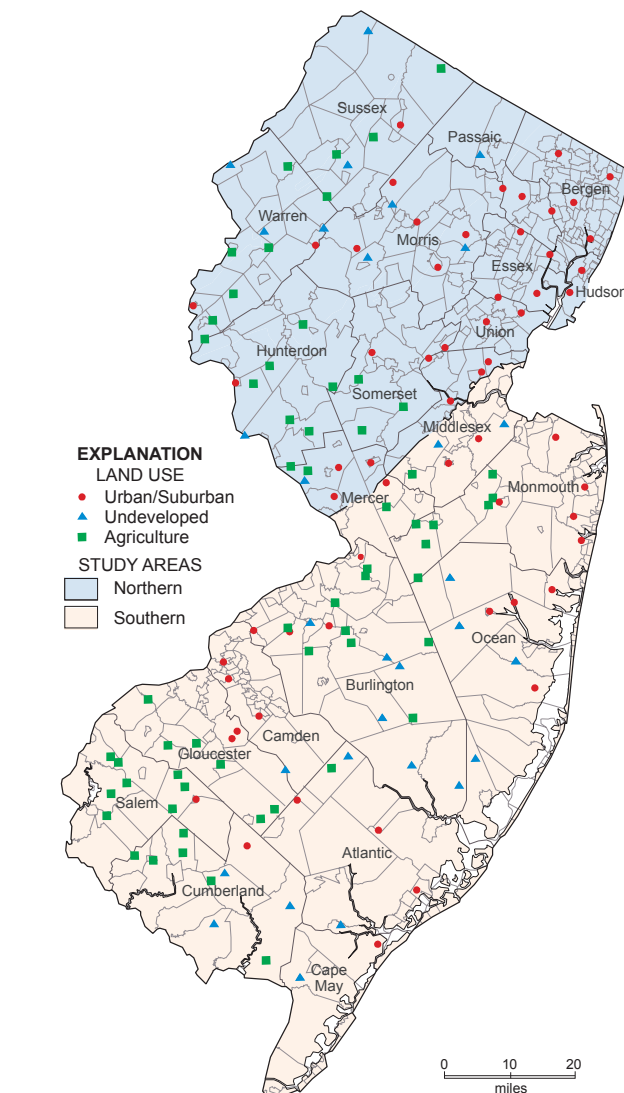# New Jersey Ambient Ground Water Quality Monitoring Network:
New Jersey Shallow Ground-Water Quality, 1999 - 2008

Introduction

The State of New Jersey has a large population and diversified land use. The State's streams, lakes, ponds, bays, ocean and groundwater are affected to varying degrees by point and non-point sources of contamination. To understand and properly manage the quality of water in the State, effective monitoring programs are needed. One such program is the New Jersey Ambient Ground Water Quality Monitoring Network (NJAGWQMN).

The NJAGWQMN is comprised of 150 wells (fig. 1) and is a cooperative project of the New Jersey Department of Environmental Protection (NJDEP) and United States Geological Survey (USGS) that monitors and provides information about land-use-related non-point-source contaminant effects on shallow-ground-water quality in the State. This information is important because this water recharges deeper aquifers used for potable-water supplies and provides base flow to local streams and wetlands. Goals of the NJAGWQMN are to: (1) assess ground-water quality status, (2) assess ground-water quality trends, (3) evaluate contaminant sources, and (4) identify emerging water-quality issues by land use. The New Jersey Geological and Water Survey (NJGWS) is responsible for network design, well installation, well maintenance, collection of ground-water samples, data interpretation, and report preparation. The NJDEP Bureau of Fresh Water and Biological Monitoring and the USGS also collect ground-water samples; and the USGS National Water Quality Laboratory in Denver, Colorado analyzes them. Chemical and physical characteristics determined (or measured) in each well-water sample include: pH, specific conductivity, dissolved oxygen (DO), temperature, alkalinity, major ions, trace elements, nutrients, gross-alpha particle activity, volatile organic compounds (VOC), and pesticides.

Well sites were located using a stratified-random site selection process as outlined by Scott (1990). The final number of wells in each land use is: 60 in agricultural areas, 60 in urban/suburban areas and 30 in undeveloped areas. Land-use designations were determined using 1986 and 1995 land-use GIS coverages,

Figure 1. Location of Ambient Ground Water Quality Monitoring Network monitoring wells in New Jersey based on land use.

1995 aerial photographs and site visits. Ground-water-flow directions were estimated based on the local geologic framework and site-specific topographic controls. Network wells are screened, or open, just below the water table and the samples collected generally represent relatively young groundwater. Wells are sam-

pled, 30 per year, on a 5-year cycle. The first sampling cycle was completed between 1999 and 2003, and the second between 2004 and 2008. The water-quality data summarized here is based on these two complete sampling cycles.

