Evolution from a Conventional Well Field to a Riverbank-Filtration System

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The City of Cedar Rapids is located in east-central Iowa and has a population of 121,000. The Cedar River alluvial aquifer is the sole source of drinking water for the City. Within the last few years, the Cedar River - which drains a major agricultural watershed - has experienced extended periods of elevated levels of nitrate and herbicides (notably, atrazine and its degradation byproducts) that were above the maximum contaminant level for drinking water. Fortunately, during these extended periods of compromised water quality in the river, RBF enabled the Cedar Rapids Water Department to obtain and treat adequate quantities of water that met all drinking-water standards. The Cedar Rapids Water Department and the United States Geological Survey (USGS) have been collaborating in an ongoing study of the river and its hydraulic interconnection with the City's wells. A primary focus of this study is to identify operational and development strategies that will optimize RBF and the water-quality benefits it affords.

The Cedar River originates in southern Minnesota and generally flows in a southeasterly direction through east-central Iowa until it discharges to the Iowa River in Louisa County. The Cedar River drains a major agricultural watershed, which also includes several urban areas. The entire watershed encompasses 7,000 square miles, in which approximately 6,500 square miles are upstream from Cedar Rapids' well fields. Land use in the watershed is predominantly agricultural (approximately 90 percent), with major crops being com and soybeans (Kalkhoff et al., 2000; Schnoebelen and Schulmeyer, 1998; Schulmeyer, 1995). Major urban areas in the watershed include:

-Albert Lea and Austin in Minnesota.
-Mason City, Clear Lake, Charles City, Forest City, Waverly, Cedar Falls/Waterloo, and Cedar Rapids/Marion in Iowa.

The Cedar River and its water quality have been the subject of extensive studies and monitoring by the Cedar Rapids Water Department, USGS, Iowa Geological Survey Bureau, and other local agencies. These studies have documented several major water-quality issues that affect the river's suitability for the three designation uses established by the Iowa Department of Natural Resources:

-Primary contact recreation (e.g., swimming).
-Wildlife, fish, and aquatic life.
-Potable water source.

Water-quality challenges come from both point and non-point sources and include excessive soil erosion/sedimentation, elevated levels of nitrate and phosphorous, and fecal coliform bacteria counts above the acceptable levels for recreational swimming. The 57-mile segment of the Cedar River upstream from the City's well field to LaPorte City has been placed on the State's list of impaired streams due to elevated levels of nitrate and fecal coliform bacteria. The most daunting challenge for the Cedar Rapids Water Department is the increasing trend of elevated levels of nitrate, especially in the spring and early summer. During these periods, monthly nitrate levels are routinely in the range of 10.0 to 14.7 mg/L as nitrogen (N). The drinking-water standard for nitrate is 10.0 mg/l.. (as N), and a single exceedance constitutes a violation. Fortunately, as illustrated in Figure 1, a 2- to 3-mwr. reduction in nitrate levels is generally accomplished as the water moves from the river to the wells. This natural reduction, combined with the monitoring and management of individual wells, has enabled the Cedar Rapids Water Department to avoid any violations of the drinking-water standard for nitrate.

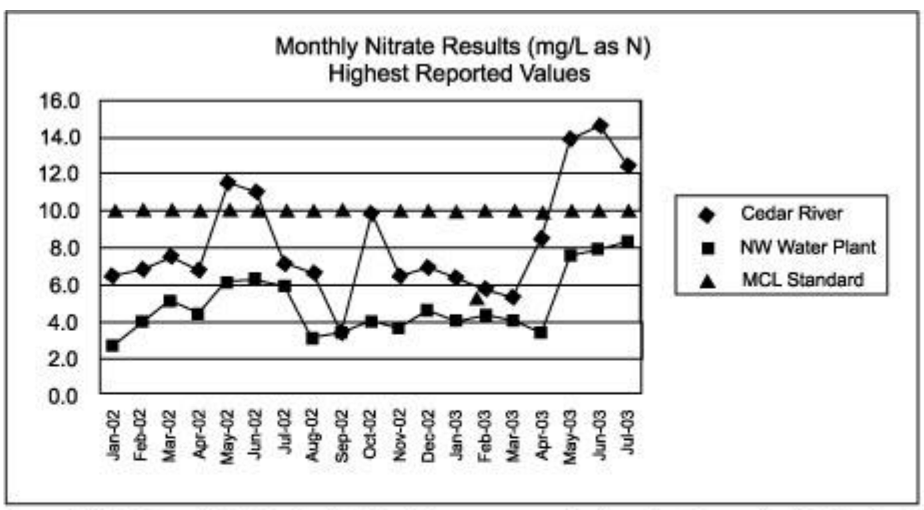

Figure 1. Highest recorded nitrate levels; Cedar River as compared to the well water supplies to Cedar Rapids' NW Water Plant (Source: Cedar Rapids Water Department).

