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Use a Multifaceted Approach to Manage High Source-Water Nitrate

A large surface water utility with high source-water nitrate cut the cost of complying with the nitrate maximum contaminant level by reducing dependence on expensive ion-exchange treatment.

BY CHRISTOPHER S. JONES, DENNIS HILL, AND GORDON BRAND

NITRATE REMOVAL DURING drinking water treatment is expensive—just ask operators at the Des Moines Water Works (DMWW) Fleur Drive Treatment Plant. Built in 1991 at a cost of nearly $4 million, the plant, which is located near the confluence of the Des Moines and Raccoon rivers in Iowa, is the world's largest ion-exchange nitrate-removal facility.

Nitrates enter the plant's watershed from farmland runoff and natural sources. The rivers flow in an area containing some of the world's best soil, which is intensely cultivated for corn and soybeans. Nitrogen application rates in the watershed average 140 lb/acre.

Ion exchange is an effective method for nitrate removal, but needn't be a utility's only strategy for complying with the US Environmental Protection Agency's 10-mg/L nitrate-N maximum contaminant level (MCL). Utilities with multiple water sources can, with timely and accurate monitoring, blend source waters to delay use of ion exchange and achieve substantial cost savings.

MULTIPLE WATER SOURCES

The Fleur Drive plant uses shallow groundwater and water from both rivers. The groundwater is supplied by a 3-mi-long infiltration gallery that runs parallel to the Raccoon River 30 ft underground. Gallery water benefits from bank-side filtration and has lower nitrate levels than river water.

River water undergoes pretreatment with ferric chloride and powdered activated carbon. Pretreated river water, gallery water, alum, and soda ash are mixed just before slaked lime is added in four underground, "conventional," continuous lime softeners in which precipitates settle and are removed. Additional treatment includes stabilization, rapid sand filtration, ion-exchange nitrate removal, and disinfection with liquid hypochlorite.

DMWW's Maffitt Park Treatment Plant, 10 mi to the west on the Raccoon River, figures in the treatment scheme during high nitrate episodes, although the plant has no nitrate-removal capability. Constructed in 2000, the Maffitt plant is an enhanced coagulation and softening facility that uses ferric chloride, lime, and occasionally soda ash to treat 25 mgd. Its primary water sources are radial collector wells influenced by the river, and a 65-acre, water-filled utility gravel pit is nearby. Water is continuously introduced into the gravel pit from the Raccoon River at the rate of 5 mgd. This same volume is also drawn from the pit and fed into the treatment plant.

Nitrate levels depend on precipitation, and they can change dramatically overnight. Surface water nitrate can exceed 18 mg/L. Nitrate levels in water from the infiltration gallery are about 40 percent less than those found in the Raccoon River, and concentrations in the collector wells are about 20 percent less than Raccoon River levels.

NITRATE REMOVAL STRATEGIES

Nitrate removal treatment began in 1992 after it became apparent that without the treatment DMWW would regularly violate the nitrate standard. Since then, the Fleur Drive removal facility has averaged 43 days/yr of use.

Ion Exchange. Fleur Drive's eight ion-exchange vessels each hold 450 ft^3 of resin and provide complete nitrate removal for 10 mgd of filter-effluent water. Only a portion of the plant's filter effluent undergoes ion-exchange treatment—as a last resort to keep finished-water nitrate levels from exceeding 10 mg/L.

Operating the ion-exchange facility is expensive—nearly $3,000/day on many days. The process generates up to 60,000 gal/day of nitrate-laden brine waste from media regeneration. Spent brine is diluted with treated water and sent to the storm sewer for return to the Raccoon River. Because river flows are usually high

To meet the nitrate standard, Maffitt well water is supplemented with 5 mgd of low-nitrate surface water from a nearby gravel pit (inset).