While the data summarized below is of the first two sampling cycles, the third sampling cycle was completed in 2013. This new data set was checked for quality assurance and the results are being analyzed. The NJGWS plans to release the new data set and an updated report on the AGWQMN in the near future. Starting in 2014, the AGWQMN moved from a 5-year sampling cycle to a 3-year cycle. This increase in sampling frequency comes from an internal audit of the AGWQMN as part of its inclusion into the National Ground Water Monitoring Network.

Water-Quality Characteristics and Major Ions

To understand the general characteristics of shallow groundwater as it is controlled by geology and affected by land use, data on water-quality characteristics such as temperature, dissolved oxygen (DO), pH and total dissolved solid (TDS) are obtained. As described by Serfes and others, (2007), there are distinct differences in natural ground-water quality between southern and northern New Jersey. Southern New Jersey shallow groundwater has a more acidic pH and lower TDS levels, which reflects its coastal plain origin (fig. 2). Northern New Jersey groundwater has a more basic pH, due to the regional bedrock geology, and it has a lower temperature because of its higher latitude and generally higher altitude (fig. 3).
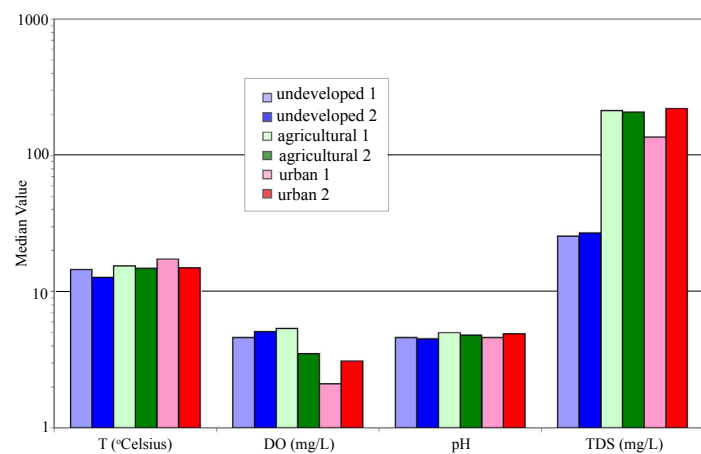
Figure 2. Physical characteristics of shallow groundwater in southern New Jersey based on land use and sampling cycle. (The numbers 1 and 2 in the key in this figure and in all subsequent figures refer to sampling cycle 1 and sampling cycle 2, respectively.)

Temperature and pH values were similar between the two sampling cycles within each region. Both sampling cycles show lower DO levels and higher TDS levels in urban land use areas as compared to undeveloped
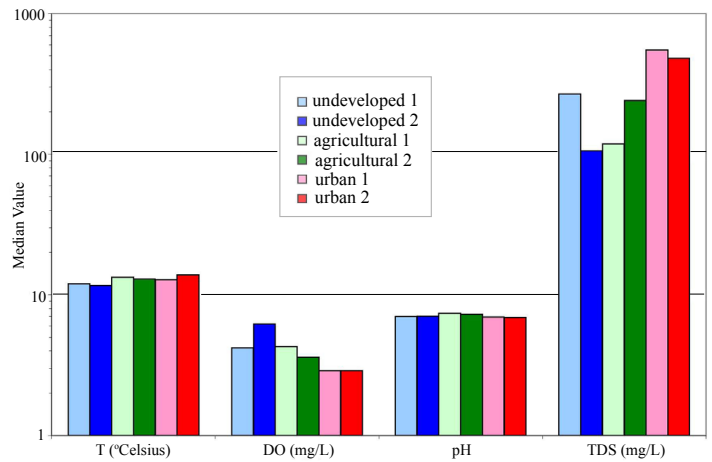

Figure 3. Physical characteristics of shallow groundwater in northern New Jersey based on land use and sampling cycle.

