PESTICIDE CONTAMINATION OF GROUNDWATER IN VIRGINIA: BMP IMPACT ASSESSMENT

S. Mostaghimi, P. W. McClellan and R. A. Cooke

Department of Agricultural Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0303, USA

ABSTRACT

The Nomini Creek Watershed/Water Quality monitoring project was initiated in 1985, as part of the Chesapeake Bay Agreement of 1983, to quantify the impacts of agricultural best management practices (BMPs) on improving water quality. The watershed monitoring system was designed to provide a comprehensive assessment of the quality of surface and groundwater as influenced by changes in land use, agronomic, and cultural practices in the watershed over the duration of the project. The primary chemical characteristics monitored include both soluble and sediment-bound nutrients and pesticides in surface and groundwater. Water samples from 8 monitoring wells located in agricultural areas in the watershed were analyzed for 22 pesticides. A total of 20 pesticides have been detected in water samples collected. Atrazine is the most frequently detected pesticide. Detected concentrations of atrazine ranged from 0.03 - 25.56 ppb and occurred in about 26 percent of the samples. Other pesticides were detected at frequencies ranging from 1.6 to 14.2 percent of all samples collected and concentrations between 0.01 and 41.89 ppb. The observed concentrations and spatial distributions of pesticide contamination of groundwater are compared to land use and cropping patterns. Results indicate that BMPs are quite effective in reducing pesticide concentrations in groundwater.

KEYWORDS

Groundwater pollution; agriculture; pesticides; water quality, best management practices.

INTRODUCTION

Over the last several decades, crop production in the United States has increased largely due to the extensive use of fertilizers as plant nutrient supplements and pesticides for crop pests and weed control. Pesticide use in agriculture has increased significantly over the last two decades. In 1982, agricultural pesticide usage exceeded 370,000 Mg of active ingredients and accounted for over 70% of all pesticides used in the United States (Cohen et al., 1984). Extensive use of agricultural chemicals, while beneficial to the nation's agrichemical industry and to crop production, has resulted in widespread contamination of surface and groundwater resources. Widespread pesticide contamination of groundwater, used as the primary source of drinking water for over 50% of the U.S. population, has been reported in 37 states (Fairchild, 1987). A 1986 EPA study indicated that at least 17 pesticides have been found in the groundwater of 23 states (Cohen et al., 1986).

Recent studies on the decline of the Chesapeake Bay have concluded that nonpoint source pollution from agricultural areas is responsible for a significant portion of the water quality degradation in the Bay (U.S. EPA, 1983). To reduce nonpoint source loading from agricultural areas to the Chesapeake Bay, Virginia has...
instituted a cost-sharing program to encourage the implementation of agricultural best management practices (BMPs). Successful implementation of the program depends on identification of cost-effective BMPs for controlling agriculturally-related pollutants. Background information to quantify the water quality consequences of agricultural practices are generally lacking, particularly for Virginia. Hence, a well designed, comprehensive nonpoint source monitoring program was needed to quantify the effects of various BMPs on surface and groundwater quality in Virginia. To this end, the Nomini Creek Watershed/Water Quality monitoring project was initiated in 1985 to provide much needed data to quantify the water quality impacts of BMP implementation on a watershed with a complex landuse, as opposed to specific testing of individual BMPs.

The groundwater monitoring component of the Nomini Creek Watershed Project was initiated in 1986. This monitoring program was designed to collect information on chemical concentrations in groundwater in a predominantly agricultural watershed, with cropping practices, landuse, soil and hydrologic conditions typical of the Virginia Coastal Plain. The objective of this paper is to describe the monitoring strategy, present a summary of the data collected from the groundwater monitoring wells and discuss the effectiveness of BMPs in reducing pesticides concentrations.

**DESCRIPTION OF THE WATERSHED**

The Nomini Creek Watershed was selected for monitoring because of its large proportion of cropland and lack of point source pollution discharges that could affect water quality. The 1500-ha watershed is located in Westmoreland County, Virginia. The watershed landuse is typical of the coastal plain of Virginia and consists of 43% cropland, 54% woodland (primarily hardwood), and 3% homestead and roads. The topography is nearly level to sloping, except along streams which have very steep streambanks with the slopes of up to 50%. The stream banks are almost entirely forested.

