Assessment of a Sinkhole Filter for Removing Agricultural Contaminants

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Abstract

The impact on water quality by agricultural activity in karst terrain is an important consideration for resource management within the Appalachian Region. Karst areas comprise about 18 percent of the Region's land area. An estimated one-third of the Region's farms, cattle, and agricultural market value are on karst terrain. Two USDA/NRCS-designed sinkhole filter caps for removing contaminants from manure-impacted infiltrating water were assessed for removal efficiency of indicator bacteria and nitrate. One sinkhole filter was located in a pasture and down slope from a barnyard and milkhouse. The other sinkhole filter was constructed in a large sinkhole in a rotationally grazed beef pasture. Geometric mean fecal coliform bacteria concentrations were reduced 85 percent after sinkhole filter installation at both locations. Mean nitrate concentrations increased from 2.0 mg N L^{-1} to 4.6 mg N L^{-1} and from 5.5 mg N L^{-1} to 12.9 mg N L^{-1} at the dairy and pasture sites, respectively. The sinkhole filters were designed to filter water without significantly delaying water infiltration and causing sinkhole flooding. The sinkhole filters removed sediment and sediment-associated contaminants, such as fecal coliform bacteria, but had no filtering effect on solutes like nitrate. Nitrate concentrations might have increased because of nitrification in the filter media between runoff events. The sinkhole filter appears to be an effective management tool, along with responsible land management, in order to reduce inputs of pathogens to karst groundwater aquifers.

INTRODUCTION

Karst land makes up about 18 percent of the Appalachian land area, but accounts for more than a third of the agricultural production. Appalachian karst topography is characterized by extensive cave and conduit systems, sinkholes, sinking streams, and lack of surface streams. Water entering the karst aquifers through sinkholes and as sinking streams undergoes little natural filtration and quickly reappears in springs. The karst springs of southeastern West Virginia have been reported to be contaminated with nitrate, fecal coliform bacteria, and *Cryptosporidium*. The USDA-NRCS proposed a sinkhole filter (Figure 1) as a structural best management practice to filter contaminants from water before it enters the karst aquifer. The purpose of this study was to assess the effectiveness of sinkhole filters for reducing nitrate, chloride, and fecal coliform bacteria concentrations.

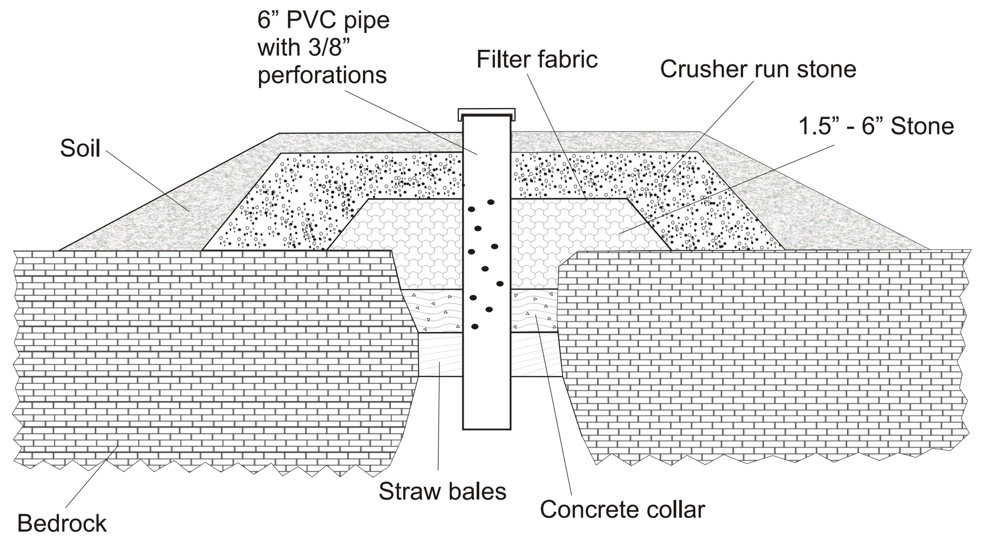

Figure 1. Schematic of design sinkhole filter

STUDY SITES AND METHODS

The basic sinkhole filter design (Fig. 1) consists of a concrete plug in the sinkhole throat. A 6" diameter PVC pipe through the concrete plug allows water to flow into the aquifer. The perforated PVC pipe is wrapped in filter fabric. A gradation of crushed rock is placed around the perforated PVC pipe. Grassed topsoil over the entire sinkhole filter completes the structure. Filter fabric is sandwiched between the coarse and fine crushed rock layers (Fig. 2). A completed sinkhole filter on crop land in northeastern West Virginia is shown in Figure 3.