(natural) areas in both regions. In both southern and northern New Jersey, sampling cycle 1 showed similar levels of DO in agricultural and undeveloped land areas. However, in sampling cycle 2 DO concentrations in agricultural areas were below the levels in undeveloped areas. Lower DO levels in urban land use areas are most likely the result of the large proportion of impervious surface area. Such surfaces have high thermal conductivity and heat storage capacity. Higher surface temperatures retards oxygen exchange with the atmosphere and organic wastewater consumes free oxygen, both lowering the DO. In agricultural areas, the lower DO levels in shallow groundwater may be attributed to the proximity of the wells to road right-of-ways and the conversion of agricultural to urban land. Road salt, lawn care and agrochemical applications are the likely causes of higher TDS values in agricultural and urban land use areas.
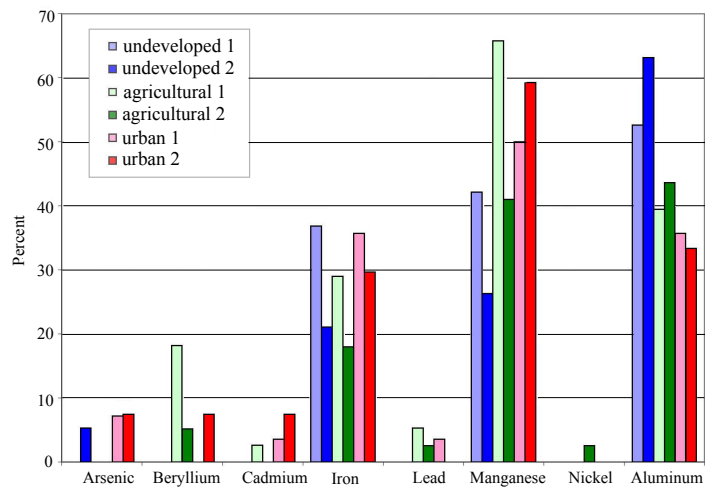
The NJAGWQMN analyzes for the following major ions: calcium, magnesium, sodium, potassium, chloride, sulfate, fluoride, and silica. Higher concentrations of major ions in northern New Jersey are a reflection of the regional geology. Such concentrations are higher in agricultural and urban areas than in undeveloped ones (figs. 4 and 5). As with TDS, this may be attributed to road salt, lawn supplements and agrochemicals. Sodium and chloride showed the largest increase in median concentration from sampling cycle 1 to 2 in southern New Jersey, whereas in northern New Jersey the median concentrations remained relatively the same. The increase in specific conductivity, sodium and chloride median concentrations in southern New Jersey has been shown in a study by the NJGWS (Bousenberry, 2007) to be from the application of road salt during the winter for deicing of roadways.
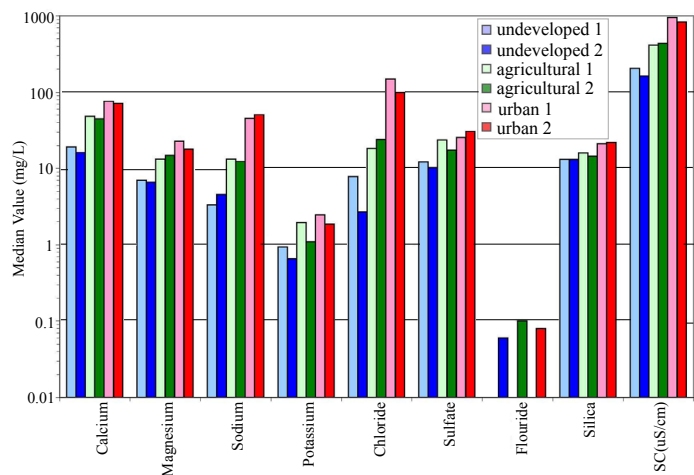
Trace Elements

Trace elements (metals) discussed here are those that exceeded the New Jersey Ground Water Standards (2010) at least once. In the coastal plain (southern New
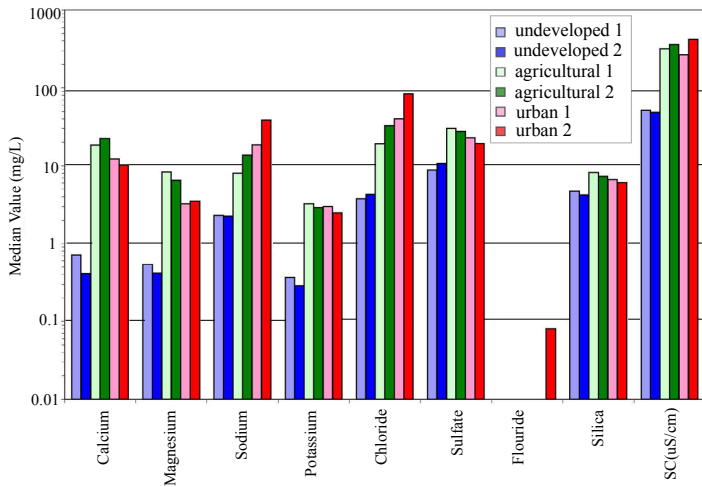
Figure 4. Major ions in shallow groundwater in southern New Jersey based on land use and sampling cycle.

Figure 5. Major ions in shallow groundwater in northern New Jersey based on land use and sampling cycle.

