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Prepared as part of the National Water-Quality Assessment Program, Source Water-Quality Assessment

Man-Made Organic Compounds in Source Water of Nine Community Water Systems that Withdraw from Streams, 2002–05

Initial findings from a national study by the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) characterize the occurrence of about 250 anthropogenic organic compounds in source water (defined as water collected at a surface-water intake prior to water treatment) at nine community water systems in nine States in the Nation (fig. 1). The organic compounds analyzed in this study are primarily man-made and include pesticides, solvents, gasoline hydrocarbons, personal-care and domestic-use products, disinfection by-products, and manufacturing additives. The study also describes and compares the occurrence of selected compounds detected in source water with their occurrence in finished water, which is defined as water that has passed through treatment processes but prior to distribution. This fact sheet summarizes major findings and implications of the study and serves as a companion product to two USGS reports that present more detailed and technical information for the nine systems studied during 2002–05 (Carter and others, 2007; Kingsbury and others, 2008).

Occurrence of Organic Compounds in Source Water and Their Relevance to Human-Health Benchmarks

About one-half (134) of the organic compounds analyzed in this study were detected in at least one sample collected during 2002–04 at the nine source-water intakes. In total, 119 compounds for which samples were analyzed were not detected at all in source water. Concentrations of detected compounds generally were less than 1 µg/L and less than available human-health benchmarks.

Recent advances in laboratory analytical methods have given scientists the ability to detect a wide variety of contaminants in the environment at low concentrations—typically as low as 0.02 microgram per liter (µg/L), which generally is 100 to 1,000 times lower than most drinking-water standards. Detections reported in this study, therefore, do not necessarily indicate a concern to human health but rather provide a characterization of the low-level environmental occurrence of a wide variety of chemicals not commonly monitored in sources of drinking water.

Concentrations of detected compounds generally were less than 1 µg/L, and annual mean concentrations of all compounds were less than human-health benchmarks. As such, adverse effects to human health are not expected (subject to limitations of available human-health benchmarks). Comparison of measured concentrations to human-health benchmarks (see inset), provides an initial perspective on the potential importance of "man-made" organic compounds present in source water. Only three compounds (atrazine, acetochlor, and dieldrin) were detected in source water at concentrations greater than a human-health benchmark when single-sample concentrations were considered.

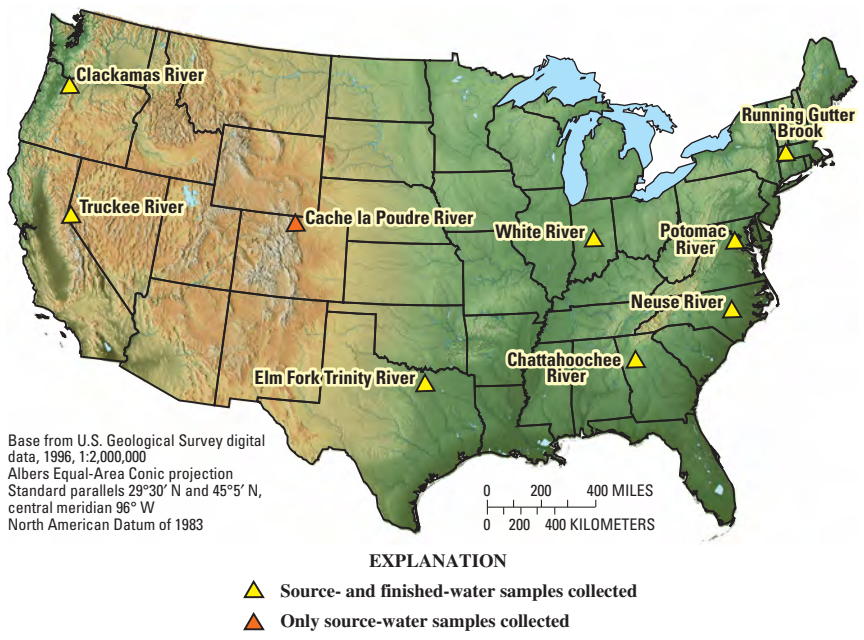


Figure 1. The nine community water systems monitored are spatially distributed across the Nation. The community water systems withdrawing from the nine streams vary in size, serving from about 3,000 people to about 2 million people. Water treatment at most of the systems is conventional, which typically includes the steps of coagulation, flocculation, sedimentation, filtration, and disinfection.

