In cooperation with the Chester County Water Resources Authority

Effects of Spray-Irrigated Municipal Wastewater on a Small Watershed in Chester County, Pennsylvania

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What is Spray Irrigation?

Spray irrigation is a method for disposing of secondary treated municipal wastewater by spraying it on the land surface (fig. 1). The sprayed wastewater either evaporates into the air, soaks into the soil, or percolates through the soil and recharges the ground water. Land application of wastewater has advantages over conventional means of disposal by direct discharge to streams because the wastewater recharges the ground-water system and increases base flow in streams. Additional benefits are derived from the "natural" treatment of the wastewater that takes place in the soil when plants and other biota remove some nutrients (nitrogen and phosphorus) from the wastewater (Pennsylvania Department of Environmental Protection, 2003). The removal of nutrients is one advantage spray irrigation has to conventional disposal methods like instream discharge.

Figure 1. View of spray head at the New Garden Township site, Chester County, Pennsylvania.

Why was Spray Irrigation Studied?

Spray irrigation was studied to determine if the treatment method increased recharge in the watershed and increased base flow in the stream draining the watershed where it was taking place and, if so, by how much. If recharge and base flow are increasing, the effects of spray-irrigated wastewater on ground- and surface-water quality need to be determined. A nitrogen budget, and the role the plants and soils had in the nitrogen budget were determined to address the question, "What happens to the additional nitrogen added to the watershed from the wastewater?" A detailed description of the study design, methods, and results is presented in Schreffler and others (2005).

How was Spray Irrigation Studied?

The study was done in a 38-acre watershed in New Garden Township, Chester County, Pa. Ground and surface water, soil, soil water, precipitation, wastewater, and plant material were all sampled in the study. Streamflow-gaging stations, monitor wells, soil probes, and a weather station were installed in the watershed, and the data from these instruments were used to answer the recharge, base-flow, and water-quality questions. Streamflow, ground-water levels, and water-quality data were collected from May 1998 through December 2001. The soil probes and the weather station were installed in May 1999. The nitrogen budget was determined for a smaller 20-acre subbasin of the watershed for the period June 1999 through December 2001. The 20-acre subbasin included the fields where the spray irrigation was being applied and the area directly downhill from the fields (fig. 2). A berm was constructed to capture all stormflow runoff from the spray fields due to precipitation and direct it through a flume, which is a structure in which flow is determined from the height of the water passing through. Soil-water instruments and a bulk precipitation sampler also were installed at the study site, and the data were used to explain what happened to the nitrogen. The bulk precipitation sampler to measure wet (rainfall or snow) and dry deposition of nitrogen was not installed on the site until August 1999.

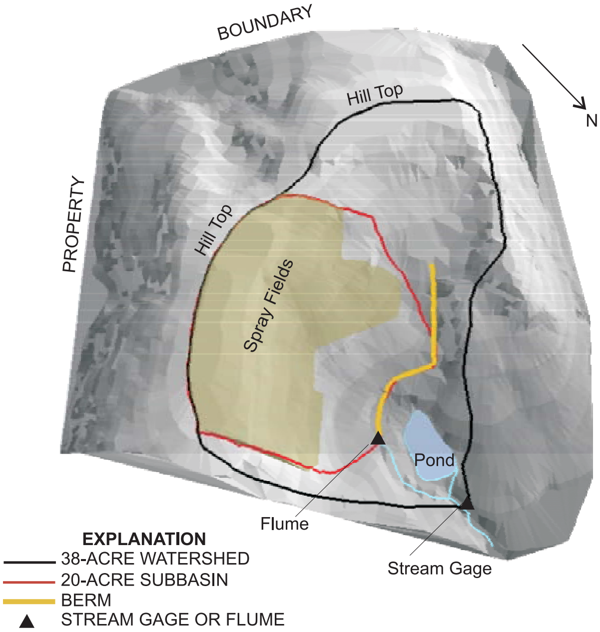

Figure 2. The 38-acre watershed, 20-acre subbasin, spray fields, berm, flume, and stream gage at the New Garden Township site, Chester County, Pennsylvania.

Did the Spray-Irrigated Wastewater Increase Recharge and Base Flow?