Figure 6. Percentage of trace elements in shallow groundwater in southern New Jersey that exceeded New Jersey Ground Water Quality Standards based on land use and sampling cycle.
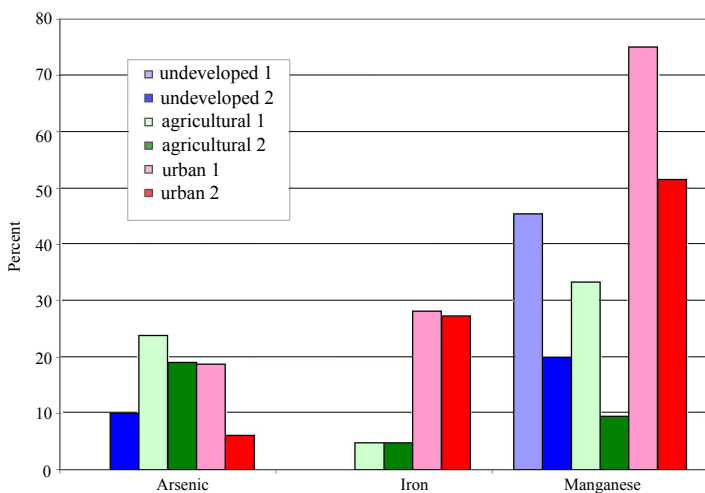
In the second round of sampling, one well located in undeveloped land use had an arsenic concentration of 3.3 µg/L. This concentration is slightly above the standard, attributable to a high degree of iron-oxide dissolution. During the same sampling cycle two wells located in urban land use yielded water with arsenic concentrations that had decreased from 112µg/L to 108 µg/L and 42µg/L to 21.9µg/L. The source of this arsenic is unknown.

Fertilizers, agrochemicals, and lawn care products may be the source or the mobilization agent for the beryllium, cadmium, lead, and nickel detected in the shallow groundwater of the coastal plain (ATS-DR, 1992 and 2002).

Arsenic concentrations in northern New Jersey (fig. 7) are mostly natural in origin and the number of detections that exceeded the New Jersey Ground

Jersey), iron and aluminum are probably natural in origin (fig. 6). Manganese has an urban and agricultural land-use association. Acidic and reducing ground-water conditions mobilize iron, aluminum and manganese. The decrease in the number of wells with excessive concentrations of iron and aluminum in groundwater from urban areas may be attributed to the increase in DO concentrations in those wells. The decrease in excessive iron and manganese concentrations between sampling cycles in undeveloped and agricultural areas can not be attributed to a change in pH, which has remained steady. The decrease may be attributed to natural fluctuations, especially in groundwater in which concentrations in sampling cycle 1 were close to the standards. The increase in aluminum in agricultural groundwater in the second sampling cycle may result from a decline in dissolved oxygen concentrations. The increase of manganese in urban area groundwater may be due to an increase in the use of lawn chemicals that mobilize manganese.
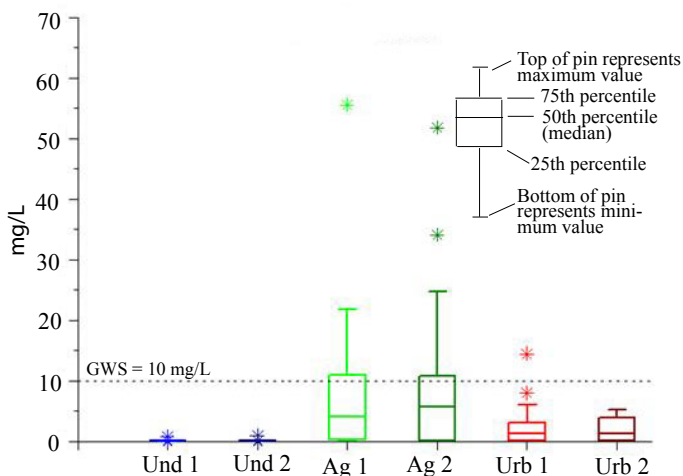

Figure 7. Percentage of trace elements in shallow groundwater in northern New Jersey that exceeded New Jersey Ground Water Quality Standards based on land use and sampling cycle.

