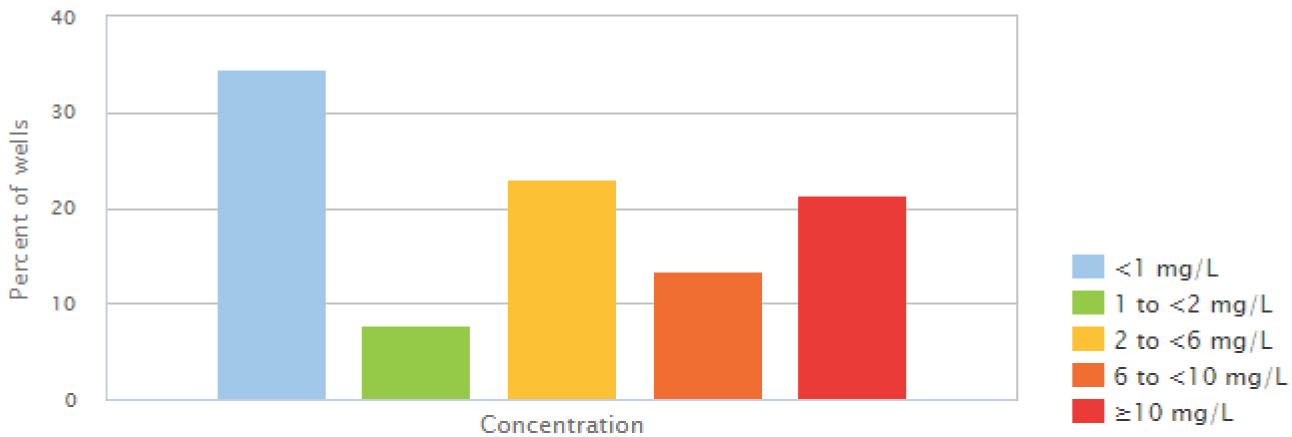
Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds

Exhibits

Exhibit 1. Nitrate in shallow ground water in agricultural watersheds of the contiguous U.S., 1992–2003



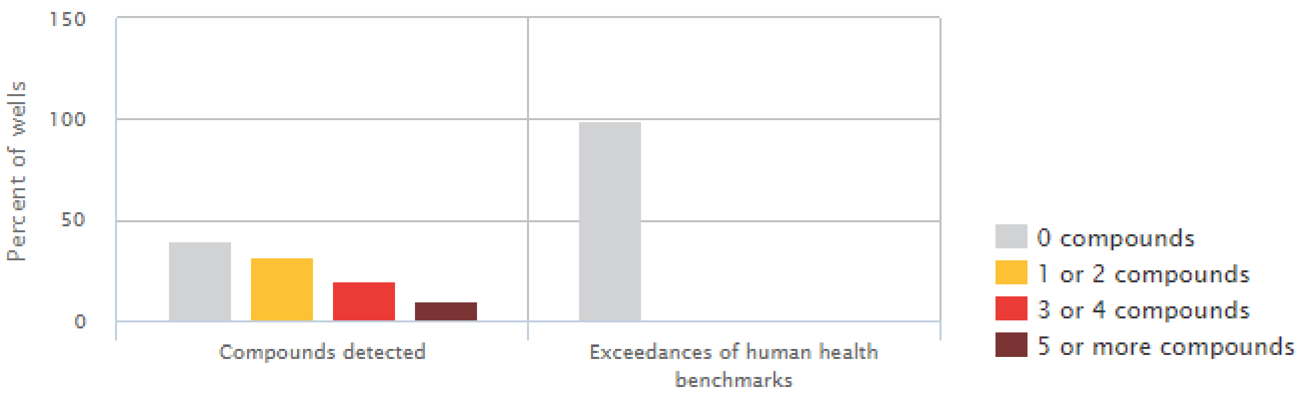
Coverage: 1,423 shallow wells in watersheds in which agriculture is the predominant land use. These watersheds are within 34 major river basins and aquifer regions studied by the USGS NAWQA Program.

