holistic way — and more along the lines of sustainable development and cleaner production — to where we're releasing less waste and fewer toxic chemicals into the system in the first place."

Steve Wordelman, president of Jones & Henry Engineers Ltd. (Toledo, Ohio), agreed. As past chairman of the Water Environment Federation (WEF®; Alexandria, Va.) Government Affairs Committee, he helped WEF put together comments on the strategy. "We think the strategy identifies some very important issues that need to be looked at, but that it would be a better effort to pull it all together and look at it from watershed standpoint," he noted. "At this point they have eight different strategy areas, and there are links between all of them, and a watershed approach would help establish the links between those individual strategies."

Show Me the Money

Now that the problems have been laid out and priorities identified, the primary challenge is finding the funding to implement the recommended programs.

"Funding has been and will continue to be the major issue in proceeding on these projects," Wordelman said.

However, EPA officials gave few indications of where the money will come from when the final strategy was unveiled, and U.S. Rep. John Dingell (D–Mich.), in a statement issued Dec. 7, blasted the agency for its failure to fund Great Lakes restoration.

"The bottom line is that we have had enough study and wasted enough time; what we need is for the federal government to invest in the lakes," Dingell said. "We need to restore and protect this precious resource, and it's going to take money to do it."

"This whole thing was kicked off by an executive order signed by President Bush where he referenced the Great Lakes as a resource of national significance," noted Chris Grubb, water resources coordinator at the National Wildlife Federation. "Now it's time to see whether the administration is willing back up its language with real commitment." In that regard, the group is waiting to see what the administration's upcoming budget request for fiscal year 2007 (FY07) will look like, he said. In the administration's FY07 budget request, which was unveiled on Feb. 6, $70 million was slated for cleaning up and protecting the Great Lakes, an increase of more than $20 million from last year's enacted budget. Additionally, "we're hoping for a bipartisan Great Lakes restoration bill to be introduced in Congress this year," Grubb said.

With a big portion of the strategy's cost targeted at collection system overflows, Adam Krantz, managing director of government and public affairs at the National Association of Clean Water Agencies (Washington, D.C.), also emphasized the critical need for federal funding.

"There's a lot of money being spent at the local level to control overflows," Krantz noted, with municipalities currently shouldering 95% of the burden. "That number continues to go up, and now we're hearing that the Clean Water State Revolving Fund [SRF] is going to be cut again," not to mention the many questions being asked about the appropriateness of congressional earmarks in light of the recent lobbying scandals, he pointed out. "So the two main areas where clean water projects are being funded — the SRF and earmarks — are now looking like they're going to be radically cut back and possibly zeroed out," he said. "The federal government can't have it both ways. If they want to be part of a plan, they have to help municipalities, as well as nonpoint pollution sources and other sources, to be part of the solution."

For more information on the Great Lakes Regional Collaboration Strategy, see www.glrc.us.

— Kris Christen, IW

Gold Mine Succeeds With Denitrification Test Plant

Mark Reinsel

A pervasive contaminant often present in groundwater and surface water in agricultural areas as a result of fertilizer use, nitrate frequently is found in municipal and industrial wastestreams following aerobic degradation of ammonia. Nitrate typically is present in mining waters because of blasting activities that use ammonium nitrate or following the degradation of cyanide used to extract metals from ore. Dissolved nitrate can be removed from water through the action of denitrifying bacteria, which convert nitrate to nitrogen gas. This denitrification process can occur only in environments that are anaerobic or anoxic.

In late 2001, a nitrate-removal pilot plant employing denitrification was constructed at a large gold mine to treat a portion of the discharge from its excess-water treatment plant (EWTP). The design of the pilot plant was based on the first stage of the denitrification system at the Stillwater Mine, a platinum and palladium mine in Montana. The Stillwater system has operated successfully since 1996, and it has been modified and expanded several times. Because Stillwater operates under a discharge load limit for nitrogen (in kilograms per day), reducing nitrate concentrations to nearly zero is more important than achieving the typical 10 mg/L discharge limit for nitrate–nitrogen.

The Stillwater system was chosen as the design basis because of its simplicity and effectiveness, and because its wastewater has characteristics similar to that of the gold mine. To be effective, each biological system requires a startup period and minor site-specific modifications.

Starting Up the Plant

The pilot plant's reactor (see Figure 1, right) contained 355 m^3 of river rock measuring 50 to 100 mm in diameter and having a void fraction of 0.39. The system was designed to reduce influent nitrate–nitrogen concentrations of 25 to 30 mg/L to less than 10 mg/L at a flow rate of 50 m^3/h. This flow rate provided a residence time of 2.8 hours.