Soils in the watershed are generally classified as Ultisols because they are moist soils that have argillic horizons. These soils develop in areas with long frost-free seasons, abundant rainfall, and adequate groundwater supplies. The major soil series underlying the watershed are Suffolk and Rumford which cover over 91% of the watershed area. The Suffolk soil series (coarse-loamy, siliceous, thermic, Typic Hapludult) which cover about 58% of watershed, are deep, well drained, have slow runoff potential with a moderate available water capacity. Rumford soils (coarse-loamy, siliceous, thermic, Typic Hapludult) comprise 34% of the watershed. These soils are deep, moderately steep to steep slopes, well drained, and are found in areas with low marine terraces. Most areas of the Rumford soils are woodland and a few are in pasture or hay. Approximately 55% of the forested land in the watershed is on Rumford soils (Mostaghimi et al., 1989).

Agricultural activities in the watershed are primarily row crops with corn, soybeans, and small grains (wheat and barley) being the major crops produced. Conventionally-tilled corn followed by small grain with no-till soybeans planted in small grain residue is the typical crop rotation in the area. Occasionally, some fields are planted to conventionally-tilled full season soybeans. The watershed BMP implementation program is designed to improve surface and groundwater quality. Improved nutrient and pesticide management are also being stressed. Implementation of these BMPs vary widely from farm to farm, depending upon conditions encountered and the acceptance of the practice by the farmer. However, the ultimate goal of each BMP adopted by the farmer is to minimize nonpoint source pollution while maintaining agricultural productivity. There are 26 farms in the watershed. Of these, 33% are farmed by owner/operators and 67% are rented.

**MONITORING PROGRAM AND PROCEDURES**

The Nomini Creek Watershed/Water Quality monitoring system was designed to provide comprehensive assessment of the quality of surface and groundwater as influenced by changes in landuse, agronomic, and cultural practices in the watershed over a 10-year duration. Specific elements of the monitoring system include: wet and dry weather physical, chemical monitoring of surface and groundwater; biological monitoring of surface water; physical and chemical analysis of soils; and chemical analysis of atmospheric deposition. The primary chemical characteristics monitored include both soluble and sediment-bound
nutrients, organics, insecticides, and herbicides both in surface runoff and groundwater. Several runoff and precipitation monitoring sites were established in order to define and characterize the spatial impact of parameters such as rainfall and landuse on pollutant losses from the watershed. Surface water quality is being monitored at the watershed outlet (QN1) and a substation (QN2) located upstream of QN1 (Figure 1). Selection of these sites was guided primarily by distribution of landuse and cultural practices in the watershed. The main station, QNI, was installed on the main stem of Nomini Creek in 1985 and drains a 1505 ha area. Streamflow at this station is strongly influenced by baseflow from marsh areas upstream of the station. These marshy conditions are typical of the coastal plain. The QN2 station was installed at the outlet of the subwatershed to monitor runoff from a 225 ha, predominantly agricultural area. This station was selected to delineate the pollutant removal ability of the marsh areas. In addition, station QN2 was established to divide the total watershed into more manageable proportions and to allow direct chemical loading comparisons between the subwatershed and the watershed as a whole.

The locations of the eight groundwater monitoring wells along with the two runoff stations and the meteorological station are shown in Figure 1. The wells were installed in predominantly farmed areas and were drilled in pairs, 100-150 m apart, with one well located hydraulically downgradient of the other. Two pairs of wells were installed in fields with a no-till corn - soybean rotation, while the other two pairs were installed in fields with conventionally-tilled corn - soybean rotation. Both the conventional till and no-till fields followed a typical corn - small grain - soybean rotation. The well depth ranged from 11.9 m to 16.5 m. Each monitoring well consists of a 15-cm diameter borehole drilled 3 m below the static water table and a 3 m long, 5-cm I.D. (internal diameter) slotted PVC well screen. The well casing consists of a 5-cm I.D. PVC pipe. All wells were developed with a portable gas displacement pump and are equipped with a locking cap. Detailed description of well construction and development are given by Mostaghimi et al., (1989).

