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Abstract

The North Boundary treatment system at Rocky Mountain Arsenal (RMA), Commerce City, Colorado, involves pumping of contaminated groundwater from an unconfined aquifer from one side of a soil-bentonite (SB) slurry wall to three pulsed-bed activated carbon adsorbers and prefilter and postfilter systems. The treated water is injected into the unconfined aquifer on the other side of the slurry wall via 38 recharge wells and 15 recharge trenches, collectively referred to as the recharge system. Recharge capacity of the recharge system has declined over time, limiting the operating capacity of the system. Two probable causes for reduction of the recharge systems is assessed.

Introduction

The U.S. Army Rocky Mountain Arsenal encompasses an area of approximately 26 square miles and is located in Commerce City, Colorado. Since 1942, RMA has been the site for the manufacture and demilitarization of chemical incendiary munitions and the

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manufacture of industrial chemicals, primarily pesticides and herbicides. These operations have resulted in extensive groundwater contamination (Environmental Science and Engineering, 1988). Remediation efforts have focused on groundwater contamination migrating off the arsenal boundaries where it could adversely impact the quality of the groundwater resources and limit the use of private and municipal groundwater wells.

Treatment System Description

Groundwater flow in the alluvial aquifer at the North Boundary is prevented from flowing off the RMA by means of a soil-bentonite slurry wall (Figure 1).

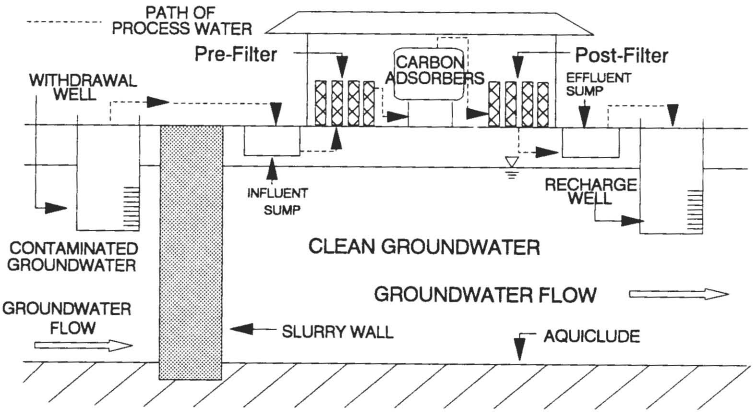

Figure 1. North Boundary Treatment System Path of Process Water

The soil-bentonite slurry wall is located in the alluvial aquifer and is keyed into an aquiclude in the upper Denver formation. Fifty-four dewatering wells are located up-gradient from and approximately parallel to the soil-bentonite slurry wall. The dewatering wells pump untreated groundwater to the North Boundary System (NBS) activated carbon treatment plant. Treated water is recharged to the alluvial aquifer down-gradient and parallel to the soil-bentonite slurry wall through a system of 38 recharge wells and 15 gravel-packed trenches.

The treatment plant consists of prefilters, three pulsed-bed activated carbon adsorbers, and post filters. The prefilter system includes three banks of spiral wound cartridge filters rated at 100 microns. The adsorbers are up-flow, pulsed bed units with a capacity of 13,620 kilograms. The post-filter system is comprised of 25-micron spiral wound cartridge filters followed by 10-micron bag filters. Activated carbon lost from the adsorbers is to be removed by the post filters. However, some fines escape to the recharge system due to leakage through the filters, breaks in the filters, and improper seals on the filters. In the past, much of the lost activated carbon has ended up in the recharge system.

The dewatering wells are grouped and separated into three influent transport and treatment manifolds. One carbon adsorber is dedicated to each manifold. The treated water from each manifold adsorber is combined to form a single plant effluent stream.

Potential Factors Affecting Recharge System Performance

Particles that are not removed in the postfilter system and pass the recharge system screens can cause some clogging of the aquifer. Particles deposited in the immediate vicinity of the recharge system are expected to cause the largest reduction in recharge rate. Microbial fouling may complicate the above process, as microbes are expected to attach to the carbon particles, effectively increasing the size of the particles. If microbes attach preferentially to small particles, then the clogging effect of the small particles will be enhanced. Particle binding can be electrostatic in nature, due to charges associated with microbial produced glycocalyx (e.g. capsule, slime) (Costerton, Irvin and Cheng 1981; Lewis and Gattie 1990). The slime also has the capability of cementing particles together to form larger aggregates.

Food sources for microbial populations growing within recharge systems are the contaminants either flowing by the microbial colonies or adsorbed onto carbon fines migrating into the recharge system from the treatment system. Contaminants flowing by microbial colonies may be assimilated into the cell capsules within short periods of water-microbe contact. Microbes are also capable of using adsorbed contaminants as food sources (Schultz and Keinath 1984; Kim and Pirbazari 1989). Potential nutrient sources for microbial populations within well systems are supplied by materials leached into the groundwater from the aquifer soils.

Study Design

To estimate the amount of carbon fines migrating into the recharge system and assess the performance of the prefilter and postfilter systems, a mass flux analysis of suspended solids throughout the NBS was performed. All suspended solids concentrations measured during mass balance analysis were assumed to be carbon fines. Carbon mass flux pathways throughout the NBS were determined by using suspended solids as a direct indicator of carbon fines concentrations. Particle size analysis of carbon fines collected at various locations of the NBS was performed to determine the range of particle sizes escaping the pre- and post-filters.