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Water Standard declined in the later sampling cycle. One well that exceeded the arsenic standard for groundwater in undeveloped areas during the second sampling cycle had a concentration of 3.4 μg/L, which is slightly above the New Jersey Ground Water Standard of 3 μg/L.
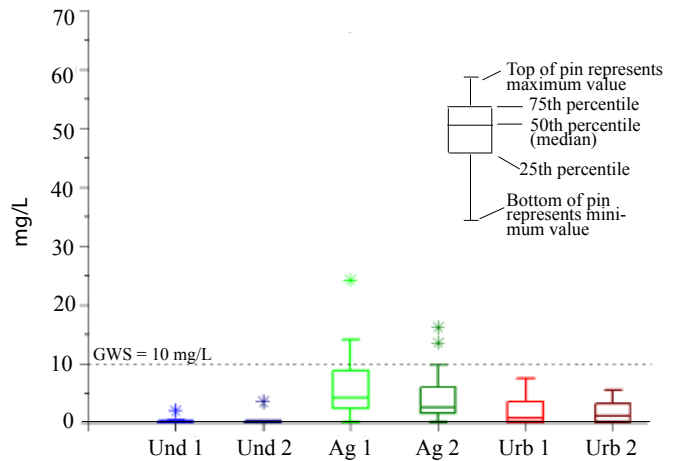
Iron and manganese concentrations exhibit a strong urban association and possibly a weak agricultural connection. The reducing conditions in agricultural and urban areas, indicated by the lower DO concentrations, promote iron and manganese mobility. The decrease in manganese concentrations exceeding the ground water standard in undeveloped land in northern New Jersey may result from the increase in DO concentrations. In urban and agricultural areas the pH remained fairly unchanged between sampling cycles, and is unrelated to the decrease in manganese concentrations. A decrease in the use of agrochemicals and/or lawn fertilizers may have caused the decrease in excessive manganese concentrations. Iron concentrations remained little changed between sampling cycles.

Nutrients

Agricultural and urban areas in southern and northern New Jersey have high concentrations of nutrients in groundwater in comparison to undeveloped areas (figs. 8 and 9). Nutrient concentrations are dominated by nitrate and are the result of nitrogen-based fertilizers, and possibly by leakage from septic and sewer systems. In both southern and northern New Jersey, no change in nitrite plus nitrate concentrations in undeveloped areas was observed between sampling cycles. Median concentrations increased slightly in urban areas. In southern New Jersey median concentrations in groundwater
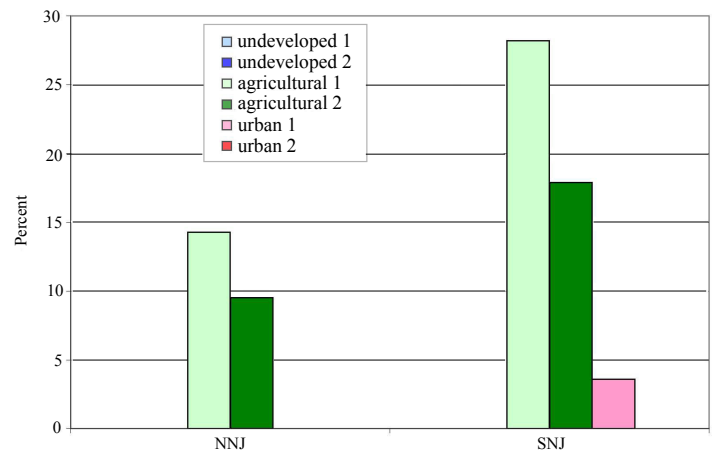

Figure 9. Box-and-pin diagram of nitrite plus nitrate concentrations in shallow groundwater in northern New Jersey based on land use and sampling cycle.

from agricultural areas increased between sampling cycles, whereas in northern New Jersey the median concentration in groundwater decreased. In both southern and northern New Jersey the number of wells yielding water that exceeded the New Jersey Ground Water Standard in agricultural and urban areas decreased (fig. 10).

Figure 10. Percentage of wells in New Jersey with nitrite plus nitrate concentrations in shallow groundwater that exceeded New Jersey Ground Water Quality Standards based on land use and sampling cycle.
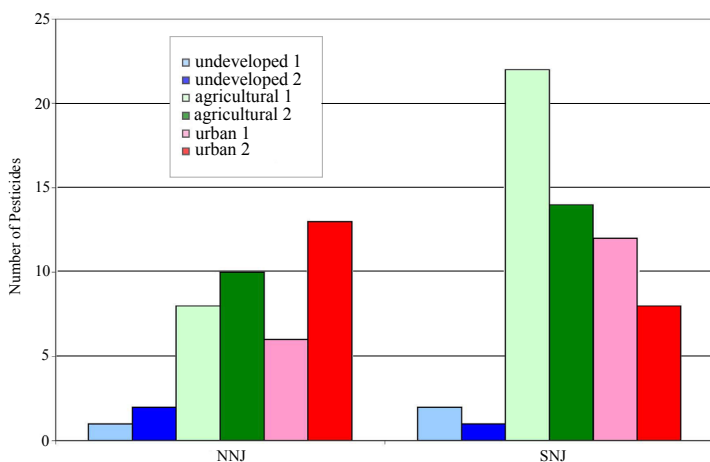
Pesticides

