than 10 mg/L. Before optimization, commercial lab testing documented an average total-N of 18 mg/L. It is now averaging 4 mg/L. Phosphorus removal has deteriorated slightly from 2.1 to 2.4 mg/L. If scheduling allows, additional phosphorus removal trials will be conducted during 2016.

The oxidation ditch has two rotors, with one at each end. A pair of submersible mixers are located downstream of the southern rotor, with no mixers by the northerly rotor. The rotors and mixers are fixed speed and are controlled manually. In order to create a more vibrant anoxic zone for nitrate removal, one of the rotors was recently turned off. Plant staff have optimized nitrogen removal in the oxidation ditch by maintaining a strongly aerobic zone for ammonia removal and a strongly anoxic zone for nitrate removal.

For phosphorus removal, a trial using the aerobic digester as a flow-through fermenter proved unsuccessful. Given the limitations of the plant's manual controls and other factors, a week-long attempt at cycling the air in the aerobic sludge digester caused more operational problems than solutions. The concept was to make the contents anaerobic (ORP of -100 to -250 mV), pump waste sludge into the digester, and return sludge from the digester to the oxidation ditch via a telescoping valve that was installed for decanting. The experiment has been abandoned and the digester is again operating normally.

An alternative approach was discussed during an October 2015 visit. As is being done in Conrad, plant staff are seeking to optimize phosphorus removal in the oxidation ditch by creating an anaerobic zone for VFA production and uptake by phosphorus eating bacteria. They are experimenting to determine the best configuration of rotors and mixers in an effort to operate the plant for some settling to occur in the ditch without getting too much deposition. Because the plant is without SCADA, VFDs, and timers, Hamilton staff is currently limited to on /off settings. As budgets allow, additional instruments and controls will be installed.

Given the staff's commitment, Harding will almost surely become another Montana success story!

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Libby

Lucas Backen enthusiastically participated in the 2015 two-day training class and strongly encouraged DEQ and Water Planet to make a plant visit. In October 2015, Mike Gehrke, Jeff Holder, and Lucas welcomed the technical support team to Libby's 0.5 MGD oxidation ditch facility.

Given the staff's commitment to optimization, there is every reason to believe that the facility will, within a year or two, produce an effluent with total-N in the 5-6 mg/L range and total-P in the 0.5 mg/L range. Using information learned in class, the plant is now denitrifying. Test strip data are showing total nitrogen removal with ammonia consistently 0.5 mg/L or lower, nitrite typically zero, and nitrate has dropped from 50 to 5-10 mg/L). For the first time in memory, effluent pH is holding without any lime addition (this is because nitrate removal adds back one-half of the alkalinity lost during ammonia removal). After a few months of optimization effort, effluent total-N has dropped by 11 mg/L to 21 mg/L.

No efforts have yet been made to remove phosphorus. Nonetheless, simply allowing some settling in the oxidation ditch (as is being done in Chinook) should reduce total-P to below 1.0 mg/L.

Given the lack of aeration control, the following experiment was suggested: shutting off the air for two hours twice per day on week days (the beginning and end of workday) and once per day on weekends and holidays to provide an effective anoxic zone for nitrate removal. To facilitate sludge deposition for bio-P removal, it was recommended that the floating mixer be turned off when the air is turned off.

As budgeting allows, the purchase of an ORP probe for an existing meter was recommended. Another priority purchase is a benchtop spectrophotometer to provide better ammonia, nitrate, nitrite, and phosphorus data.

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Manhattan

Robert Seamons, Chief Operator of Manhattan's 0,4 MGD extended aeration facility, attended the first two-day training class in 2012. The first day of the classroom training consisted of instructor-led lectures. The second day was taken up with classroom discussions of the training participants' plants.

As the first operator to present at Montana's first two-day nutrient class, Robert established a high standard. It didn't hurt that he was a member of the plant's design team (Stahly Engineering & Associates, Inc.) and was able to share a complete understanding of the facility's design and operation.