Summary of Major Findings

- *About one-half (134) of the organic compounds analyzed in this study were detected in at least one source-water sample collected at the nine source-water intakes. In total, 119 compounds for which samples were analyzed were not detected at all.*
- *Concentrations generally were less than 1 microgram per liter, and annual mean concentrations of all compounds were less than available human-health benchmarks in source- and finished-water samples. On the basis of this screening-level assessment of compounds, adverse effects to human health are not expected.*
- *The most commonly detected compounds in source water were the disinfection by-product chloroform; the herbicides simazine, atrazine, metolachlor, and deethylatrazine (DEA), a degradate of atrazine; and the musk fragrance hexahydrohexamethylcyclopentabenzopyran (HHCB).*
- *The number of compounds detected and their total concentration were largest at source-water withdrawal sites for community water systems with considerable agricultural and urban land in their watersheds.*
- *Most of the compounds detected commonly in source-water samples (about two-thirds) also were detected commonly in finished-water samples at relatively similar concentrations but almost always at concentrations less than available human-health benchmarks.*
- *Organic compounds typically did not occur alone. More than 75 percent of source- and finished-water samples contained five or more organic compounds, and about one-half of the samples contained 14 or more compounds, typically including degradates.*

Compounds Commonly Detected in Source Water

The compounds most commonly detected, in more than one-half of the source-water samples, include the disinfection by-product chloroform; the herbicides simazine, atrazine, metolachlor, and DEA, a degradate of atrazine; and the fragrance HHCB. The number of compounds detected and their total concentrations were largest at source-water withdrawal sites with considerable agricultural and urban land in their watersheds.

Detected compounds represent a variety of sources and uses (including industrial, agricultural, domestic, and others); therefore, different pathways (including overland runoff and groundwater and wastewater discharges) to the sources of drinking-water supplies are possible. In general, the number of compounds detected and their total concentration were largest at source-water withdrawal sites for the five community water systems with considerable agricultural and urban land in their watersheds: the Elm Fork Trinity River in Texas, the White River in Indiana, the Neuse River in North Carolina, the Chattahoochee River in Georgia, and the Potomac River in Maryland (fig. 2).

Chloroform—As the most frequently detected compound, chloroform was detected in nearly 70 percent of all samples and in samples from eight of the nine stream sites. Chloroform is a common disinfection by-product formed during the treatment of wastewater and municipal drinking water and also has many industrial uses, including the production of refrigerants for home air conditioners and large commercial freezers. The compound was detected year-round at five of the nine sites. The Elm Fork Trinity, Neuse, Potomac, and White Rivers have major upstream wastewater discharges in their watersheds, which also may contribute to the common occurrence of HHCB, a musk fragrance used in personal-care products. The fifth site, Running Gutter Brook, does not receive any major wastewater discharge. Chloroform can have multiple sources including lawn irrigation using treated drinking water, leaking drinking-water distribution lines, and leaking sewerage or septic systems, and it also forms naturally in some soils by microbial processes. An understanding of local hydrology and all possible sources of contaminants is needed to fully characterize source-water quality.

Herbicides—Simazine, atrazine, degradates (breakdown product) of atrazine (DEA and deisopropylatrazine), metolachlor, prometon, and 2,4–D were detected in about 50 percent or more of samples at six of the nine sampled

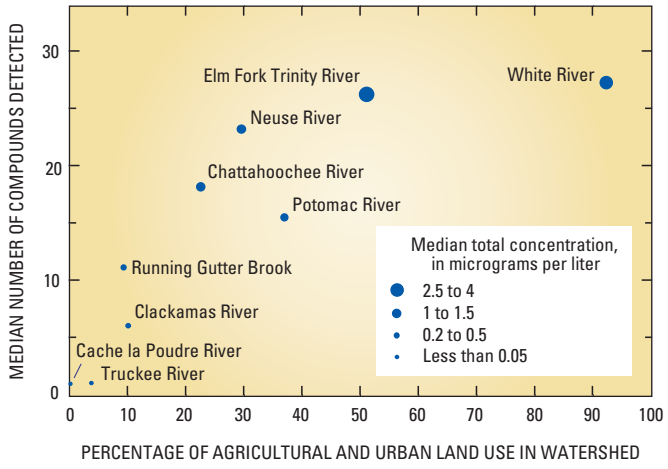


Figure 2. The total number of compounds and their total concentration in samples generally increased with the amount of agricultural and urban land use in a watershed, and the presence of wastewater discharge upstream from the community water system, which explains, in part, why relatively large numbers of compounds were detected at the Elm Fork Trinity, White, Neuse, Chattahoochee, and Potomac Rivers.