Statewide, urban and agricultural lands had the most wells with pesticide detections in both sampling cycles (fig. 11). In southern New Jersey the percentage in agricultural and urban land decreased between sampling cycles, whereas in undeveloped areas it remained the same. In northern New Jersey the percentage of detection of pesticides between sampling cycles increased in all land uses. In urban and undeveloped areas one additional well had a pesticide detection in sampling cycle 2, whereas 3 additional wells in agricultural areas

Figure 8. Box-and-pin diagram of nitrite plus nitrate concentrations in shallow groundwater in southern New Jersey based on land use and sampling cycle.
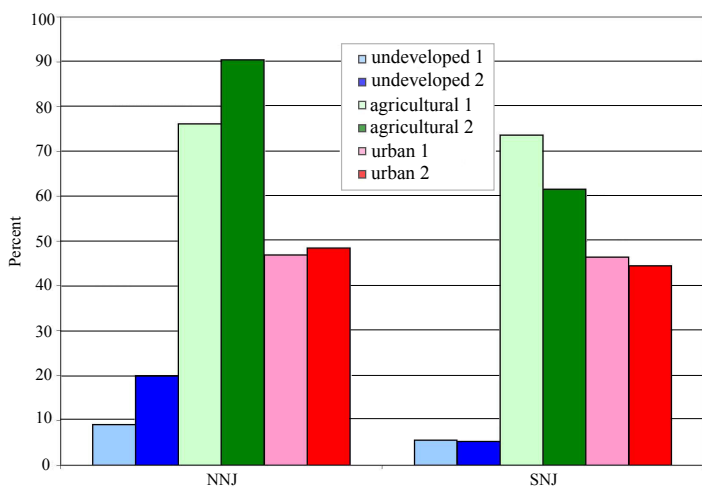
Figure 11. Percentage of wells in New Jersey with pesticide detections in shallow groundwater based on land use and sampling cycle.

had detected pesticides. The percentage of detection of pesticides in urban areas statewide remained unchanged between sampling cycles at 28 wells, while in undeveloped areas 1 additional well had a detectable pesticide, whereas agricultural areas had 1 fewer. The variety of pesticides detected in southern and northern New Jersey is highest in agricultural and urban areas in both sampling cycles, as expected (fig. 12). The variety of pesticides detected between sampling cycles decreased in southern New Jersey, whereas in the north it increased.
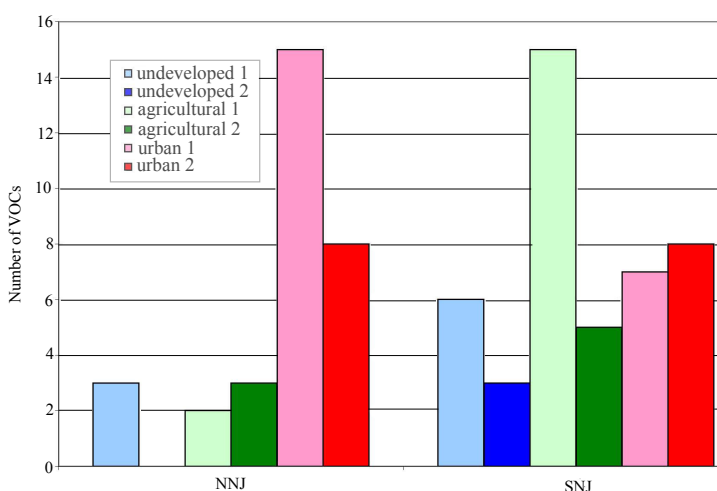

Figure 12. Pesticide compounds detected in shallow groundwater in New Jersey based on land use and sampling cycle.

In 2007, the pesticide sampling schedule was changed to incorporate more degradation by-products. During this change, most of the samples collected were in northern New Jersey. This may account for the increase in the percentage and the variety of pesticides detected. The most common compounds statewide, as well in both sampling cycles were: atrazine, deethylatrazine, metolachlor, prometon and simazine. These compounds

are all herbicides that are used to control grasses and broad-leaf plants, except for deethylatrazine which is the major metabolite of atrazine.

Volatile Organic Compounds (VOC)

A statewide decrease in the occurrence of VOC detected in ground water was observed in all areas. An overall decrease between sampling cycles of the variety of VOC compounds detected was observed in both southern and northern New Jersey (fig. 13). In southern New Jersey, 16 compounds were detected in sampling cycle 2 as compared to 28 compounds in sampling cycle 1. Northern New Jersey decreased from 20 specific compounds in sampling cycle 1 to 10 compounds in sampling cycle 2.


Figure 13. Volatile Organic Compounds detected in shallow groundwater in New Jersey based on land use and sampling cycle.