On an annual basis, spray irrigation increased the ground-water recharge to the study watershed. In order to determine the amount of increased recharge, water budgets for the study watershed were compared to water budgets of the Red Clay Creek Basin above the U.S. Geological Survey streamflow-gaging station (01479820) near Kennett Square, Pa. (drainage area 28.3 mi^2). The 38-acre (0.07 mi^2) study watershed is within the larger Red Clay Creek Basin. The water budgets for Red Clay Creek would not show measurable affects of the spray irrigation because the amount of wastewater applied is small when compared to the larger size basin. Water budgets and recharge estimates were determined for 2000 and 2001 in the study watershed (fig. 3A and 3B) and Red Clay Creek Basin (table 1).

Table 1. Annual water budgets and recharge estimates for the Red Clay Creek Basin, 2000 and 2001.

[All units in inches]

Year	Precip-itation	Stream-flow	Change in ground-water storage	Evapo-trans-piration	Ground-water recharge
2000	42.9	19.4	0	23.6	12.5
2001	36.3	14.7	-2.7	24.3	6.6

The total amount of ground-water recharge to the study watershed was 21.3 in. (inches) and 10.9 in. for 2000 (fig. 3A) and 2001 (fig. 3B), respectively. The total recharge includes the natural recharge from precipitation plus additional recharge from spray irrigation. Compared to the annual recharge determined for the Red Clay Creek, spray irrigation increased recharge in the study watershed by approximately 8.8 and 4.3 in. for 2000 and 2001, respectively. This was a 70-percent increase in recharge in 2000 and a 65-percent increase in recharge in 2001 in the study watershed. In 2000, a total of 22.6 in. of wastewater was applied to the watershed and the 8.8 in. increase in recharge was equal to about 39 percent of the spray irrigation applied. In 2001, a total of 14.4 in. of wastewater was applied, and the increase in recharge of 4.3 in. was equal to about 30 percent of the spray irrigation applied.

Prior to wastewater application, base flow in the stream draining the watershed was determined for a 1-year period. The spray-irrigated wastewater increased base flow from the watershed. The magnitude of the increase was related to the time of year when spray application rates increased. Spray application rates were established during the permitting process for the facility, and more wastewater was applied during the summer months than during the winter months. During the late fall through winter and into the early spring, when spray application rates were low, base flow increased by approximately 50 percent over the period prior to wastewater application. During the early spring through summer and into the late fall, when spray application rates were high, base flow increased by approximately 200 percent over the period prior to wastewater application.

Did the Wastewater Affect Water Quality?

The spray-irrigated wastewater affected the ground-water quality in the watershed but did not affect the quality of stream water leaving the watershed at the streamflow-gaging station. The effects of the spray irrigation on ground-water quality were manifest in changes in concentrations of nitrate and chloride. Nitrate and chloride are in wastewater, and chloride is a by-product of the disinfection process at the sewage-treatment facility. Other chemical constituents were affected by the wastewater application, but the changes in concentrations were not as pronounced as nitrate and chloride.

Nitrate and chloride have regulatory limits set by the U.S. Environmental Protection Agency for public drinking water supplies that are called maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs). If the concentration of a constituent is above the MCL in a public water supply, some type of treatment to lower the concentration to a concentration less than the MCL is required. The MCL for nitrate is 10 mg/L (milligrams per liter). SMCLs are based on aesthetic properties of water such as taste, odor, or the staining of plumbing fixtures. The SMCL for chloride is 250 mg/L.

Effects on Ground-Water Quality

Overall, the spray-irrigated wastewater increased the concentrations of nitrate and chloride in ground water under the spray fields. The increase in concentrations appeared to take place after the spray irrigation began (fig. 4). However, a different pattern was observed in ground water at the bottom of the hill. There, the spray-irrigated wastewater decreased concentrations of nitrate and increased concentrations of chloride. The decreasing concentration of nitrate and the increasing concentration of chloride appeared to take place after the start of the spray irrigation (fig. 5). In particular, chloride concentrations appeared to increase about 1 year after the spray irrigation began. This was