The potential for the reduction in system recharge capacity due to microbial fouling was investigated by collecting water samples from the recharge system. Microbial samples were collected from several of the recharge wells and trenches in 1989. Ten recharge wells were sampled 1990. In late 1990, an additional 5 trenches were installed and in 1991 all fifteen trenches were sampled. The samples were analyzed for pH, reduction/oxidation (redox) potential, and microbial functional group identification and enumeration.

Results

Water from the floor drain sump, which is high in solids concentration, was pumped into the influent sump of the first well manifold (A). A sample of the water flowing into Sump A from the floor drain sump was collected near the termination of pump-down activities. This sample had a suspended solids concentration of approximately 38 mg/l. High solids input at the head of the plant results in solids migrating throughout the system. This produces increased carbon fines concentrations in the effluent stream which then enters the recharge wells. It was concluded that improvements in removing the carbon fines in the water from the floor drain sump prior to pumping into Sump A will eliminate the introduction of fines into the treatment system. A second alternative would be to recirculate the defining water in a closed loop system, thereby significantly reducing input into the treatment system.

At certain times when the solids loadings on the pre-filters were high, the filter effluent suspended solids concentrations were as high or higher than the respective influent concentrations. Trapped solids on the filter cartridge surface appeared to be migrating through the spiral weaving of the cartridge filters and ending up in the filtrate. After the initial high loadings, the influent suspended solids concentrations were higher than the effluent concentrations, indicating that under lower solids loadings the prefilters did seem to function properly.

Based on an effluent suspended solids concentration of 0.5 mg/l, and a total system flow rate of 871.7 liters per minute, the average annual solids loading to each of the 38 recharge wells was approximately 5.99 kilograms per year. The impact of this amount of carbon fines entering the wells is aquifer and well dependent. Plugging of the well packings and the surrounding aquifer due to cumulative deposition of the carbon fines from the NBS was considered to contribute to the problem of reduced recharge capacity at the NBS. However, it appeared that this was not the complete cause, based on the magnitude of carbon fine mass entering the wells annually.

Microbiological Enumeration and Identification

The recharge system water samples had an average pH of 7.7 which is conducive to microbial growth. The average redox potential in the recharge system was +153 Mv, indicating a fairly oxidized water. The water in the recharge trenches varies from weakly aerobic to mildly reducing.

Heterotrophic aerotolerent bacteria were found in the recharge system. Oligotrophic by nature, the heterotrophic aerotolerent microbes assessed in this study are indicative of wells with relatively low organic carbon. The levels of heterotrophic bacteria in the recharge system remained constant over the three years of sampling averaging 6.6×10^3 colony forming units (CFUs/ml) of groundwater. The range of heterotrophic bacteria found is within the "expected" range of populations found in most groundwater wells. Although heterotrophic bacteria may add to the microbial fouling of the recharge system, the NBS recharge system samples do not seem to have enough significant populations to cause recharge system capacity reductions.

Facultative bacteria are typically found in wells receiving water high in organic content and predominate in organic rich environments where oxygen can be limiting. High populations of facultative anaerobes were present in the recharge system, averaging 5.6×10^5 CFU's per milliliter of groundwater. Typical facultative populations for recharge systems are two to three orders less than those found in the recharge system tested in this study.

Fermenters are part of the facultative class of microbes, but differ from the other facultative types due to their characteristic acidic by-products or slime. The level of fermenters varied over the three years of sampling with the highest populations found in 1990 averaging 4.4×10^4 CFU's per milliliter of groundwater. The levels in 1989 and 1991 were lower by an order of magnitude. The acidic by-products produced by these organisms may coat the gravel in the recharge system where it may accumulate and eventually cause fouling.

Combined Effects of Activated Carbon Fines and Biofouling

It is postulated that activated carbon fines are concentrating the limited quantity of organic matter in the recharge water by adsorption, thereby building up a high enough concentration of food to support microbial populations on and around each carbon particle. Thus, clogging could be due to the combined effect of the activated carbon fines and biofouling. This type of beneficial relationship between microbial populations and carbon fines has been documented by several studies (Schultz and Keinath 1984; Hoffman and Oettinger 1987; Zappi et al. 1990).

Conclusions

The NBS recharge system has suffered a loss in recharge capacity which limits the flow rate through the treatment plant. The clogging of the alluvial aquifer around the recharge system could be due solely to activated carbon fines that are lost from the treatment system and are deposited in the aquifer. However, the presence of a microbial population suggests that activated carbon fines acting alone are not the reason for the reduced recharge capacity. Microbial sampling of the recharge system at the NBS showed populations have fluctuated over the course of this study, but their presence in the recharge system was associated with low recharge rates. These relationships suggest that microbial growths are promoting reduced recharge capacity through biofouling. An intriguing possibility is that activated carbon particles concentrate the food supply by adsorbing organics which, in turn, allows a microbial population to flourish. Therefore, the clogging is more than likely attributed to both the activated carbon fines and microbial action.

Acknowledgements

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