In agricultural and undeveloped areas in southern New Jersey, the percentage of detection decreased (fig. 14). Urban areas in southern New Jersey showed an increase as a percentage, but remained constant at 17 wells. The percentage increase is due to the fact that 1 urban well was replaced, and its new location is not in the coastal plain. Eleven of the 12 monitoring wells in undeveloped areas in southern New Jersey had a detectable concentration of chloroform in sampling cycle 2. This may be attributed to natural and anthropogenic origins. Chloroform has been found to be produced by soil fungi and termites (Hoekstra et al., 1998). Anthropogenic origins are atmospheric deposition, septic systems, leaking sewers, and chlorinated drinking water used to water lawns and gardens, and to fill swimming pools. Sampling cycle 2 confirms the interpretation based on cycle 1 that the occurrence of VOC in groundwater results from land use practices in northern New Jersey. Most wells with detectable VOC were in urban and agricultural areas. Between sampling cycles in northern New Jersey the number of such wells in undeveloped and urban areas decreased, whereas in agricultural areas it remained constant at 3 wells (fig. 14).
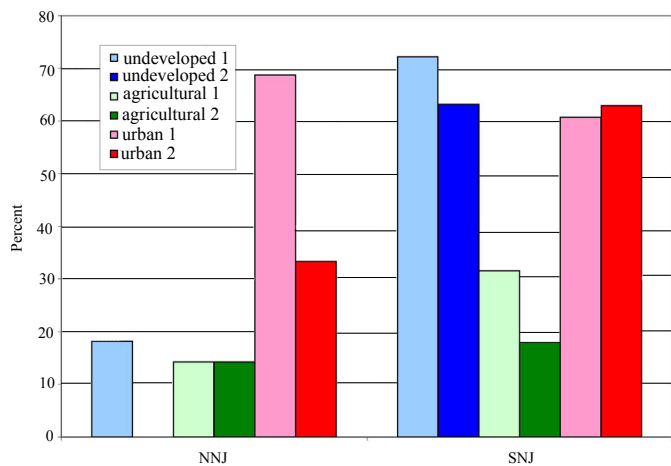
Figure 14. Percentage of wells in New Jersey with VOC detections in shallow groundwater based on land use and sampling cycle.

Methyl tertiarybutyl ether (MTBE), an additive in gasoline, showed a steep statewide decline in the percentage of detection in shallow groundwater (fig. 15). In southern New Jersey, urban and undeveloped areas showed a decrease in the occurrence of MTBE. Wells in agricultural areas were the exception to this general trend. During sampling cycle 1 they had a percentage of detection of 13 percent that increased to 15 percent in sampling cycle 2; an increase from 5 to 6 wells. In undeveloped-land wells, the percentage decreased from 6 percent to 0 percent and in urban areas it dropped from 43 percent to 30 percent. During the first round of sampling in northern New Jersey, 50 percent of the urban wells, 14 percent of agricultural wells, and 9 percent of the wells in undeveloped land had detectable MTBE. In sampling cycle 2 there was no detectable MTBE in wells located in urban and undeveloped areas. Detectable MTBE declined from 3 wells to 1 well at the same time in agricultural areas. The decrease of MTBE in shallow groundwater is attributed to a ban on using MTBE in the State of New Jersey. In 2005 the State passed legislation
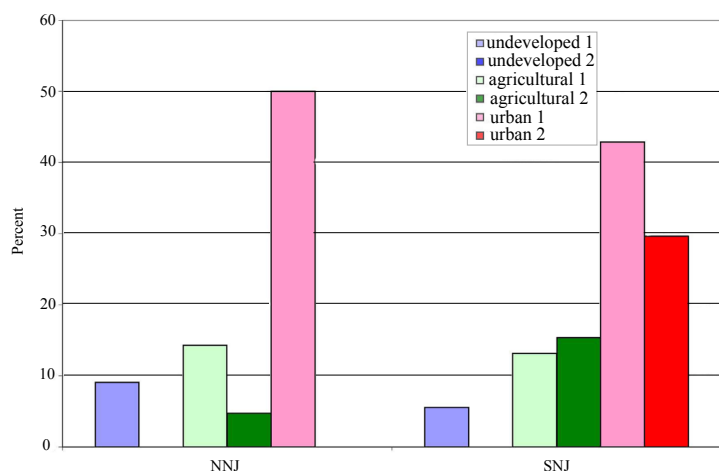

Figure 15. Percentage of wells with MTBE detections in shallow groundwater in New Jersey based on land use and sampling cycle.

banning use of MTBE in gasoline by 2009. Southern New Jersey had more detectable MTBE than northern New Jersey in sampling cycle 2, most likely due to atmospheric deposition, because the predominant wind patterns are from the west.