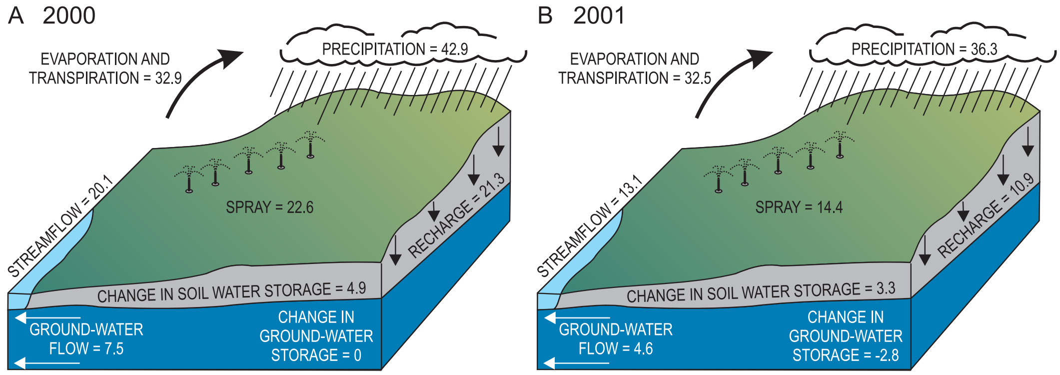

Figure 3. Water budgets and recharge estimates for (A) 2000 and (B) 2001 at the New Garden Township site, Chester County, Pennsylvania. (Water volume expressed as inches over the watershed area.)

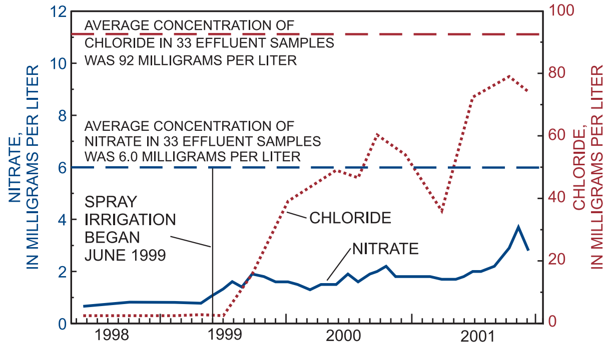

Figure 4. Maximum nitrate and chloride concentrations in water from four monitor wells in the spray fields and average wastewater concentrations at the New Garden Township site, Chester County, Pennsylvania.

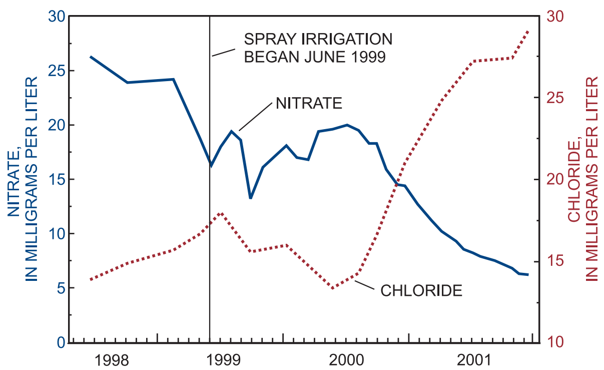

Figure 5. Maximum nitrate and chloride concentrations in water from two monitor wells at the bottom of the hill at the New Garden Township site, Chester County, Pennsylvania.

probably because of the traveltime needed for the wastewater to reach the bottom of the hill.

Prior to the start of spray irrigation, nitrate concentrations in the ground water at the bottom of the hill near the pond were about 25 mg/L. These concentrations were higher than the average nitrate concentration in the wastewater. In this area, mushroom soil had been composted in the past (prior to 1990), and nitrate leached from the mushroom soil into the ground water. The net effect was that spray-irrigated wastewater with lower concentrations of nitrate (average 6.0 mg/L) flushed the ground water with higher concentrations of nitrate (25 mg/L) from the area, thus lowering the nitrate concentrations.

Chloride is a conservative constituent. Chloride does not react, change, or transform within the environment and is carried readily with the water. Concentrations of chloride in ground water under the spray fields and in ground water at the bottom of the hill increased. In ground water under the spray fields, chloride concentrations increased throughout the study and approached the average concentration in the applied wastewater (fig. 4). Because the concentration of chloride in the wastewater was higher than the concentration in ground water at the bottom of the hill, chloride concentrations started to increase about 1-year after spraying began and continued to increase throughout the remaining study period (fig. 5).