EPA's drinking water standard for nitrate is a Maximum Contaminant Level (MCL) of 10 mg/L.

Trend analysis has not been conducted because these data represent one cycle of sampling. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: USGS, 2007a

Exhibit 2. Pesticides in shallow ground water in agricultural watersheds of the contiguous U.S., 1993-2003



Coverage: 1,412 shallow wells in watersheds where agriculture is the predominant land use. These watersheds are within 34 major river basins and aquifer regions studied by the USGS NAWQA program.

Samples were analyzed for 75 pesticides and eight pesticide degradation products. No wells exceeded benchmarks for more than one compound.

Trend analysis has not been conducted because these data represent one cycle of sampling. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: Gilliom et al., 2007

Introduction

Nitrogen is a critical plant nutrient, and most nitrogen is used and reused by plants within an ecosystem (Vitousek et al., 2002), so in undisturbed ecosystems minimal "leakage" occurs into ground water, and concentrations are very low. When nitrogen fertilizers are applied in amounts greater than can be incorporated into crops or lost to the atmosphere, however, nitrate concentrations in ground water can increase. Elevated nitrogen levels in ground water also might result from disposal of animal waste or onsite septic systems. Nitrate contamination in shallow ground water raises potential concerns for human health where untreated shallow ground water is used for domestic water supply. High nitrate concentrations in drinking water pose a risk for methemoglobinemia, a condition that interferes with oxygen transport in the blood of infants.

More than a billion pounds of pesticides (measured as pounds of active ingredient) are used in the U.S. each year to control weeds, insects, and other organisms that threaten or undermine human activities. About 80 percent of this total is used for agricultural purposes (U.S. EPA, 2011). Although pesticide use has resulted in increased crop production and other benefits, pesticide contamination of ground water poses potential risks to human health if contaminated ground water is used as a drinking water source—especially if untreated.

This indicator reports on the occurrence of nitrate and pesticides in shallow ground water in watersheds where agriculture is the primary land use, according to criteria outlined in Gilliom et al. (2007). Ground water samples were collected by the U.S. Geological Survey's (USGS's) National Water Quality Assessment (NAWQA) program from 1992 to 2003 (pesticide sampling began in 1993). NAWQA surveyed 51 major river basins and aquifer regions across the contiguous United States during this period; the agricultural watersheds sampled were within 34 of these study units. Although agriculture is more prevalent in some parts of the country than in others, the watersheds were chosen to reflect a broad range of hydrogeologic conditions and agricultural activities. Ground water samples were collected from existing household wells where possible and new observation wells otherwise, all targeted at the uppermost aquifer and avoiding locations where ground water condition could be biased by point sources (e.g., directly downgradient from a septic system). Most of the wells sampled ground water from less than 20 feet below the water table, indicating as directly as possible the influence of land use on shallow ground water quality. To the extent feasible, the wells were intended to sample recently recharged water. Data analyses were based on one sample per well. Related indicators report concentrations of nutrients and pesticides in streams that drain agricultural watersheds (see the N and P in Agricultural Streams indicator and the Pesticides in Agricultural Streams indicator).

The nitrate component of this indicator represents 1,423 wells. Results are compared with the federal drinking water standard of 10 mg/L, which is EPA's Maximum Contaminant Level (MCL) to prevent methemoglobinemia (U.S. EPA, 2006). MCLs are enforceable standards representing the highest level of a contaminant that is allowed in finished drinking water. MCLs take into account cost and best available treatment technology, but are set as close as possible to the level of the contaminant below which there is no known or expected risk to health, allowing for a margin of safety.