![Nomini Creek Watershed](https://iwaponline.com/wst/article-pdf/28/3-5/379/27199/379.pdf)  

Figure 1. Location of monitoring stations in Nomini Creek Watershed.
Pesticide (herbicide and insecticide) application data for the entire watershed are obtained by farmer's survey. The rate and timing of herbicide application is dependent upon the cropping pattern adopted by the farmer. Generally, corn is planted between late April and early May. The post-emergent sprays are usually applied in early July. Several insecticides are applied in the watershed to control insect population. The insecticides are applied at varying rates depending upon the insect problems encountered.

The groundwater monitoring wells are being sampled at least once a month. A submersible, gas driven bladder pump is used to purge about 4-6 well volumes of water before the sample is taken. This amount of purging is required to stabilize pH, electrical conductivity, temperature, and dissolved oxygen of the discharged water. All pesticide samples are collected in 4-l glass bottles, refrigerated at 4°C, and immediately transferred to the laboratory for analysis. A detailed description of the sample collection and handling protocol, along with QA/QC procedures, is described by Mostaghimi (1989).

Landuse information is collected on either a quarterly or monthly basis through field visits and interviews with individual farmers. On a quarterly basis, crop, landuse, and chemical application data are obtained for each field in the watershed through site visits and interviews with individual farmers. The quarterly surveys also are used to record changes in field boundaries within the watersheds which have been selected for detailed monthly visits. During site visits to these fields, crop, percent cover, crop height, and crop condition at the time of the visit, and cultivation operations are recorded. Monthly interviews are used to record dates of tillage, planting, harvesting, chemical applications, seeding rates, crop yields, and general descriptions of cultural practices for each field.

The pre-BMP implementation phase of the project covered the period from 1986 through spring 1989. The main objective of this phase was to collect adequate baseline information representative of existing conditions in Virginia Coastal Plain. Hydrologic, landuse, and water quality data collection is continuing through the post-BMP implementation phase of the project. This will aid in quantifying the long-term impacts of agricultural management practices on water quality.

RESULTS AND DISCUSSION

Groundwater samples obtained from the eight monitoring wells were analyzed for pesticide concentrations using several statistical procedures. Most of the pesticides reportedly used in the watershed were detected at varying concentrations and frequencies. A total of 20 different pesticides were detected in groundwater at concentrations ranging from trace levels or above detection limits to 41.89 ppb (Table 1).

The frequency of pesticide detections in groundwater was examined. Atrazine was by far the most commonly detected of all the pesticides sampled, with a frequency of detection of 25.7 percent of total samples analyzed during this period. Atrazine, a member of the s-triazine group, is moderately adsorbed, moderately persistent, and moderately soluble in water. Other pesticides in the s-triazine group including metribuzin, and simazine were also detected at varying frequencies (Table 1). Metribuzin, a member of the s-triazine class, was detected in 14.2 percent of the samples. Cyanazine, although reportedly used in near well fields, was not detected in any of the samples analyzed. Simazine was detected in 7 percent of the samples although there is practically no recent record of its application in the watershed. This herbicide is characterized by a high leaching potential, which has been derived from its moderate to low partition coefficient and relatively long half-life (Cohen et al., 1984).