Concentrations of nitrate in ground water under the spray fields increased throughout the study; however, the maximum concentration of nitrate detected in 129 samples in water from 4 monitor wells on the spray area was 3.7 mg/L. This concentration was below the MCL for nitrate and below the average nitrate concentration in the wastewater (fig. 4). The average concentration of nitrate in 33 wastewater samples was 6 mg/L. Nitrate is a non-conservative constituent in the environment. Nitrate can transform and is used by plants and micro-organisms and, as a result, its concentration can and does change. Nitrate concentrations in ground water under the spray fields increased but did not reach the average concentration in the wastewater, which indicated that some of the nitrate was being removed or transformed.

Effects on Stream-Water Quality Leaving the Watershed

As of the end of this study in December 2001, the spray-irrigated wastewater did not increase or decrease concentrations of nitrate or chloride in water from the pond or in stream base flow leaving the watershed. However, the wastewater affected the ground water under the spray fields and at the bottom of the hill. Because base flow is ground water discharged to streams, changes in the concentrations of nitrate and chloride are expected sometime in the future, but when this will take place is unknown. Changes in stormflow or storm-related loadings of nitrate and chloride in the stream were not assessed.

What Happened to the Nitrogen?

The combination of inputs, outputs, and changes in storage of nitrogen (in pounds) is referred to as a nitrogen budget. The nitrogen budget for the 20-acre subbasin was determined from June 1999 through December 2001, when all inputs, outputs, and storage changes of nitrogen were determined or estimated. Input sources of nitrogen to the 20-acre subbasin included the spray wastewater and wet and dry deposition from the atmosphere. In addition, certain plants called legumes take nitrogen out of the air and deliver it to the soil. This could be an input of nitrogen to the basin. Output sources of nitrogen included stormflow and base flow leaving the subbasin at the flume (fig. 2), ammonium degassing from the wastewater being sprayed (volatilization), harvesting and removing the crop, and ground-water migration out of the basin. In addition, denitrification, a process in which nitrogen is converted to nitrogen gas that dissipates into the atmosphere, could be a possible output. The storage of nitrogen in the subbasin was in the soil, the water in the soil, and the ground water under the site.

In nature, nitrogen is comprised of different forms such as nitrate, nitrite, ammonium, and organic nitrogen. For this fact-sheet, only the results for total nitrogen are discussed. Information about the types and forms of nitrogen at this site is presented in Schreffler and others (2005).

For the study period June 1999 through December 2001, a total of approximately 5,420 lb (pounds) of nitrogen was added to the subbasin from the wastewater (fig. 6). The wastewater was the largest contributor of nitrogen to the subbasin. About 75 percent or 4,100 lb of nitrogen from the wastewater was applied during the growing season, April through September. The other input of nitrogen was from the atmosphere as wet (rainfall or snow) and dry deposition. Inputs from atmospheric deposition were distributed relatively evenly throughout the year. The total amount of nitrogen from the atmosphere was 380 lb of wet and 110 lb of dry deposition measured from August 1999 through December 2001. An additional 90 lb of nitrogen was estimated to

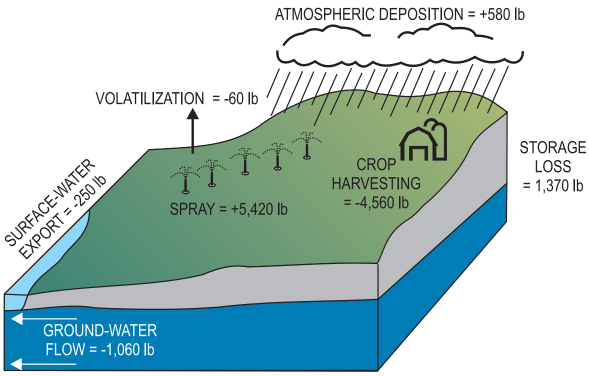

Figure 6. Nitrogen budget June 1999 through December 2001 at the New Garden Township site, Chester County, Pennsylvania.

be deposited in June and July 1999 for a total of 580 lb over the June 1999 through December 2001 study period (fig. 6). Input from legumes was assumed to be zero because a uniform cover crop of orchardgrass, which is not a legume, was planted in the spray fields.