Data on 75 pesticides and eight pesticide degradation products were collected from 1,412 of the wells in the NAWQA study. These 83 chemicals account for approximately 78 percent of the total agricultural pesticide application in the United States by weight during the study period (Gilliom et al., 2007). Three types of U.S. EPA human health-related standards and guidelines were used to evaluate pesticide data: Maximum Contaminant Levels (MCLs) (as described above), Cancer Risk Concentrations (CRCs), and Lifetime Health Advisories (HA-Ls). In all three cases, the standard and guideline levels are concentrations pertaining to lifetime exposure through drinking water. The CRC is a guideline for potential carcinogens associated with a specified cancer risk of 1 in 1,000,000, based on drinking water exposure over a 70-year lifetime. The HA-L is an advisory guideline for drinking water exposure over a 70-year lifetime, considering non-carcinogenic adverse health effects. Specific standards and guidelines used for this indicator are listed in Gilliom et al. (2007), and additional information on these types of benchmarks, their derivation, and their underlying assumptions is provided in Nowell and Resek (1994). For this indicator, if a chemical had multiple benchmarks, the MCL took precedence; if no MCL was available, the lower of the CRC (at 1 in 1,000,000 cancer risk) and HA-L values was selected. An exceedance was identified if the concentration of a contaminant exceeded the relevant standard or guideline (Gilliom et al., 2007).

What The Data Show

During the study period:

- Nitrate concentrations were 2 mg/L or above in 58 percent of wells sampled in areas where agriculture is the primary land use (Exhibit 1). By comparison, background nitrate levels in areas with little human influence are generally expected to be below 1 mg/L (Nolan and Hitt, 2002), which suggests that more than half of the ground water sampled has been influenced by human sources of nitrate.
- Nitrate concentrations in about 21 percent of the wells exceeded the federal drinking water standard (10 mg/L).
- About 60 percent of wells in agricultural watersheds had a least one detectable pesticide compound, and 9.5 percent had detectable levels of five or more pesticides (Exhibit 2). Roughly 1 percent of wells had pesticides present at concentrations exceeding human health benchmarks.

Limitations

- These data only represent conditions in agricultural watersheds within 34 of the major river basins and aquifer regions sampled by the NAWQA program from 1992 to 2003. Although sample wells were chosen randomly within each agricultural watershed, the watersheds and aquifers themselves were selected through a targeted sample design. The data also are highly aggregated and should only be interpreted as an indication of national patterns; thus this indicator does not attempt to portray regional differences.
- This indicator does not provide information about trends over time, as the NAWQA program has completed only one full sampling cycle to date. Completion of the next round of sampling will allow trend analysis, using the data presented here as a baseline.
- Drinking water standards or guidelines do not exist for 43 percent (36 of 83) of the pesticides and pesticide degradation products analyzed. Current standards and guidelines also do not account for mixtures of pesticide chemicals and seasonal pulses of high concentrations. Possible pesticide effects on reproductive, nervous, and immune systems, as well as on chemically sensitive individuals, are not yet well understood.
- This indicator does not provide information on the magnitude of pesticide concentrations, only whether they exceed or fall below benchmarks. It also does not describe the extent to which they exceed or fall below other reference points (e.g., Maximum Contaminant Level Goals [MCLGs] for drinking water).

Data Sources

Summary data for this indicator were provided by USGS's NAWQA program. Nitrate data have not yet been published and were provided directly by USGS (2007a); however, concentration data from individual sample sites are publicly available through NAWQA's online data warehouse (USGS, 2007b). Pesticide occurrence and exceedances were determined from individual site results in Appendix 6 of Gilliom et al. (2007) (http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/).

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Technical Documentation

Identification

1. Indicator Title

   Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds

2. ROE Question(s) This Indicator Helps to Answer

   What are the trends in the extent and condition of ground water and their effects on human health and the environment?

3. Indicator Abstract

   This indicator reports on the levels of nitrate and pesticides in shallow ground water in predominantly agricultural watersheds between 1992 and 2003. This information provides some understanding of the condition of ground water and how it may be affected by human activities.