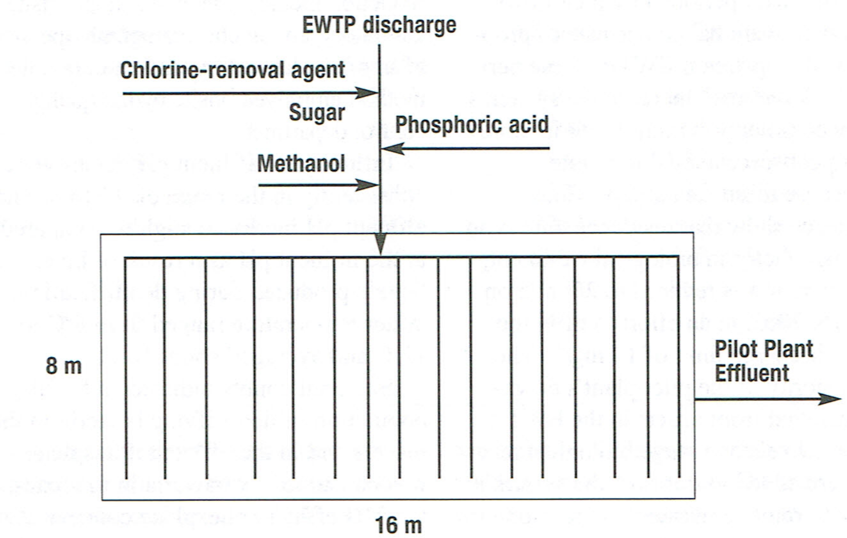
The gold mine's pilot system was inoculated with bacteria from the Stillwater Mine. Methanol and sugar were the carbon sources added to feed the bacteria, which convert the nitrate to nitrogen gas and the carbon sources to carbon dioxide. During operation, nitrogen and carbon dioxide gases could be seen bubbling from the reactor's surface. Phosphoric acid also was added to provide the bacteria with a needed phosphate source. A reducing agent, such as sodium metabisulfite, was added to the EWTP discharge to neutralize the chlorine in the water. Without this step, the chlorine would inhibit denitrifying activity.

Assessing Pilot Plant Results

Following startup in February 2002, the system's flow rate was increased steadily until it reached the design flow rate of 50 m^3/h in August 2002. At this point, the pilot plant was operated at varying flow rates to meet the nitrate–nitrogen discharge limit of 10 mg/L, including two periods at a flow rate of 100 m^3/h. In November 2002, two small reactors were added to the pilot system to treat effluent from the main reactor. This provided two sets of reactors in series that operated from November 2002 through April 2003.

Beginning in May 2002, effluent from the main reactor, or first stage, contained concentrations of nitrate–nitrogen below the target of 10 mg/L for several brief stretches. For the weeks in which the discharge limit of 10 mg/L was met, the reactor was operated at 25 to 30 m^3/h,

Figure 1. Pilot Plant Schematic View (Plan View)



EWTP = excess-water treatment plant.

below the design flow of 50 m^3/h. As will be discussed later, the discharge limit also was met at higher flow rates by using two reactors in series.

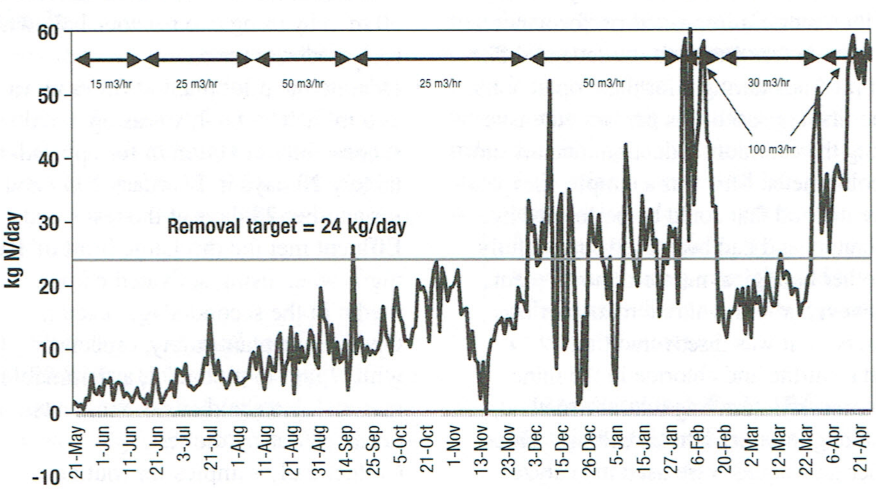
The influent nitrate–nitrogen concentration varied, averaging 35 to 40 mg/L. This level was well above the assumed influent concentration of 25 to 30 mg/L used in designing the pilot plant.

Figure 2 (see below) shows the nitrate–nitrogen load, in terms of kilograms per day, removed in the main reactor. This load is the product of the nitrate removed — influent concentration minus effluent concentration — multiplied by the flow rate. As a daily average, the highest nitrate–nitrogen load removed was approximately 60 kg/d, significantly more than the design objective of 24 kg/d, which was based on the Stillwater system's performance while operating continuously at full capacity.