The primary nitrogen output or loss from the 20-acre subbasin was plant harvesting. Plant harvesting removed about 4,560 lb of nitrogen during the three growing seasons from 1999 to 2001 or about 77 percent of the total nitrogen removed during the study period. An additional 1,060 lb of nitrogen was removed from the watershed in ground-water migration off site. This accounted for 18 percent of the total nitrogen removed from the 20-acre subbasin. Total nitrogen leaving the subbasin in streamflow was 250 lb, which accounted for about 4 percent of the total nitrogen removed from the subbasin. In addition, approximately 60 lb of nitrogen (1 percent of the total) was lost through ammonia volatilization. This took place only during the growing season when air temperatures were high.

The changes in storage of nitrogen in soil, the water in the soil, and ground water were quantified. Additional details on the complexities of the different forms of nitrogen are presented in Schreffler and others (2005). In summary, the amount of nitrogen stored in the soil was the predominant storage component for nitrogen in the 20-acre subbasin. Some forms of nitrogen increased in the soil from spring 1999 to fall 2001. However, concentrations of nitrate in the soil generally showed no change over the study period.

Nitrogen stored in soil water and ground water substantially decreased over the study period in the 20-acre subbasin. The amount of nitrogen in the soil water and ground water in spring-summer 1999 was about twice as much as the amount of nitrogen in water collected in the last samples in 2001. Looking at the 20-acre subbasin as a whole, the amount of nitrogen in ground water was reduced even though concentrations of nitrate in water samples from monitor wells on the spray area showed significant increases during the study period. However, because the spray-irrigated water helped to flush nitrate from the mushroom compost disposal area out of the 20-acre subbasin, the amount of stored nitrogen in the ground-water system as a whole decreased. Overall, the change in storage of nitrogen in soil, the water in the soil, and ground water was a net loss of about 1,370 lb.

Based on the estimates for the individual components of the nitrogen budget, the amount of nitrogen input and released from storage exceeded the amount of nitrogen lost from the basin by 1,440 lb. This imbalance results from overestimating the inputs or underestimating outputs (or a combination of both) and reflects the difficulty in accurately quantifying all terms in the nitrogen budget.

Conclusions

Wastewater has to be treated and eventually disposed. Land disposal of wastewater through spray irrigation at this site increased recharge to the watershed and increased the base flow leaving the watershed. As a result of spray irrigation, concentrations of nitrate and chloride increased in ground water under the spray fields. Although nitrate concentrations were increasing, they remained below the average concentration of nitrate in the applied wastewater, which indicated that some of the nitrate being applied was being removed. Also, the nitrate concentrations were below the MCL set by the USEPA for nitrate. Chloride concentrations were increasing in ground water under the spray fields and were approaching the average concentration of chloride in the wastewater. The chloride concentrations were below the SMCL set by the USEPA for chloride. Increasing chloride concentrations indicate that wastewater is reaching the ground water and other contaminants or constituents that may be present in the wastewater also could be reaching the ground water.

The nitrogen budget indicated spray irrigation did not cause an increase in nitrogen losses in ground and surface waters leaving the 20-acre subbasin from June 1999 through December 2001. In addition, no net increase in the storage of nitrogen in the form used by plants and micro-organisms took place in soil and ground water under the 20-acre subbasin. Plant uptake and harvesting was the primary route for removing nitrogen from the 20-acre subbasin. Seventy-five percent of the total nitrogen in the spray-irrigated wastewater was applied during April through October. This spray-irrigation site was designed so that some nitrogen applied would be removed from the site through harvesting of plant material and that did take place. In fact, some nitrogen already stored in the soil before spray irrigation started was removed from the subbasin through harvesting of the crop. These data show the importance of plant harvesting at spray-irrigation sites and the importance of timing spraying with plant growth so that much of the applied nitrogen is used by plants. The results of the study have shown that the landscape can be used to filter nitrogen out of the water prior to discharge from the watershed, and at this site, spray irrigation was a better method of disposing of wastewater from the treatment facility than discharging the water directly to a stream.

References Cited

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