4. Most Recent Update

   05/2008

Data Sources

5. Data Sources

   This indicator is based on ground water samples collected by the U.S. Geological Survey's (USGS's) National Water Quality Assessment (NAWQA) program.

6. Data Availability

   Summary data for this indicator were provided by USGS's NAWQA program. Summary nitrate data have not yet been published and were provided directly by USGS; however, concentration data from individual sample sites are publicly available through the NAWQA database (https://www2.usgs.gov/science/cite-view.php?cite=1171) or through USGS's general water quality database (http://waterdata.usgs.gov/nwis/qw).

   The full pesticide data set is available at http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/ (Appendix 6 of Gilliom et al., 2007). This indicator reports on the subset of sites with a land use classified as "agricultural."

Methodology

7. Data Collection

This indicator is based on measurements of nitrate and pesticide concentrations in samples of shallow ground water.

Survey Design

The data for this indicator were collected between 1992 and 2003 (nitrate analysis began in 1992; pesticide sampling began in 1993) as part of the NAWQA program, which set out to examine 51 study areas (i.e., major river basins and aquifer regions) across the contiguous 48 states. This program was specifically designed to watersheds and aquifers associated with a variety of land uses and hydrogeologic settings. NAWQA's overall sample design represents a comprehensive effort to assess the nation's water quality through study units spread across the contiguous 48 states, as shown in the map on NAWQA's Web site (http://water.usgs.gov/nawqa/).

This indicator reports chemical concentrations in ground water in watersheds where agriculture was considered the primary land use, according to a standard set of criteria described in Table 3-1 of Gilliom et al. (2007) (http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/table_3_01.html). "Agricultural" watersheds are those that are more than 50 percent cropland or pasture and no more than 5 percent urban. Classifications were based on the National Land Cover Dataset (NLCD). Agricultural watersheds were sampled in 34 of the 51 study units; the other study units did not have any ground water samples that were representative of agricultural watersheds. NAWQA also sampled ground water in forested and urban areas, which can provide some useful context for the agricultural data. A full list of pesticide sampling sites and their land use classification can be found in Appendix 5 of Gilliom et al. (2007); a list of wells tested for nitrate can be obtained from USGS.

During the study period, ground water samples were collected from each study unit using existing household wells where possible (because of the expense of drilling new wells) and new observation wells otherwise. Samples for this indicator were deliberately collected at or near the top of the water table only (i.e., shallow wells) to ensure that the sample was representative of the ground water most likely to be consumed by humans who use private wells. This was appropriate as the purpose of this indicator is to evaluate potential risks to human health. However, sampling did not specifically target aquifers used as drinking water sources, or target sensitive populations such as infants (for whom high nitrate concentrations can lead to a condition called methemoglobinemia, or "blue baby" syndrome) or people who are particularly susceptible to pesticide contamination.

In collecting samples, NAWQA avoided locations where ground water condition could be biased by point sources (e.g., directly downgradient from a septic system). NAWQA also did not consider data from springs, drains, wells that were too close to other wells, and other locations that might taint or bias the overall result (see explanation at http://water.usgs.gov/nawqa/nutrients/datasets/nutconc2000/). Most of the wells sampled ground water from less than 20 feet below the water table, indicating as directly as possible the influence of land use on shallow ground water quality. To the extent feasible, the wells were intended to sample recently recharged water. Although sample wells were chosen randomly within each watershed, the watersheds and aquifers themselves were selected through a targeted sample design.

This indicator is based on samples from 1,423 wells analyzed for nitrate and 1,412 wells for pesticides. Data analyses were based on one sample per well. This is considered a scientifically valid way to assess ground water conditions because conditions in ground water are relatively stable (i.e., slow flow, slow dispersion), and changes in ground water chemistry occur on a relatively slow timescale. Thus, even one sample should be sufficient for comparison with guidelines for prolonged exposure (Gilliom et al., 2007). NAWQA is currently working on a design to better relate individual well water samples to regional patterns of contamination, but these data are not currently available.