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when the ion exchange facility is operating, the plant's discharge is considered to have low environmental impact. But, to cut costs and waste, DMWW uses other nitrate-reduction strategies when it can

Source Water Blending. River nitrate levels rise in the spring, with the Raccoon River peaking earlier than the Des Moines River because of an upstream impoundment on the Des Moines. Continuous monitoring by DMWW's testing laboratory and on-line measurement devices frequently enable operators to juggle the incoming water mix from the gallery and the two rivers to keep nitrate levels below 10 mg/L.

Depending on soil moisture and the stage of the Raccoon River, water yield from the infiltration gallery ranges from 10 to 40 mgd. Raccoon River water can be fed into the plant in either 17-, 30-, or 40-mgd increments. The Des Moines River intake is equipped with one 50-mgd and two 25-mgd pumps, one of which offers a variable frequency drive that enables operators to feed any amount of Des Moines River water up to 100 mgd. Energy and chemical costs are lower for Raccoon River water if nitrate removal isn't required. Water operators weigh all these factors to introduce the most economical mix of source water while at the same time minimizing the amount of water needing ion-exchange treatment.

A similar scenario plays out at the Maffitt plant, but without nitrate removal. Water from the site's radial collector wells responds quickly to changes in river flow and quality, and nitrate concentrations in the wells often exceed 10 mg/L, with a peak of 13.9 mg/L. Well yield ranges from 8 to 20 mgd, depending on river stage and temperature.

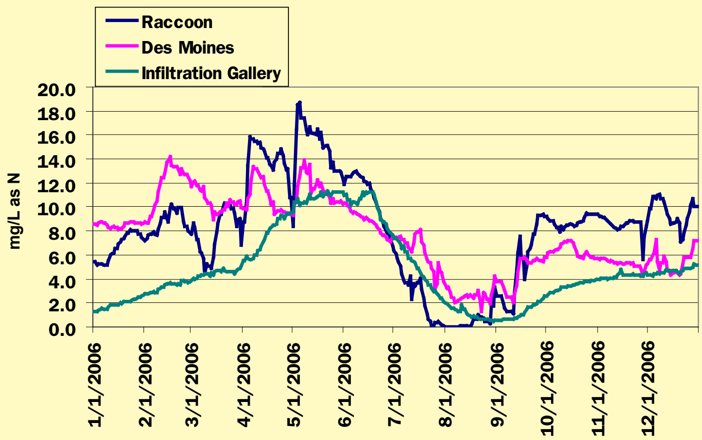
Maffitt well water is supplemented with 5 mgd of low-nitrate surface water from the nearby gravel pit. A similar volume from the river continuously feeds the gravel pit, so the surface water benefits from off-river storage for about 40 days, allowing for settling. Solar-powered circulators are used to repress cyanobacteria blooms. Water from the gravel pit dilutes the total raw water nitrate to manageable concentrations without the use of expensive ion-exchange or membrane treatment.

Off-River Storage and Biological Denitrification. The Fleur Drive plant is located within a large city park created to protect the infiltration gallery from development and contamination. During the 1930s, a series of ponds was constructed in the park to enhance water yield from the gallery. Levees separate the ponds from one another. Culverts and breeches connect the ponds, and water flows through them in a circuitous manner. Water residence time in the ponds averages about 11 days. Water from the pond overflow 100 ft from the Raccoon River flows back to the river. The total area of all the ponds is about 20 acres, with water depth averaging 3–4 ft.

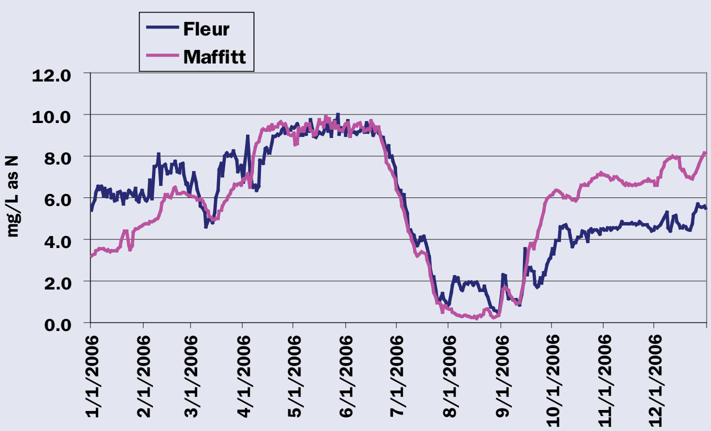
Of the 1.5 to 5 mgd introduced to the ponds from the Raccoon River, about half reaches the infiltration gallery, and the other half is lost to overflow. Nitrate levels in the overflow water are only about 20 percent of those observed in the river. Algae and bacteria in the ponds begin consuming nitrate soon after ice-out in the spring. The ponds are more biologically active than the river because of reduced turbidity, higher water temperature, and the ponds' relative tranquility compared to the river.