The Manhattan plant is equipped with a pre-anoxic zone but no internal recycle pumping. Given the presence of surplus secondary clarifier capacity, it was recommended that the RAS rate be doubled (or more) to return more nitrate to the plant's pre-anoxic zone. Shortly upon returning to the plant, the RAS rate was raised from 1Q (one times the influent flow) to 2.5Q (2.5 times). Doing so reduced the nitrate concentration to 5 mg/L.

Manhattan's effluent has seen a slight improvement: total-N now averages 8 mg/L. It averaged 10 mg/L before the training. Phosphorus removal has significantly improved. Effluent total-P averages 0.4 mg/L; before the classroom training it averaged 1.5 mg/L.

No visits were made to the 0.4 MGD extended aeration treatment facility. The improvements were the result of operational changes made by an informed operator.

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Lolo

Two visits were made during 2014. Jasen Neese, Chief Operator of Lolo's 0.34 MGD plate steel activated sludge treatment plant, had not been to any of the classroom training but actively engaged in optimization discussions with DEQ, Water Planet, and HDR Engineer Sean Everett.

Between the two 2014 visits, the amount of aeration in the first of three aeration tank cells was reduced to a minimum. Doing so reduced phosphorus from 4-5 mg/L to 3 mg/L; one sample was 0.25 mg/L! On average, however, effluent total-P is not much improved since before the optimization efforts: 4.4 vs. 4.6 mg/L.

Prior to the first visit, total-N was typically around 25-30 mg/L. The ammonia concentration was less than 0.5 mg/L, but the nitrate was 20-25 mg/L. Nitrate dropped to 17 mg/L, reducing the total-nitrogen by over 5 mg/L to an average 21 mg/L.

At the recommendation of the technical support team, an ORP probe was purchased. An initial set of readings provided encouraging information: -50 mV in the first cell, +130 in the second, and +220 in the third. The plant has very limited control (ball valves on a common aeration header), but the following ORP targets were discussed: below -100 mV in the first cell and +100 to +150 mV in the second and third cells.

For the long-term the technical team agreed with the operator's idea of turning the air off completely in the first aeration zone and mixing the contents with a mixing device, which the operator agreed to research.

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East Helena

Chief Operator Steve Leitzke attended the two-day training classes in 2014 and 2015 and four days of in-plant technical support were provided in 2014 and 2015. A contingency of EPA Region 8 officials joined DEQ and Water Planet staff during the July 2014 site visit.

Except during late winter/early spring, East Helena's 0.434 MGD extended aeration activated sludge treatment facility effectively removes ammonia. However, a considerable amount of nitrate remains in the effluent. Plant staff experimented with the creation of a post anoxic-zone by shutting off the air to two of the six aeration drops.

Given the long hydraulic retention time in the aeration basin (over 48 hours at times) and the low wintertime water temperatures (5° C), for year-round ammonia removal it may be necessary to cover the aeration basin, as has been done at the Conrad plant. As is, process changes have reduced total-N by 50%, 20 to 10 mg/L.

Quizzically, during the summer the mixed liquor remains fairly constant without any sludge wasting. However, routine wasting is required during winter months. Endogenous respiration occurring as a result of the long periods of hydraulic retention is presumably the cause for the summertime solids destruction.

Changes to the plant's computer system (SCADA) are scheduled to occur within the next year. The changes will provide staff with the opportunity to cycle aeration on and off to create alternating aerobic and anoxic conditions for total-N removal. Once total-N is achieved, the flexibility provided by the changes in SCADA programming should allow staff to create anaerobic zones for biological phosphorus removal.

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Columbia Falls

In response to Public Works Director Lorin Lowry and Wastewater Superintendent Hugh Robertson's active participation in the first of the two-day training classes (2012) and request for in-plant support, a total of five Columbia Falls site visits were made during the period of 2013-2015. Both the DPW Director and Plant Superintendent have retired, and experienced operator Gene Woods has been promoted to plant supervisor. The 0.55 MGD A2O facility (anaerobic-anoxic-aerobic) is designed to provide nitrogen removal and biological phosphorus removal supplemented with alum. The plant produces an excellent effluent: BOD and TSS are generally below 5 mg/L, total-P is well below 0.5 mg/L and total-N averages 7 mg/L.