Because of NAWQA's scientific sampling design, results are considered to be fairly representative of conditions in agricultural watersheds nationwide. Gilliom et al. (1995) provide an official description of the sample design.

Sample Collection

All NAWQA ground water sampling procedures are documented in official USGS reports. Lapham et al. (1995) document official procedures for establishing well sites. Koterba et al. (1995) discuss sample collection and preservation, while Koterba (1998) describes procedures for obtaining ancillary data at each well site, including information about the location of the well screen relative to the water table.

Sample Analysis

Samples were analyzed for nitrate, 75 pesticides, and eight pesticide degradation products using a variety of laboratory methods. For each chemical, NAWQA used the laboratory method that has been shown to be most sensitive and accurate. NAWQA measured nitrate concentrations using procedures described in Fishman (1993). Pesticide concentrations were measured using two primary laboratory methods: gas chromatography/mass spectrometry (GC/MS) (Zaugg et al., 1995) and high-performance liquid chromatography (HPLC) (Werner et al., 1996). Appendix 1 of Gilliom et al. (2007) (http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix1/) provides a list of the 75 pesticides and eight related degradation products for which NAWQA analyzed samples, along with compound-specific laboratory methods and detection limits.

8. Indicator Derivation

This indicator reports nitrate concentrations in ground water, the number of pesticides detected in ground water, and the percentage of cases in which observed pesticide concentrations exceeded a standard or guideline for the protection of human health. These standards and guidelines have all been determined scientifically by EPA. Standards were available for 47 of the 83 pesticide analytes.

Three types of U.S. EPA human health-related standards and guidelines were used to evaluate pesticide data: Maximum Contaminant Levels (MCLs), 106 Cancer Risk Concentrations (CRCs) (1 in 1,000,000 cancer risk), and Lifetime Health Advisories (HA-Ls). In all three cases, the standard and guideline levels are concentrations pertaining to lifetime exposure through drinking water. For this indicator, if a chemical had multiple benchmarks, the MCL took precedence; if no MCL was available, the lower of the CRC and HA-L values was selected for comparison. An exceedance was identified if the observed concentration of a contaminant exceeded the relevant standard or guideline.

For more information on how concentrations were compared against the appropriate human health standards and guidelines where available, see Gilliom et al. (2007).

9. Quality Assurance and Quality Control

USGS has many procedures in place to ensure the quality of its data. NAWQA provides several references that describe quality assessment/quality control (QA/QC) procedures for the collection and analysis of ground water samples. Martin (1999) discusses field and laboratory protocols such as field blanks and replicates. NAWQA also discusses how and why certain wells were excluded from this particular analysis (e.g., http://water.usgs.gov/nawqa/nutrients/datasets/nutconc2000/).

Analysis

10. Reference Points

EPA has established drinking water standards or guidelines for nitrate and for 47 of the 83 pesticide analytes. Three types of U.S. EPA human health-related standards and guidelines were used to evaluate pesticide data: MCLs, CRCs, and HA-Ls.

- MCLs are enforceable standards representing the highest level of a contaminant that is allowed in finished drinking water. MCLs take into account cost and best available treatment technology, but are set as close as possible to the level of the contaminant below which there is no known or expected risk to health, allowing for a margin of safety.
- The CRC is a guideline for potential carcinogens associated with a specified cancer risk of 1 in 1,000,000, based on drinking water exposure over a 70-year lifetime.
- The HA-L is an advisory guideline for drinking water exposure over a 70-year lifetime, considering non-carcinogenic adverse health effects.

The CRC and HA-L are derived from assumptions about drinking water intake, body weight, and exposure frequency, along with knowledge about the cancer or non-cancer potency of a given chemical.