NAWQA Approach to Source Water-Quality Assessments and Comparisons to Other Monitoring

Beginning in 2002, NAWQA initiated "Source Water-Quality Assessments" to characterize the quality of water in selected rivers used as a source of supply to selected community water systems in the United States (Delzer and Hamilton, 2007). The long-term goal of this effort is to complete assessments by 2013 at about 30 systems that withdraw water from streams by using standard protocols and nationally consistent methods. NAWQA findings are intended to complement ongoing drinking-water monitoring required by Federal, State, and local programs, which focus primarily on post-treatment compliance monitoring of contaminants regulated by the U.S. Environmental Protection Agency in drinking water (*http://www.epa.gov/safewater/ccr/index.html*). Many of the compounds analyzed by USGS are unregulated and not required to be monitored under the Federal Safe Drinking Water Act. In addition, many of these compounds are not included in other source-water and finished-water monitoring programs such as the Unregulated Contaminant Monitoring Regulation (U.S. Environmental Protection Agency, 2007) and the U.S. Department of Agriculture's Pesticide Data Program (U.S. Department of Agriculture, 2008).

sites. Some of these compounds—including simazine, atrazine, DEA, and metolachlor—were detected year-round in samples from Elm Fork Trinity, Potomac, and White Rivers, which drain watersheds with large amounts of agricultural or mixed (including some urban) land use. Continuous occurrence may be attributed, in part, to inputs from ground-water discharge. Few herbicides were detected in samples collected from the Cache la Poudre, Clackamas, and Truckee Rivers and from Running Gutter Brook, which drain relatively undeveloped watersheds. The occurrence of herbicides and their degradates generally reflects patterns in land use and chemical use. The most commonly occurring herbicides in source water for community water systems correspond to those detected most frequently in ambient stream water across the Nation (Gilliom and others, 2006).

Comparisons Between Source Water and Finished Water

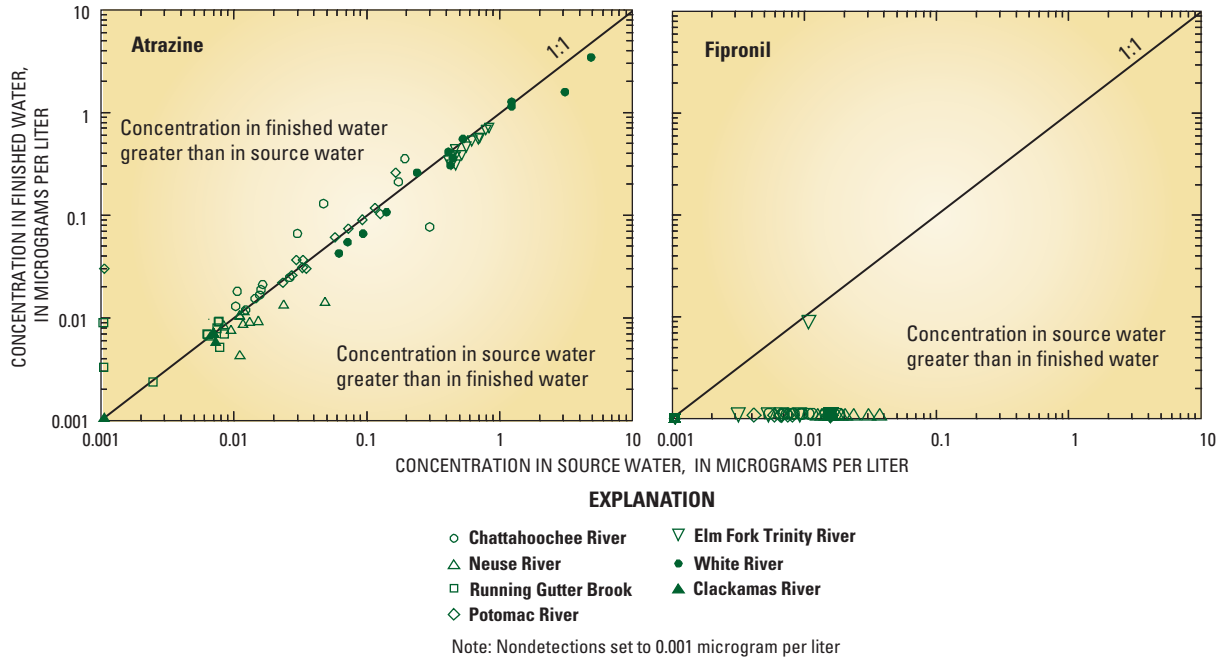
About two-thirds of the compounds detected commonly in source water also were detected in finished water and at relatively similar concentrations and were almost always at concentrations lower than available human-health benchmarks.