Radioactivity

Gross alpha-particle radiation was generally higher in southern than in northern New Jersey (figs. 16 &17) in sampling cycles 1 and 2. This is most likely due to the greater abundance of radium-224 in southern New Jersey and the low groundwater pH which increases radium's mobility. In both sampling cycles throughout the State the highest radium activity was in agricultural and urban areas. More radium is mobilized in these areas because agricultural and lawn-care chemicals compete
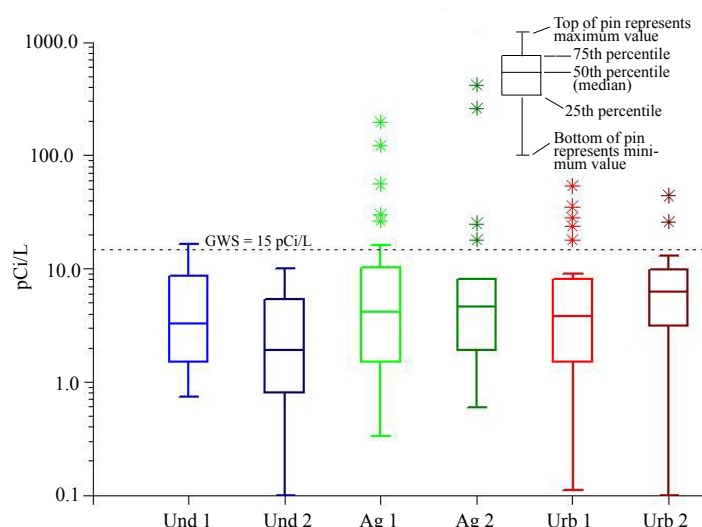
Figure 16. Box-and-pin diagram of gross alpha radiation concentrations in shallow groundwater in southern New Jersey based on land use and sampling cycle.
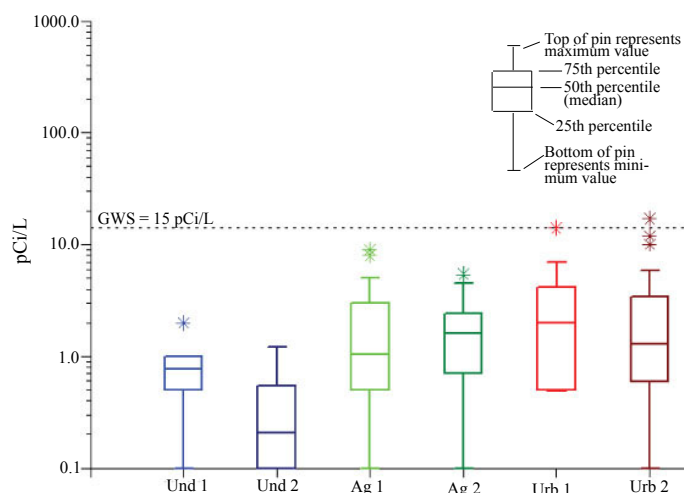
Figure 17. Box-and-pin diagram of gross alpha radiation concentrations in shallow groundwater in northern New Jersey based on land use and sampling cycle.

with radium for adsorption sites. In southern New Jersey agricultural and urban wells showed an increase in median gross alpha concentrations, and a decrease in undeveloped land areas. In northern New Jersey the median gross-alpha value decreased in undeveloped and urban areas between sampling cycles. In agricultural areas the median concentration increased slightly.

Summary

In both sampling cycles, in agricultural and urban areas, total dissolved solids concentrations, as well as the concentration, percentage, and variety of major ions, trace elements, nutrients, volatile organic compounds, and pesticides are higher than in undeveloped areas. Although nitrite plus nitrate median concentrations in shallow groundwater fluctuated slightly in urban and agricultural areas between sampling cycles, they were nevertheless higher than those in undeveloped areas. The highest concentration and percentage of detection was in agricultural areas. The number of wells that exceed the nitrite plus nitrate New Jersey Ground Water Standard decreased between sampling cycles statewide. At the same time the variety and abundance of pesticides decreased in southern New Jersey, whereas in northern New Jersey they increased. This increase may be attributed to an augmented sampling schedule which included more compounds and metabolites. Pesticide concentrations remained mostly unchanged between sampling cycles. Atrazine, deethylatrazine, metolachlor, prometon, and simazine were the most common pesticides in southern and northern New Jersey in both sampling cycles. The variety and abundance of VOCs in southern and northern New Jersey decreased between sampling periods, whereas their concentrations remained fairly unchanged. MTBE (methyl tertiarybutyl ether) showed the steepest decline in percentage of detection statewide. Increased use of agrochemicals and lawn chemicals may be attributed to the increased radioactivity between sampling cycles. Although there seem to be some trends between sampling cycles in southern and northern New Jersey, two sampling cycles are not enough to establish long-term trends.

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