The current drinking water standard for nitrate is 10 milligrams per liter (mg/L), which is EPA's MCL (https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations). Specific pesticide standards and guidelines used for this indicator are listed in Appendix 3 of Gilliom et al. (2007), and additional information on these types of benchmarks, their derivation, and their underlying assumptions is provided in Nowell and Resek (1994). For information on EPA's current MCLs and HA-Ls, see https://www.epa.gov/dwreginfo/drinking-water-regulations#List and https://www.epa.gov/dwstandardsregulations/drinking-water-contaminant-human-health-effects-information, respectively.

In terms of background concentrations, natural background levels of nitrate in undeveloped areas are generally below about 1 mg/L, according to an extensive USGS study (Nolan and Hitt, 2002). Synthetic pesticides should not be present in undisturbed waters.

11. Comparability Over Time and Space

The same sampling methods were used at all locations during the study period (1992-2003). No corrections have been made to adjust for spatial or temporal biases.

12. Sources of Uncertainty

Uncertainty for this indicator stems from a combination of measurement error and other sources. Because uncertainty varies depending on the chemical and analytical method in question, it is difficult to make a single definitive statement about the impact of uncertainty on this indicator. However, because results from over 1,400 wells were generalized over the entire nation, the summary figures reported by this indicator should be considered reasonably accurate.

Uncertainty estimates are not available for the exact subset of data included in this indicator. However, NAWQA has published uncertainty figures for the overall data collection effort, which should be indicative of uncertainty for this indicator. Mueller (1998) specifically discusses nutrient (nitrate) data, while Martin (2002) evaluates uncertainty for pesticide data.

Additional uncertainty can be attributed to NAWQA site selection as it is the result of a targeted design as opposed to a statistical survey. Indications of differences between NAWQA agricultural basins and all agricultural basins in the country are not available.

13. Sources of Variability

Because this indicator relied on samples that were collected only once per well, it did not account for day-to-day or year-to-year variability in ground water concentrations of the chemicals in question. However, ground water conditions were assumed to be relatively constant over time; movement of water and dispersion of contaminants are slow processes, particularly as compared with changes in aboveground streams. Thus, ground water conditions do not require the same frequency of sampling as conditions in surface water (which NAWQA sampled 10 to 49 times over the course of a given year) to be reflective of long-term trends.

14. Statistical/Trend Analysis

No trend analysis has been conducted on this indicator, as the NAWQA program has completed only one full sampling cycle to date. The data presented here may serve as a baseline for future surveys.

Limitations

15. Data Limitations

Limitations to this indicator include the following:

1. These data only represent conditions in agricultural watersheds within 34 of the major river basins and aquifer regions sampled by the NAWQA program from 1992 to 2003. Although sample wells were chosen randomly within each agricultural watershed, the watersheds and aquifers themselves were selected through a targeted sample design. The data also are highly aggregated and should only be interpreted as an indication of national patterns; thus this indicator does not attempt to portray regional differences.
2. This indicator does not provide information about trends over time, as the NAWQA program has completed only one full sampling cycle to date. Completion of the next round of sampling will allow trend analysis, using the data presented here as a baseline.
3. Drinking water standards or guidelines do not exist for 43 percent (36 of 83) of the pesticides and pesticide degradation products analyzed. Current standards and guidelines also do not account for mixtures of pesticide chemicals and seasonal pulses of high concentrations. Possible pesticide effects on reproductive, nervous, and immune systems, as well as on chemically sensitive individuals, are not yet well understood.

4. This indicator does not provide information on the magnitude of pesticide concentrations, only whether they exceed or fall below benchmarks. It also does not describe the extent to which they exceed or fall below other reference points (e.g., Maximum Contaminant Level Goals [MCLGs] for drinking water).
5. Contaminant levels do not necessarily reflect the concentrations that humans will be exposed to in their drinking water supply, as nitrate and pesticides may be partially or completely removed through water treatment. This indicator also does not provide information about the condition of deeper aquifers, which are more likely to be used for public water supplies. Because ground water condition is vertically heterogeneous, results from one depth do not necessarily represent other depths.

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