Samples of source and finished water were collected during 2004–05 at eight of the nine community water system sites. Finished-water samples were collected after source-water samples and time was allowed to account for the retention time in the treatment plant (which ranged from 1 hour to 5 days). In general, the routine treatment steps used by the eight community water systems, which are typical of many systems across the Nation, are not designed to specifically remove most of the organic compounds monitored in this study (see inset). The resulting comparisons are therefore not intended to characterize treatment efficacy, but rather to provide a preliminary indication of the potential significance of the presence of the organic compounds most commonly detected in source water to the quality of finished water prior to distribution.

Results of the analyses of samples of finished water were similar to those for source water in that annual mean concentrations of organic compounds were less than human-health benchmarks. On the basis of this screening-level assessment, adverse effects to human health from consumption of the water are not expected. Annual mean concentrations of all compounds in finished water were lower than available human-health benchmarks. Maximum concentrations of only two compounds (atrazine and benzo[a]pyrene) were detected in finished water at concentrations greater than a human-health benchmark when single-sample concentrations were considered. Maximum concentrations of most other compounds were from two to five orders of magnitude less than their human-health benchmarks, except for the disinfection by-products. Annual mean concentrations of the sum of the four disinfection by-products analyzed in finished-water samples were less than the Maximum Contaminant Level of 80 µg/L for total trihalomethanes.

About two-thirds of the compounds that were characterized as commonly occurring in source-water samples (that is, compounds detected in 10 percent or more of samples) also were detected in finished-water samples at relatively similar detection frequencies and concentrations. Differences in concentrations for these compounds between source water and the associated finished-water sample generally were less than 25 percent. For example, when atrazine was present in source water, it was usually detected in finished water at a similar concentration (fig. 3). Some exceptions included the insecticides fipronil and diazinon, which were more commonly found in source water but not in finished water, in part because of degradation or transformation associated with chlorine disinfection (Valder and others, 2008; fig. 3). In addition, disinfection by-products were detected more frequently in finished water than in source water, which is an expected consequence of the water treatment process.

Seasonal variations in source water typcially were reflected in finished-water quality—Multiple samples were collected to characterize variability in source- and finished-water samples at each of the community water systems. Analyses of these samples showed variations in the detection frequency and concentration of selected compounds in source water at most sites, in large part because of different hydrologic pathways to the streams, streamflow, sources of the compounds, and chemical use. Several compounds were detected year-round in both source- and finished-water samples. Wastewater discharge may be a relatively constant source for some of these compounds, such as chloroform or HHCB. Herbicides and herbicide degradates had the most pronounced seasonal change in concentration throughout the year, but the magnitude and timing of these changes varied among the sites. For example, atrazine concentrations at the White River varied by tenfold or more during the year, whereas concentrations at the Neuse River varied less (fig. 4). The highest concentrations generally



Note: Nondetections set to 0.001 microgram per liter

Figure 3. Although water treatment steps used by the eight water systems differ somewhat, large differences in the amount of change in concentration between source water and finished water generally were not observed for most compounds, such as atrazine, that had similar detection frequencies in source and finished water. Some compounds, for example fipronil, were present in source water but were not detected in finished water, likely because of degradation or transformation as a result of disinfection with chlorine.

occurred in the spring after chemicals were applied in row-crop areas. For many compounds, such as atrazine, changes in concentration over time in source water were reflected in the associated finished water (fig. 4). Differences in atrazine concentrations in source and finished water at the Neuse River between February and June may be related to the use of powdered activated carbon for taste- and odor-compounds.