Two sinkhole filters were studied. The first was located in a pasture down slope of a dairy milkhouse and cattle loafing area. The sinkhole often received surface flow from the pasture and the milkhouse area. The sinkhole contained a large, solutionally-enlarged basin in the limestone bedrock beneath the sinkhole filter. The subterranean basin stored water until storms caused the basin to overflow into a fracture open to the aquifer. Water samples were collected from the basin several months prior to filter installation as well as several months following the installation.

The second sinkhole filter (Fig. 4) was constructed in a large sinkhole in pasture rotationally grazed by beef cattle on a stocker beef operation. The sinkhole drained directly through solutionally-enlarged joints to the aquifer so a 50 L polypropylene sampling reservoir was positioned below the filter's drainage pipe. The reservoir was perforated so it could empty between storms. A PVC passive stormflow collector situated in the throat of the sinkhole was used to collect storm samples prior to sinkhole filter installation.

All water samples were analyzed for fecal coliform bacteria by membrane filtration (45 µm) using mFC agar nutrient medium and incubated at 44.5 °C. Nitrate-N and Cl^- concentrations were determined by suppressed ion chromatography on filtered (45 µm) water samples.

Figure 2. Filter fabric sandwiched between the crushed rock layers is an important part of the design

Figure 3. Sinkhole filter on cropland in Berkeley Co., WV

Figure 4. Sinkhole filter number 2.