Prior to 1963, the City of Cedar Rapids obtained its water supplies directly from the Cedar River. River water underwent treatment processes similar to those used today - lime softening, disinfection by chloramination, filtration, and the addition of fluoride and phosphate for corrosion control. This provided for safe drinking water, but failed to avoid the intermittent aesthetic problems (taste and odor) primarily associated with elevated algae levels in the river. This prompted the City to construct and convert its water supplies to a series of shallow wells along the Cedar River.

Today, Cedar Rapids obtains all of its water supplies from a series of shallow wells constructed in the sand and gravel alluvium along the Cedar River. The City now has four well fields consisting of 45 vertical wells and four horizontal collector wells. Total current production capacity of the wells is generally assumed to be approximately 65 MGD, but output will vary depending on river level and recent operating conditions. Withdrawal rates now average about 36 MGD, with a maximum demand of 50 MGD. Approximately 80 percent of the water is used for grain processing and other wet industries.

Vertical wells are drilled to the top of the bedrock with depths ranging from 42 to 72 ft and are located about 30 to 900 ft from the river. The two original horizontal collector wells placed in service in 1995 consist of a 13-ft diameter center column extending to a depth of approximately 60 ft (about 2 ft above bedrock) and six lateral screens extending about 200 ft from the central column. The two collector wells placed in service this year are of similar construction, except for the use of a 16-ft diameter center column. All of the well laterals were constructed so as not to extend under the river channel except under high water conditions.

The USGS and other agencies have conducted extensive studies of the Cedar River and the alluvium that serves as the drinking-water supply for Cedar Rapids. These studies have determined that the Cedar River is generally a "gaining stream" - that is, water will typically move through alluvium to the river; however, pumping of the wells will reverse the normal flow pattern and induce the infiltration of water from the Cedar River into the alluvium. The USGS found that induced filtration from the Cedar River supplies approximately 74 percent of the recharge to the City's wells. The balance of the recharge is from the underlying aquifer (21 percent) and the infiltration of precipitation (5 percent). The USGS also determined that the travel times for the movement of water from the Cedar River to the nearest vertical well ranged from 7 to 17 days (Schulmeyer, 1995; Schulmeyer and Schnoebelen, 1998).

The movement of water through sand and gravel formations due to pumping is commonly called induced RBE RBF has been widely used in Europe as a pretreatment process for almost 100 years, and there has been recent interest and research concerning its use in North America. The natural filtration and biological activity that occur during the movement of water through the alluvium affords several water-quality benefits. These include a reduction in turbidity and microbiological improvements with the removal/reduction of viruses, bacteria, and protozoan organisms (e.g., Giardia and Cryptosporidium), as well as a reduction in the levels of nitrates, herbicides, and other potential contaminants. USGS studies of Cedar Rapids' wells have confirmed that, "The filtering efficiency of the aquifer is equivalent to a 3-log reduction rate or 99.99-percent reduction in particulates" (Schulmeyer, 1995).

When the Cedar Rapids Water Department and USGS initiated their cooperative study in 1992, it was restricted to a 231-square mile area along the Cedar River that encompasses the City's four well fields. Initially, the primary focus was to develop an understanding of the hydraulic interconnection of the river and wells and the factors that affect the quantity and quality of the water drawn from the wells. For example, studies regarding new well development would simply attempt to identify sites that would yield significant water with relatively low levels of iron and manganese. There was very little consideration given to "RBF' and enhancing the water-quality benefits it affords.

Beginning about 1995, the scope of the study was expanded to include additional physical and chemical parameters, as well as the addition of biological monitoring (e.g., Microscopic Particulate Analysis). This was prompted by two primary considerations. The ongoing cooperative study confirmed that well water was consistently of higher quality than the river; however, the study also confirmed that the movement of recharge water through alluvium could also readily transport contaminants from me river to me wells. Additionally, Iowa regulatory officials issued a preliminary determination mat me newly constructed collector wells were groundwater under me direct influence of surface water (GWUDI) sources.

To date, major study activities and work products of me USGS/Cedar Rapids Water Department cooperative study include:

-Identification and mapping of contaminant sources in me immediate vicinity of the City's wells.
-Development of a regional groundwater model covering 231 square miles, which simulates groundwater flow under steady-state conditions.
-Construction of a detailed groundwater flow model, which simulates groundwater flow and well recharge under transient conditions (a computer model is now complete and being tested).
-Completion of extensive water-quality monitoring (physical and chemical parameters) of me river and wells.