The second most heavily used group of pesticides in the watershed are those of the amide family. Those amide herbicides commonly used in the watershed include alachlor and metolachlor. These herbicides were frequently detected in groundwater; however, their concentration levels were below the HALs of 0.4 ppb for alachlor and 100 ppb for metolachlor. The frequency of detection of alachlor was 10.9 percent (Table 1). Most of the samples with detected alachlor were in wells located in the no-till fields. Metolachlor was also detected in several wells with a detection frequency of 11.4 percent. Dicamba and 2,4-D were found in 5.6 percent and 10.6 percent of the samples, respectively (Table 1). Their presence in groundwater suggests intense weed and brush controls in no-till fields and/or enhanced surface water to groundwater transport.
Table 1. Concentration (ppb) of pesticides detected in groundwater of No mini Creek Watershed.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Trade Name</th>
<th>Mean (ppb)</th>
<th>Standard Deviation (ppb)</th>
<th>Maximum (ppb)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alachlor</td>
<td>Lasso</td>
<td>0.11 (44)*</td>
<td>0.12</td>
<td>0.44</td>
<td>0.109</td>
</tr>
<tr>
<td>Atrazine (b)</td>
<td>Aatrex</td>
<td>1.12 (108)</td>
<td>2.58</td>
<td>25.56</td>
<td>0.257</td>
</tr>
<tr>
<td>Bentazon</td>
<td>Basagran</td>
<td>0.27 (10)</td>
<td>0.16</td>
<td>0.55</td>
<td>0.026</td>
</tr>
<tr>
<td>Carbaryl</td>
<td>Sevin</td>
<td>0.29 (19)</td>
<td>0.33</td>
<td>1.22</td>
<td>0.049</td>
</tr>
<tr>
<td>Carbofuran</td>
<td>Furadan</td>
<td>0.46 (45)</td>
<td>0.85</td>
<td>3.67</td>
<td>0.116</td>
</tr>
<tr>
<td>Dicamba (b)</td>
<td>Banvel</td>
<td>0.25 (22)</td>
<td>0.97</td>
<td>4.68</td>
<td>0.056</td>
</tr>
<tr>
<td>Disulfoton</td>
<td>Disyston</td>
<td>0.39 (10)</td>
<td>0.83</td>
<td>2.87</td>
<td>0.026</td>
</tr>
<tr>
<td>Fenvalerate (b)</td>
<td>Pydrin</td>
<td>0.70 (6)</td>
<td>0.10</td>
<td>0.28</td>
<td>0.016</td>
</tr>
<tr>
<td>Flauzifop-butyl (b)</td>
<td>Fusilade</td>
<td>13.31 (5)</td>
<td>12.15</td>
<td>31.60</td>
<td>0.030</td>
</tr>
<tr>
<td>Linuron (b)</td>
<td>Lorox</td>
<td>1.00 (8)</td>
<td>1.17</td>
<td>3.79</td>
<td>0.021</td>
</tr>
<tr>
<td>Malathion</td>
<td>-</td>
<td>0.32 (27)</td>
<td>0.06</td>
<td>0.12</td>
<td>0.079</td>
</tr>
<tr>
<td>Metolachlor (b)</td>
<td>Dual</td>
<td>0.27 (45)</td>
<td>0.46</td>
<td>2.85</td>
<td>0.114</td>
</tr>
<tr>
<td>Metribuzin (b)</td>
<td>Lexone</td>
<td>0.11 (57)</td>
<td>0.39</td>
<td>2.73</td>
<td>0.142</td>
</tr>
<tr>
<td>Permethrin (b)</td>
<td>Pounce</td>
<td>0.22 (9)</td>
<td>0.41</td>
<td>1.36</td>
<td>0.024</td>
</tr>
<tr>
<td>Sethoxydim</td>
<td>Poast</td>
<td>8.39 (6)</td>
<td>15.03</td>
<td>41.89</td>
<td>0.036</td>
</tr>
<tr>
<td>Simazine</td>
<td>Princep</td>
<td>0.84 (24)</td>
<td>0.88</td>
<td>3.67</td>
<td>0.069</td>
</tr>
<tr>
<td>Trifluralin (b)</td>
<td>Treflan</td>
<td>0.08 (47)</td>
<td>0.11</td>
<td>0.54</td>
<td>0.120</td>
</tr>
<tr>
<td>2,4-D (c)</td>
<td>-</td>
<td>0.50 (43)</td>
<td>0.99</td>
<td>4.74</td>
<td>0.106</td>
</tr>
</tbody>
</table>

a = sample size (N) used to compute mean and standard deviation is indicated in parenthesis.
b = herbicides/insecticides used in the Nomini Creek watershed.