Pilot pond experiments have shown that bacteria in the pond water and the bottom benthic layer convert most of the nitrate into nitrogen gas. Nitrate concentrations in pilot pond water diminished under both aerobic and anaerobic conditions, and tests show many species of organisms are responsible for this reduction. These nitrate-reducing mechanisms quickly and effectively remove nearly all

2006 Source Water Nitrate
Nitrate levels in water from the infiltration gallery are much less than those found in the rivers.



2006 Finished Water Nitrate
The Fleur Drive nitrate-removal facility averages 43 days/yr of use to maintain nitrate levels comparable to the Maffitt plant.



the nitrate from water in the park ponds.

Although water from the ponds isn't directly introduced into the treatment plant, nitrate data show that off-river storage of this type can provide substantial nitrate reduction in nearby groundwater collection systems. Nitrate levels in the radial collector wells at the Maffitt plant 10 mi away closely mirror those in the river, so bank-side filtration there doesn't provide much nitrate removal. It's likely the reason nitrate levels in the infiltration gallery are so much lower than those in the river and the Maffitt radial collectors is because 1 mgd or more of low-nitrate (<2 mg/L) water seeps from the bottom of the ponds into the gallery to dilute the bank-filtered river water. Low-nitrate water from the surrounding soil structure may also add low-nitrate water to the gallery.

Denitrification also occurs in the gravel pit at the Maffitt plant, though not as rapidly as in the park ponds. The gravel pit also provides a substantial volume buffer in that the detention time nearly matches the length of a typical high-nitrate episode. High-nitrate river water can be introduced to the gravel pit without concern because it will be diluted and the nitrate assimilated by algae or reduced to nitrogen gas by bacteria.

CONTINUOUS MONITORING

DMWW operates a testing laboratory staffed with several chemists and a microbiologist. Samples of finished water, filter effluent, and source water for both treatment plants are analyzed daily for nitrate during high nitrate episodes. USEPA method 300.0 is used in the lab for nitrate analysis. DMWW's water operators use the lab results to make decisions about the source water blend and ion-exchange removal. The ion-chromatography procedure also fulfills compliance-monitoring requirements.

The utility also uses continuous, on-line measurement equipment to monitor nitrate in filter effluent and Raccoon River water, and operators have access to the measurements through the utility's SCADA system. The online measurements compare favorably with those produced by ion chromatography in the lab. Continuous on-line measurement enables operators to make timely decisions on source-water blend and ion-exchange treatment that minimize waste and keep the finished water from exceeding 10 mg/L nitrate-N. With accurate measurement of minute-to-minute filter effluent nitrate levels, the utility doesn't activate the ion-exchange facility until nitrate exceeds 9.5 mg/L.

A third on-line measurement device monitors Raccoon River nitrate levels 20 mi upstream from the Fleur Drive plant and provides DMWW staff with 12-hr advance warning of high nitrate episodes.

EFFECTIVE SOLUTIONS

Use of off-river storage for effective nitrate removal offers a cheap alternative to the steep capital and operating costs of ion-exchange and membrane treatment. Biological denitrification also has the added benefit of reducing the total nitrate load from the rivers. Using critical information obtained from both standard laboratory testing and on-line measurement, operators can make decisions regarding source water and treatment options.