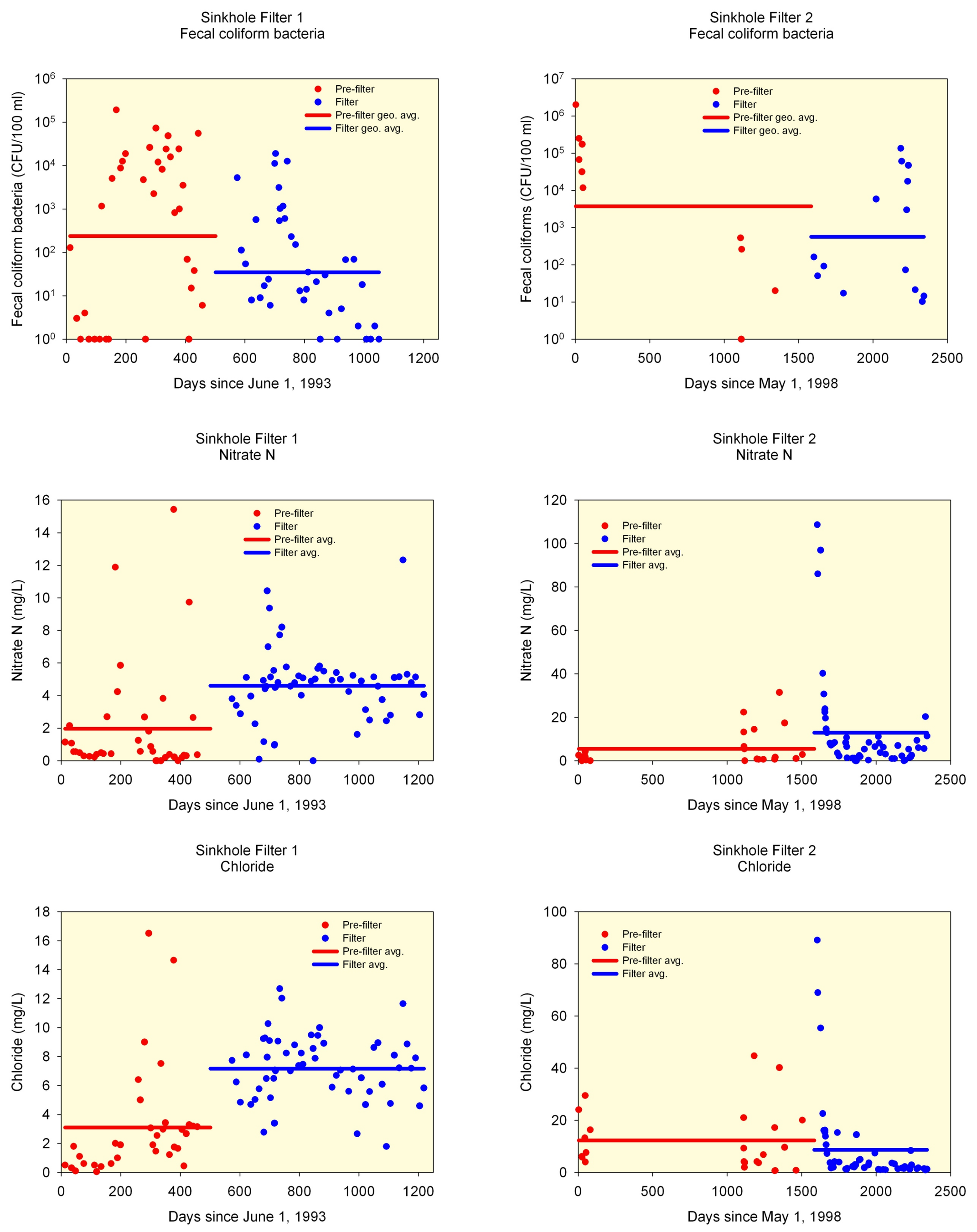

Figure 5. Observed concentrations of fecal coliform bacteria, nitrate-N, and Cl^- before sinkhole filter installation (red) and after sinkhole filter installation (blue). Solid lines represent pre- and post-filter installation means (geometric mean for fecal coliforms).

RESULTS

Mean concentrations and statistical significance ($P \leq 0.05$) between pre- and post-filter installation concentration medians are shown in Table 1. Observed concentrations are also shown in Figure 5.

Geometric mean concentrations of fecal coliform bacteria decreased 85 percent from 238 CFU/100 ml to 35 CFU/100 ml at sinkhole # 1 following sinkhole filter installation. An 85 percent decrease in geometric mean fecal coliform bacteria concentrations was also realized at sinkhole #2 with a decrease from 3783 CFU/100 ml to 566 CFU/100 ml. The decrease at sinkhole #2 was not significant at the $P = 0.05$ level, but was significant at the $P = 0.10$ level.

There was a highly significant increase in mean nitrate-N concentrations after sinkhole filter installation at both sinkholes. Mean nitrate-N increased from 2.0 mg/L to 4.6 mg/L and from 5.5 mg/L to 12.9 mg/L at sinkholes 1 and 2, respectively. High nitrate-N concentrations in sinkhole 2 after filter installation may have been caused by fertilization to ensure a lush canopy of grass on the filter. When the first eight observations after filter installation at sinkhole 2 were excluded from analysis there was virtually no change in mean nitrate-N concentration (5.5 mg/L to 5.6 mg/L).

Cl^- is often found to be a conservative ion so little change was expected. However, there was a significant increase from 3.1 mg/L to 7.2 mg/L and a significant decrease from 12.3 mg/L to 8.6 mg/L at sinkholes 1 and 2, respectively.

Table 1. Pre- and post-sinkhole filter installation mean concentrations of nitrate-N and Cl^- and geometric mean concentration of fecal coliforms. Statistical significance is for the Wilcoxon nonparametric test of medians.

Water quality parameter	Means: Pre-filter installation	Post-filter installation[2]	Significance[1,2]
Sinkhole filter 1:			
Fecal coliforms (CFU/100 ml)	238	35	0.02
Nitrate - N (mg/L)	2.0	4.6	<0.01
Cl^- (mg/L)	3.1	7.2	<0.01
Sinkhole filter 2:			
Fecal coliforms (CFU/100 ml)	3783	566	NS
Nitrate - N (mg/L)	5.5	12.9 (5.6)	0.01 (NS)
Cl^- (mg/L)	12.3	8.6 (3.5)	<0.01 (<0.01)

[1] NS = not significant at $P \leq 0.05\%$ level.
[2] Numbers in parentheses are for calculations based on removal of the first eight observations following installation of sinkhole filter.

DISCUSSION

The sinkhole filters appear to be effective in reducing fecal coliform bacteria concentrations. The 85 percent reduction in geometric mean concentrations is probably a result of sediment entrapment within the filters. Fecal coliform bacteria are often attached to sediment and become trapped along with the sediment. However, high concentrations of fecal coliform bacteria during some storms following sinkhole filter installation indicates that bacteria attached to very fine sediments and colloidal materials and unattached fecal coliform bacteria were able to move through the filters. Other sediment related contaminants like phosphorus and some pesticides also might be effectively trapped by the sinkhole filter, but further studies will be necessary in order to make those determinations.

The sinkhole filters were not effective for reducing nitrate concentrations. Nitrate is a solute and is not subject to physical filtration. Increases in nitrate concentrations indicate that nitrification might have been occurring within the filters. Chloride was analyzed since it is a conservative ionic solute and would not be expected to change like nitrate. However, chloride concentrations increased at one sinkhole and decreased at the other. Since the sinkhole filters were not effective for reducing nitrate, a nutrient management practice accounting for animal waste inputs in the sinkhole areas might be a more effective means for reducing soluble nutrient concentrations.

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