A total of 6 insecticides, carbaryl, carbofuran, disulfoton, flauzifop-butyl, malathion, and sethoxydim were detected at various concentration levels in wells sampled. Carbaryl, carbofuran, and malathion were detected at frequencies of 4.9, 11.6, and 7.9 percent, respectively (Table 1). The frequencies of detection of these insecticides are low, considering their rate of application in the watershed. The maximum concentration levels of carbaryl, carbofuran, and malathion were 1.22 ppb, 3.67 ppb, and 3.12 ppb, respectively (Table 1). The other insecticides, disulfoton, flauzifop-butyl, and sethoxydim had 2.6, 3.0, and 3.6 percent frequencies of detection, respectively. These insecticides are known to have relatively moderate to high adsorption characteristics indicating that, under normal farming practices, it is unlikely that they would leach by matrix flow to the groundwater. Flauzifop-butyl was detected above its detection limit in three of the wells sampled. Concentrations were 20.32, 14.56, and 31.62 ppb in wells GN3, GN7, and GN8, respectively. These concentrations were obtained in groundwater samples taken in December 1986 (for GN7 and GN8) and February 1987 (for GN3). A plausible explanation for this one time detection of flauzifop-butyl may be the effects of preferential flow. Preferential movement of water and soluble chemicals through large pores (e.g., decayed plant roots) could bypass soil matrix and, therefore, reach groundwater in a short period of time.

Most of the wells in which atrazine was detected had less than 0.25 ppb concentrations (Figure 2). Less than 2 percent of the samples contained atrazine at levels greater than the EPA proposed health advisory level (HAL) of 3 ppb (U.S. EPA, 1986). One of the wells samples had a concentration of atrazine of 25.56 ppb. The second largest concentration of atrazine in any one well was 4.47 ppb. Thus, the observed concentration of atrazine of 25.56 ppb could be attributed to point sources of pollution and/or lack of well head protection.
The temporal variation of pesticide concentrations was also examined. Pesticides were detected in samples collected throughout the year. The percentage of samples with a pesticide detection on a month-by-month basis is shown in Figure 3. The months of May and December, followed by June and November were the most likely time to detect pesticides in groundwater. Only few detections were observed during the period from January through April. The time of detection may be dependent on the time of pesticide application, rainfall pattern and intensity, and cropping practices (e.g., crop rotation, tillage method). Preplant herbicides are applied before crop emergence and may be incorporated into the soil. Post-emergent treatments are applied after the crop has emerged and when weeds are at or near emergence. Snowmelt and spring rainfall occurs before chemical application, so the presence of the herbicides in March and April represents residual concentrations that have been leached through the soil from previous months. In general, pesticides were detected in about 10 percent of the samples collected during the months of November and December.

Low evapotranspiration rate, coupled with time lag in chemical movement, may be the reason for pesticide detection in these months. When the pesticide data are separated in terms of their usage (insect and weed control), the results are not surprising. Most of the herbicides were detected in May following their application to no-till soybeans fields. Other herbicides persisted throughout the year; however, their frequencies of detection were much less than for insecticides. In general, the temporal concentration patterns

Figure 2. Frequency of atrazine detections in specified concentration ranges.

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Pesticide contamination of groundwater 385
of pesticides in groundwater appear to be dependent upon the rate of groundwater recharge, pesticide application cycles resulting from crop rotation, and the season of the year.

PESTICIDE DETECTION BY MONTHS
1986 - 1991

Due to the low detection frequency of the pesticides analyzed, only detected pesticide concentrations were included in the statistical analysis. Only atrazine, metribuzin, and trifluralin had enough detected samples to conduct meaningful statistical tests. The Kruskal-Wallis test was run on the atrazine, metribuzin, and trifluralin detected concentrations to determine whether concentrations of pesticides differ significantly among wells. None of these pesticides analyzed indicated a significant difference at the 0.05 level among any of the wells. Therefore, there is no clear indication of site effects on the concentration of the pesticides. The Wilcoxon rank sum test was run on the detected samples of pesticide concentrations to determine whether concentrations of pesticides differed significantly between upgradient and downgradient wells. No statistically significant difference at the 0.05 level between the two well locations was observed, despite visual observation of sampling results pointing to the contrary. The results of the statistical analyses may be biased due to the small sample size used. It is, however, important to point out that the high concentrations of some pesticides in downgradient wells indicate that lateral flow is the primary mode of transport after the leachate reaches the groundwater.