As depicted in Figure 2, the rate at which nitrate was removed generally increased as the flow rate increased. In fact, the highest removal rates occurred at the highest flow rate (100 m^3/h).

It is significant that the periods in

Figure 2. Nitrate Load Removed (Main Reactor)



which the most nitrate was removed coincided with periods in which flows to the system were halted because of problems at the upstream EWTP. These periods of "downtime" increase the system's residence time, providing bacteria more time to consume available nitrate.

Because these data and previous experience show that residence time is an important factor in biological treatment, the flow rate was reduced to 25 m^3/h on Sept. 16, 2002, in an effort to meet the nitrate discharge limit of 10 mg/L. The vast majority of the pilot plant's downtime resulted from upsets in the EWTP.

The two second-stage biological reactors were added to improve the system's ability to remove nitrate. One reactor contained the same rock as in the main reactor. The other contained activated carbon, providing significantly more surface area for bacterial growth but at much greater expense.

Between Jan. 31 and Feb. 18, 2003, the flow rate to the system was 100 m^3/h, which provided a residence time of 1.5 hours in the main reactor. Flow to the second stage was adjusted to provide the same residence time, for a total residence time of 3 hours. Effluent from the second-stage reactor containing rock typically was below the discharge limit of 10 mg/L. However, effluent from the second-stage reactor containing activated carbon typically was less than 0.1 mg/L. The media's greater surface area increased the quantity of bacteria in a particular volume, undoubtedly leading to the reactor's improved performance.

Nitrate was analyzed via several different methods during pilot-plant operations. The first approach was performed onsite using the cadmium reduction method and a colorimeter. This was a simple, inexpensive method that could be performed by operators and had been used successfully at other biological nitrate-removal plants. However, after no nitrate reduction was observed, it was discovered that metabisulfite and chloride in the mine water were interfering with the method, resulting in faulty nitrate readings. Three other techniques were used to analyze nitrate levels successfully: a cadmium reduction method conducted at an offsite laboratory, an ion chromatograph operated at an offsite laboratory, and an ultraviolet method employed onsite by the quality control department.

Influent and effluent pH values were consistently in the range of 6.5 to 8. The effluent pH increased slightly compared to the influent pH as a result of bicarbonate produced during denitrification. Water temperature ranged from 8°C to 12°C and averaged about 10°C.

Bacterial counts indicated a healthy population of denitrifying bacteria in the reactor and in the effluent. Phosphate was consumed by bacteria in the reactor. The effluent phosphate concentration was always greater than 1 mg/L, indicating that phosphate did not limit bacterial activity. Methanol and sugar also were consumed by bacteria in the reactor. Only 20% to 30% of the carbon added to the influent was consumed, indicating that carbon also did not limit the system. Removal of sulfate and selenium was minimal.

Achieving Project Goals

Before the start of the pilot program, an operation and testing plan was developed, complete with specific goals. The following list summarizes the plan's goals and the corresponding results achieved during the test:

- Meet the nitrate–nitrogen discharge standard of 10 mg/L. The discharge standard was met at flows up to the design rate of 50 m^3/h by using two reactors, both with rock media, in series.
- Operate the pilot plant at flows up to 100 m^3/h. The facility was operated successfully at 100 m^3/h for approximately 20 days in February 2003 and for another 28 days at the test's end. Effluent met the discharge limit of 10 mg/L when using activated carbon media in the second-stage reactor.
- Operate the plant safely, especially with regard to methanol, a flammable material. No accidents or incidents occurred during the test.
- Collect daily samples for routine parameters. Plant operators measured pH, temperature, and concentrations of nitrate–nitrogen, chlorine, phosphate, and dissolved oxygen at multiple locations at least daily. Daily samples for offsite analysis of nitrate–nitrogen, methanol, and dissolved organic carbon also were collected.
- Collect steady-state samples to measure methanol, dissolved organic carbon, mercury, sulfate, and selenium. Steady-state samples were collected at flow rates of 15, 25, 50, and 100 m^3/h.
- Perform impulse-tracer tests to determine system volume and residence time. Two tracer tests were run.
- Remove several drums of reactor solution as a contingency. One drum of solution containing active denitrifying bacteria was removed each month, and the three freshest drums were kept onsite. These drums were never required for reinoculation.
- Complete test by Sept. 15, 2002. The test took approximately twice as long as originally scheduled. The delay resulted from the time required by the bacteria to acclimate and grow, and the need to optimize the treatment process, including adding the reactors in series.
- Determine whether biofilm nutrients are a limiting factor. The testing revealed that concentrations of methanol and phosphate added to the pilot plant did not limit denitrification.