A years-old inventory of waste sludge held in an aerobic digester was found to be releasing such high concentrations of ortho-phosphorus into solution during dewatering that the facility was struggling to meet its 1.0 mg/L total-P limit, even with alum addition. Since 2014 the sludge inventory was removed, the plugged diffusers were replaced, and the waste sludge inventory was kept at a minimum. The plant has continued to utilize chemicals to meet its phosphorus limit.

To improve biological phosphorus removal at the plant, staff experimented with mixing the return activated sludge with the influent flow in the equalization basin. In-house testing indicated that the equalization was working as a fermenter and boosting bio-P removal, but the experiment was discontinued because of concerns about mixing, equalization pump rates, and problems with sludge wasting.

The facility consistently removes ammonia, but nitrate concentrations are typically high: 6-8 mg/L. To troubleshoot nitrate removal, plant staff collected grab samples of mixed liquor from the anaerobic, anoxic, and aerobic zones and tested all three for nitrate using the plant's benchtop spectrophotometer. The results demonstrated that the nitrate present in the aerobic zone (6.8 mg/L) could be reduced if more flow were recycled to the anoxic zone (0.5 mg/L nitrate-N). The internal recycle rate was increased and nitrogen removal has improved to 7 mg/L total-N.

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Hamilton

Before participating in DEQ's training and technical support program, nitrogen removal at Hamilton's 1.984 MGD oxidation ditch facility was fully optimized. In recent years, effluent total-N has historically averaged 3 mg/L. The aeration rotors on the plant's oxidation ditch cycle on for four hours and off for two hours to create alternating aerobic conditions for ammonia removal and anoxic conditions for nitrate removal.

In an effort to explore options for similarly optimizing phosphorus removal, DEQ and Water Planet technicians met with plant staff in October of 2015 (a few weeks before the preparation of this report) and learned that phosphorus removal declines when sludge is dewatered as a result of a high phosphorus pressate returning to the ditch. No testing has been done, but rough calculations indicate that the ortho-P concentration in the pressate are as high as 200 mg/L. During a period in September when no sludge dewatering occurred, effluent phosphorus dropped from 2+ mg/L to approximately 0.6 mg/L.

Absent data it is hard to be certain, but it appears that the weeks-long holding time in the aerobic sludge digester/sludge holding tanks is increasing the ortho-P concentration in the sludge. Opportunities for reducing the retention time were discussed with plant staff and are being considered. If the ortho-P concentration in the pressate flow (approximately 10-15 gallons per minute) can be decreased by freshening the sludge, the ditch should be able to remove the phosphorus contained in the small volume of pressate. To reduce retention time, plant staff are evaluating the possibility of using only the smallest of the three sludge holding tanks (the two largest are now in use). Plant staff will, as resources allow, test the holding tanks and sludge pressate for ortho-P.

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Big Sky

Plant Superintendent Grant Burroughs attended a two-day training class in June 2014. Later that year, DEQ and Water Planet made one site visit to provide technical support. Plant staff showed a lot of interest in realizing opportunities for more sustainable treatment, improved nitrogen removal, and operational cost savings.

The 0.66 MGD sequencing batch reactor (SBR) aeration blowers are much larger than those at similarly sized treatment facilities. To reduce over-aeration, thereby reducing the shearing of bacterial floc and allowing anoxic conditions to develop during the air off cycles, two major process changes were made during the plant visit. Three of the four 100 HP blowers were manually shut down so only one would operate at any one time. The air on/air off settings were changed to increase the air off time.

Following the training class but prior to the site visit, plant staff purchased an oxygen reduction potential (ORP) meter to assist with process control. For optimal ammonia-nitrogen removal, it was suggested that the ideal end of react (air on) ORP be +100 to +150 mV (ammonia removal is optimized when it is consistently below 0.5 mg/L). For optimal nitrate-nitrogen removal, the ideal end of mix fill ORP (air off) is -100 mV (nitrate removal is optimized when it is 4 mg/L, or lower; nitrite should always be less than 0.5 mg/L).

Plant staff are now closely monitoring environmental conditions: DO, ORP, and nitrogen series. As a result, effluent nitrogen has improved considerably: 14 mg/L vs. 25 mg/L before the optimization efforts began.

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