The effects of landuse on pesticide concentrations in groundwater were also examined by grouping the 8 wells into two land use categories (no-till and conventional tillage) and then comparing the corresponding concentrations between categories. The Wilcoxon rank sum test was run on the pesticide data to determine whether groundwater concentrations of pesticides differed significantly between wells located in no-till and conventional tillage fields. Detected concentrations of the pesticides were examined and concentrations of the 3 pesticides were found not to be significantly different at the 0.05 level. The Kruskal-Wallis test was run on the detected samples of atrazine to determine whether the concentration of atrazine differs significantly during various growing seasons. A significant difference among crop and crop residue was detected at the 0.05 level. Atrazine concentrations were lowest under small grains and highest under soybean residue and corn. The lowest percent of detections of atrazine also occurred during the growing seasons of
small grains. Significant differences among crop covers could not be compared for the other pesticides because of the small sample size of detected concentrations.

The effect of BMP implementation on the occurrence of selected pesticides in groundwater is shown in Table 2. Data are given for the five most commonly detected pesticides in the groundwater at Nomini Creek. The results indicate that BMPs were quite effective in reducing both the frequency of detection and peak concentrations for most pesticides. The frequency of atrazine detection, the most commonly detected pesticide in the watershed, was reduced from 28.1 to 22 percent due to BMP implementation. In addition, the percentage of samples with atrazine concentrations in excess of Health Advisory Limits (3 ppb) was reduced from 2 percent during the pre-BMP phase to less than 0.5 percent for the post-BMP period. While the percentage of samples in which metolachlor was detected increased from 9 to 14, its peak concentration was reduced by a factor of two as a result of BMP implementation. The most dramatic improvement, in terms of reductions in the frequency of occurrence, was observed for metribuzin as indicated in Table 2.

Agricultural use of pesticides is contributing to groundwater contamination in the Nomini Creek Watershed. It should be noted, however, that pesticide concentrations detected in groundwater underlying the watershed were generally below the levels assumed to contribute to chronic health problems to humans.

Table 2. Effect of BMP implementation on the occurrence of selected pesticide in groundwater at Nomini Creek Watershed.

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Pre BMP</th>
<th>Post BMP</th>
<th>Pre BMP</th>
<th>Post BMP</th>
<th>Pre BMP</th>
<th>Post BMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrazine</td>
<td>28</td>
<td>22</td>
<td>25.56</td>
<td>4.47</td>
<td>2.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Metolachlor</td>
<td>9</td>
<td>14</td>
<td>2.86</td>
<td>1.48</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Alachlor</td>
<td>11</td>
<td>11</td>
<td>0.18</td>
<td>0.44</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Metribuzin</td>
<td>20</td>
<td>5</td>
<td>2.73</td>
<td>1.24</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>15</td>
<td>7</td>
<td>0.54</td>
<td>0.37</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Eight wells located in predominantly agricultural areas were used to monitor the quality of groundwater beneath the watershed. A total of 20 pesticides were detected in samples collected between June 1986 and December 1991. Atrazine was the most prevalent pesticide with concentrations ranging from 0.03 to 25.56 ppb detected in 25.7 percent of the samples. Other pesticides were detected at frequencies ranging from 1.6 to 14.2 percent and concentrations ranging from 0.01 to 41.89 ppb. Simazine was detected at concentrations in the range of 0.06 to 3.67 ppb, although there is no record of its use in the watershed. Ongoing data collection during the post-BMP phase of the project will provide more definitive relationships between pesticide concentrations in groundwater and land use, hydrologic variables, and cultural practices.

Statistical analysis of the data indicated no significant differences between pesticide concentrations in groundwater and well locations or tillage practices. Statistical analysis of the atrazine data indicates that concentrations of atrazine are generally lower when fields are planted in small grains as opposed to corn or soybean crops. In general, however, pesticides were detected in samples collected throughout the sampling period. Samples collected in late spring and late fall contained pesticides more frequently than other samples. The BMPs are quite effective in reducing the frequency of occurrence and peak concentrations of
pesticides in groundwater. Agricultural use of pesticides is contributing to groundwater contamination in the Nomini Creek watershed. It should be noted, however, that pesticide concentrations detected in groundwater underlying the watershed were generally below the levels assumed to contribute to chronic health problems to humans.

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REFERENCES