Estimating Capital Costs

Capital costs for a full-scale biological nitrate removal system were estimated for eight scenarios, including using different media, carbon sources, residence times, number of stages, and treatment capacities. The scenarios were estimated to have capital costs of $4.5 million to $23 million and footprints ranging from 4400 to 11,500 m^2 (see Table 1, p. 9).

With a capacity of 2000 m^3/h, the first scenario is insufficient for the current mining situation. This scenario was the original cost estimate before the pilot plant was built.

The second scenario uses rock media in a single stage at a residence time of 3

Table 1. Biotreatment Capital Costs

Scenario	Media	Nutrient	Residence time (h)	Stages	Capacity (m^3/h)	Footprint (m^2)	Capital cost
1	Rock	MeOH/sugar	3.0	1	2000	N/A	$4.5 million
2	Rock	MeOH/sugar	3.0	1	3000	7700	$5.9 million
3	Rock	MeOH/sugar	4.5	1	3000	11,500	$7.7 million
4	Rock	MeOH/sugar	3.0	2	3000	8500	$6.9 million
5	Rock/Carbon	MeOH/sugar	3.0	2	3000	7200	$15 million
6	Carbon	MeOH/sugar	3.0	2	3000	5900	$23 million
7	Rock	proprietary	2.0	2	3000	5600	$5.3 million
8	Carbon	proprietary	2.0	2	3000	4400	$16 million

MeOH = methanol.

hours to treat a flow rate of 50 m^3/h. This scenario was evaluated as part of the pilot plant in December 2002 and January 2003. Although it often met the nitrate removal target of 24 kg/d, this configuration did not meet the discharge limit of 10 mg/L. Therefore, this option is not viable.

The third scenario differs from the second in that it has a longer residence time of 4.5 hours to treat a flow rate of 30 m^3/h. Evaluated as part of the pilot plant from Feb. 18 until March 28, 2003, this scenario only met the discharge limit when the influent nitrate concentration was less than 30 mg/L. Therefore, this option also is probably not viable.

The fourth and fifth scenarios — two-stage systems with a total residence time of 3 hours and with either rock or carbon in the second reactor — were evaluated Feb. 6–17, 2003. Effluent from the second-stage reactor with rock generally met the discharge limit, and effluent from the second-stage reactor with carbon nearly always met the discharge limit. Therefore, both are viable options.

The sixth scenario, using carbon media in both stages, was not evaluated. Based on the performance of the second-stage reactor with carbon, effluent from a reactor with carbon should meet the discharge limit easily at a residence time of 3 hours or less. However, the cost of activated carbon makes this the most expensive alternative, at an estimated capital cost of $23 million.

The seventh and eighth scenarios envisioned using a proprietary carbon source similar to one employed at another mine. However, they were not evaluated because of concerns by the client regarding expense and timing. If this carbon source could decrease residence times, capital costs would be lower than those for the fourth and fifth scenarios, the most viable options. Bench-testing using this proprietary nutrient reduced nitrate levels 50% more than an equivalent amount of methanol and sugar.

Developing Full-Scale Design Criteria

Based on the pilot-plant operation, recommended design criteria were developed for a full-scale plant. Specifically, the influent and effluent nitrate–nitrogen concentrations should be 35 to 40 mg/L and 5 mg/L, respectively, with a total residence time of 3 hours. The plant would comprise two stages, each employing rock media with an assumed void volume of 0.39, and operate at a treatment rate of 3000 m^3/h. The first and second stages each would have residence times of 1.5 hours. For a carbon source, methanol and sugar — together or alone — would be used, depending on which is less expensive. The nitrate removal pilot plant would furnish the bacteria.

The estimated operating cost for a full-scale biological nitrate removal plant, including reagents, labor, and maintenance, is $0.086/$m^3$ (see Table 2, below).

Although the pilot plant successfully removed nitrate, the mining company's management decided not to implement a full-scale biological treatment plant. Near the end of the nitrate pilot test, a reverse osmosis (RO) pilot test was set up to run concurrently. The RO system was attractive for two reasons: It would remove all contaminants from the wastewater, not just nitrate, and the concentrated wastestream contained enough gold to make recovering the precious metal feasible. Following a successful RO pilot test, a full-scale RO system was installed at the mine. At last report, it was recovering enough gold to offset more than the operating costs of water treatment.

Table 2. Biotreatment Operating Costs

Parameter	Cost ($/$m^3$)	Basis
Methanol	$0.072	40 mg N/L, $0.60/kg, 3 mg methanol/mg N
Phosphoric acid	$0.004	40 mg N/L, $0.80/kg, 85% purity, 1 mg P/30 mg N
Labor	$0.007	6 operator-equivalents @ $15,600/yr
Maintenance	$0.003	Equipment cost = $600,000, flow = 14.3 M m^3/yr
Total	**$0.086**	

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