Mixtures and Pesticide Degradates

Individual compounds typically did not occur alone. More than 75 percent of source- and finished-water samples contained mixtures of five or more compounds. About one-half of the samples contained 14 or more compounds (fig. 5), typically including degradates.

The most commonly occurring compounds in mixtures, not surprisingly, were the individual compounds that were detected most frequently. These include the herbicides atrazine (and its degradate DEA), metolachlor, simazine, and prometon, as well as one or more disinfection by-products, such as chloroform, particularly in finished water. In finished-water samples, disinfection by-products increased the number of compounds in a sample relative to the associated source-water sample.

Mixtures of compounds commonly included pesticide degradates. For example, atrazine was found with one or more of its degradates, such as DEA, in nearly 95 percent of samples in which it was detected. At three of the sites—Potomac, Elm Fork Trinity, and White Rivers—DEA was detected in every sample with its parent compound, but typically at concentrations less than those of atrazine.

Degradates of the herbicides metolachlor, alachlor, and acetochlor were analyzed in samples from the Elm Fork Trinity, Neuse, Potomac, and White Rivers—watersheds in which these herbicides were most likely to be used. Like atrazine, these degradates gener-

Human-Health Benchmarks Used in This Study

A screening-level assessment of the potential effects of detected compounds on human health was based on a comparison of annual mean concentrations in source- and finished-water samples to available human-health benchmarks. Specifically, concentrations of the regulated compounds were compared to U.S. Environmental Protection Agency Maximum Contaminant Levels (MCLs), and concentrations of unregulated compounds for which the USEPA has published toxicity information were compared to USGS Health-Based Screening Levels (HBSLs; Toccalino and others, 2007). About one-half of detected compounds do not have human-health benchmarks or adequate toxicity information for evaluating results in a human-health context. This screening-level assessment provides an initial perspective on the potential significance of man-made organic compounds in source water; it is not a substitute for a comprehensive risk assessment, which includes consideration of many more factors, such as additional avenues of exposure.

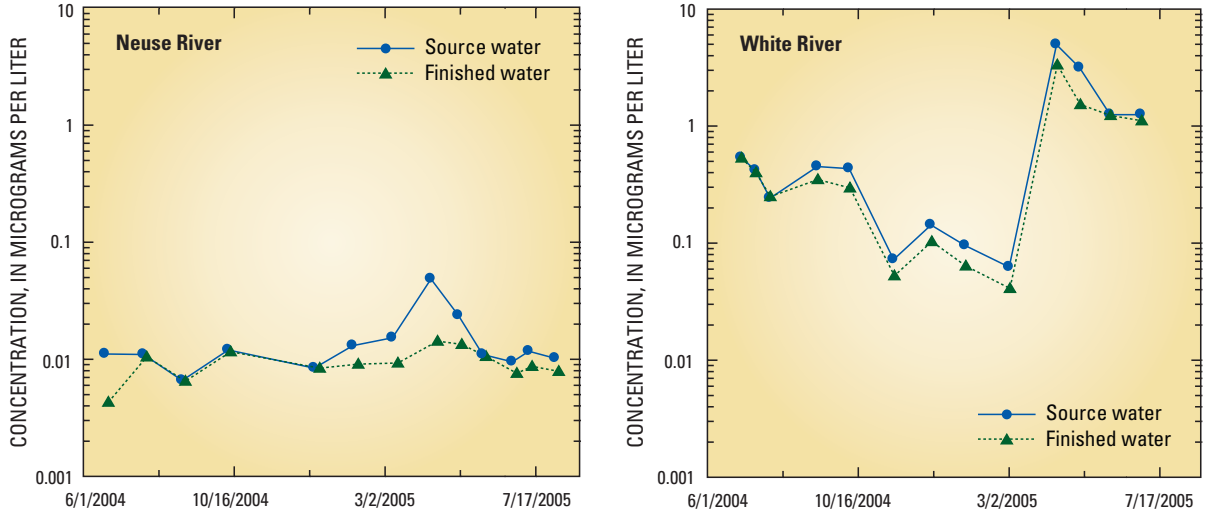


Figure 4. Seasonal changes in atrazine concentrations in source water were reflected in the associated finished water. At most community water systems, finished-water concentrations generally were similar to or less than those in source water. Lower concentrations in finished water compared to source water at the Neuse River may be the result of seasonal use of powdered activated carbon for taste- and odor-compounds.

ally were detected with their parent compounds. In contrast to atrazine, however, the summed concentrations of degradates for metolachlor and alachlor typically were greater than those of their parent herbicides, which is most likely due to the chemical properties of these herbicides. Specifically, atrazine is more mobile and chemically stable, allowing it to persist in the hydrologic system longer than metolachlor and alachlor. Little is known about the potential effects of most herbicide degradates on human health.