This research, along with the Cedar Rapids Water Department's Source Water Assessment study, has documented the importance of the river and the potential contaminant threats it poses to our water supplies. They have also confirmed me protection and other benefits afforded by RBE Consequently, the cooperative study was recently expanded to include the entire Cedar River Watershed. The Cedar Rapids Water Department, USGS, and Iowa Geological Survey Bureau have partnered to conduct three separate comprehensive synoptic studies of water quality of samples at 64 locations throughout the watershed. A dye tracer/time-of-travel study has been completed on me lower main stem of the Cedar River, with plans for more dye tracing on other sections at low flow conditions, as well as possible Lagrangian sampling. In Lagrangian sampling, the same mass of water is sampled as it moves downstream. The objective of this study will be to validate time-of-travel models and to determine the fate of nitrogen compounds as they are transported down the river (D.J. Schnoebelen, 2002).

In summary, me Cedar Rapids Water Department has attempted to develop a better understanding of me river and its wells, which would allow the implementation of management and protection programs for its drinking-water supplies. Although we did not fully understand its role until just recently, RBF is a valuable pretreatment process and is an integral component of our multi-barrier strategy for protecting water quality. It has enabled the Cedar Rapids Water Department to avoid any violations of the drinking-water standard for nitrate that would necessitate me construction and operation of costly nitrate removal facilities.

Without RBF; the Cedar Rapids Water Department would not have been able to supply quality water that meets all drinking-water standards while maintaining the competitive rates required by its major customers, me local industries. Although very beneficial, it must be acknowledged that RBF does not completely remove contaminants, as evidenced by the presence of nitrates and herbicides in Cedar Rapids' well supplies. RBF; along with watershed protection programs, must be a key element of Cedar Rapids' multi-barrier approach to the protection of its water supplies and public health.

REFERENCES AND ACKNOWLEDGEMENTS

The following references and publications were used in the research and preparation of this report (though not all are cited in the text):

National Water Research Institute

-Ray, C., G. Melin, and R.B. Linsky, editors (2002). Riverbank Filtration: Improving Source-Water Quality, Kluwer Academic Publishers, Dordrecht.

United States Geological Survey

-Becher, K.D., S.J. Kalkhoff, D.J. Schnoebelen, K.K. Barnes, and V.E. Miller (2001). Water-Quality Assessment of the Eastern Iowa Basins - Nitrogen, Phosphorous, Suspended Sediment and Orgamc Carbon in Surface Water, 1996-98, U.S. Geological Survey Water-Resources

Investigations Report 01-4175.
-Kalkhoff, S.J., K.K. Barnes, K.D. Becher, M.E. Savoca, D.J. Schnoebelen, E.M. Sadorf, S.D. Porter, and D.J. Sullivan (2000). Water Quality in the Eastern Iowa Basins, Iowa and Minnesota, 1996-98, U.S. Geological Survey Circular 1210.
-Schnoebelen, D.J. (2002). Written correspondence.
-Schnoebelen, D.J., D.E. Christiansen, and K.D. Becher (2002). "City of Cedar Rapids: Source Water Assessment of Public Drinking-Water Supplied from Ground-Water."
-Schulmeyer, P.M. (1995). Effect of the Cedar River on the Quality of the Ground-Water Supply for City Rapids, Iowa, U.S. Geological Survey Water-Resources Investigations Report 94-4211.
-Schulmeyer, P.M., and D.J. Schnoebelen (1998). Hydrogeology and Water Quality in the Cedar Rapids Area, Iowa, 1992-1996, U.S. Geological Survey Water-Resources Investigations Report 97-4261.

Iowa Department of Natural Resources

-"Progress Report One - Cedar River Assessment Survey," June 2001. -"Source Water Assessment and Protection Program and Implementation Strategy for the State of Iowa," March 2000. Iowa Department of Natural Resources - Geological Survey Bureau

-Seigely, LS., and M.P. Skopec. Written reports of three comprehensive synoptic monitoring programs conducted at 62 sites on the Cedar River on August 26, 2000; June 2,2001; and June 7,2003. Cedar Rapids Water Department . -Grapp, S.J., J.D. North, and R.E. Hesemann (2002). "City of Cedar Rapids Source Water Assessment," Cedar Rapids Water Department

-Grapp, S.J., J.D. North, and R.E. Hesemann (2002). "City of Cedar Rapids Source Water Assessment."