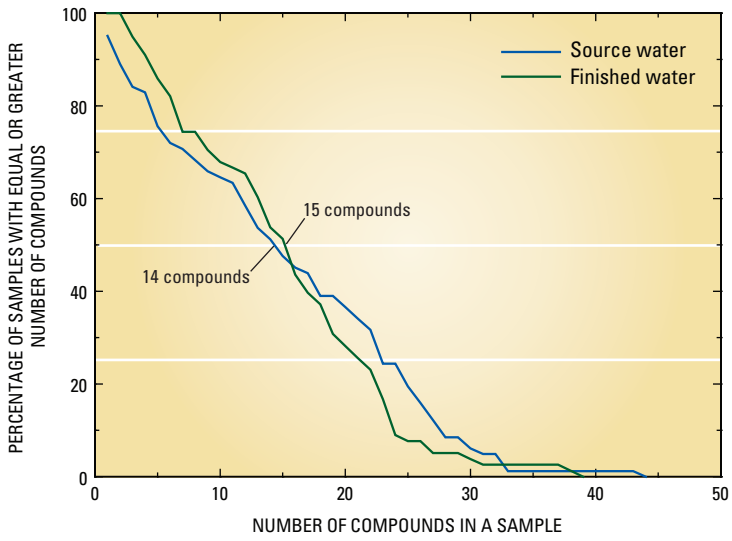


Figure 5. Samples of both source and finished water typically contained mixtures of compounds. One-half of finished-water samples contained 15 or more compounds. Disinfection by-products in finished water and degradates in both source and finished water contributed to common mixtures.

Possible Implications and Utility of These Findings

Many of the compounds detected most commonly in source- and finished-water samples were among those most commonly detected in ambient stream water across the Nation (Gilliom and others, 2006). In addition, the occurrence of many compounds in source and finished water was similar at community water systems on rivers that have upstream wastewater facilities and that drain large areas of agricultural and urban land. Any application of these findings to a national perspective, however, must be considered preliminary because they reflect conditions at only a few community water systems, and some compounds included in this study have only recently been monitored systematically in source and finished water (including, for example, compounds used in personal-care products, such as HHCB). Continued research is needed to better understand the sources, transport mechanisms, fate in the environment, and possible effects of these compounds to human health. In addition to other agencies and universities, research examining these issues is being conducted by the USGS Toxic Substances Hydrology Program (see *http://toxics.usgs.gov/*) and the NAWQA Program. Resource management and research efforts might include the following:

- Emphasizing watershed management and source-water protection strategies to help manage the sources and transport of compounds to source water and ultimately to finished water.
- Continuing development of toxicity information for commonly occur-

ring unregulated compounds, their degradates, and common mixtures of compounds in source water and finished water. The common occurrence of mixtures of compounds means that the total combined toxicity in source water may be greater than that of any single compound that is present. Continued research is needed because human-health benchmarks are based on toxicity data for individual compounds, and the additive or synergistic effects of mixtures of compounds at low levels are not well understood.

- Monitoring and assessing organic compounds that are not commonly monitored in water supplies but are present in finished water, which may ultimately lead to the development or implementation of treatment technologies for their removal.

Finished-Water Sampling, Water Treatment, and Significance of Comparisons to Source Water

Water treatment processes differ among the systems sampled. Specifically, treatment at five of the systems is considered conventional, including the steps of coagulation, flocculation, sedimentation, filtration, and disinfection. One water system uses slow sand filtration and disinfection, a second system adds ozone as a preliminary treatment step to conventional treatment, and a third system uses direct filtration treatment that follows many of the steps used in conventional treatment.

Washington Aqueduct on the Potomac River in Washington, D.C.

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This fact sheet is free of charge, and also is available on the Web at *http://water.usgs.gov/nawqa/swqa/*. Also included at the NAWQA Web site are downloadable data on organic compounds, information on sampling designs and methodology (Carter and others, 2007; Kingsbury and others, 2008; Valder and others, 2008), and frequently asked questions (FAQs).

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