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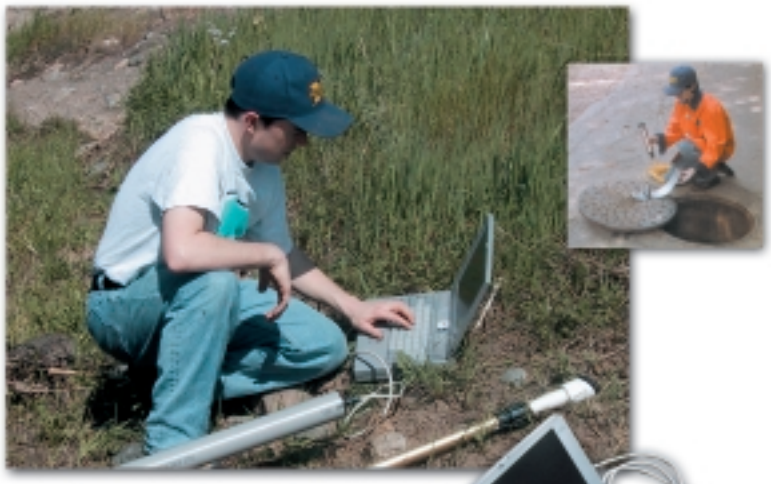

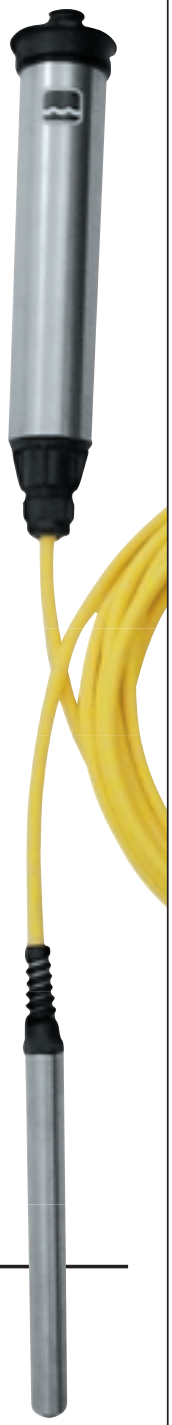

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ASSESSING THE QUALITY OF THE NATION'S WATER RESOURCES

Pixie A. Hamilton, Guest Associate Editor
(pahamilt@usgs.gov)

This issue of *IMPACT* highlights findings from the first decade of studies (1991 to 2001) by the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS). The articles also discuss the Program's approaches and models designed to help understand and estimate the fate and transport of contaminants in different geographic areas and environmental settings and over different time frames. NAWQA was established by Congress in 1991 with a goal of developing long-term, consistent, and comparable science-based information on nationwide water-quality conditions. This information is used to support sound management and policy decisions by decision makers at all levels – local, state, and national – who, every day, face complex regulations and management issues related to water resources.

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WATER RESOURCES
IMPACT

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INTRODUCTION
ASSESSING THE QUALITY OF THE NATION'S WATER RESOURCES

By the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey

Timothy L. Miller

Water is the basis for life, and for our nation's economic vitality. Our water resources support a complex web of human activities and fishery and wildlife needs that depend upon clean water. Population growth and increasing demands for water, however, coupled with contamination from point and nonpoint sources, threaten the quality and quantity of our water resources. We must improve management of these resources in response to our society's changing demands and to the possible effects of those demands on human health and safe drinking water, aquatic ecosystems, wetlands, native and endangered species, and recreation.

Every day, decision makers face complex regulations and management issues related to mitigating agricultural and urban impacts on watersheds, protecting human health and drinking water, applying best management practices to improve impaired waters, developing Total Maximum Daily Loads (TMDLs), reducing hypoxia and fish kills, registering pesticides, and developing effective environmental monitoring strategies. It is challenging at all governmental levels – local, state, interstate, and national – to prioritize these issues, especially in light of their economic implications. Recognizing these challenges, the Congress in 1991 established the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS). The goal is to develop long-term consistent and comparable science-based information on nationwide water-quality conditions to support sound management and policy decisions. This information, collected in more than 50 major river basins and aquifers across the nation, provides an objective basis for decision makers, managers, and planners at all levels of government to cost-effectively address the multitude of water-resource issues.

NAWQA is shaped by and coordinated with ongoing efforts of other federal, state, tribal, and local agencies. The program assesses the status and trends of the quality of streams, ground water, and aquatic ecosystems, and identifies factors that affect those conditions. Typical questions addressed include:

- *What contaminants are found in streams and ground water? At what concentrations?*
- *In which geographic regions and environmental settings are elevated concentrations most prevalent?*
- *How do agriculture and urban development affect water quality?*
- *What natural features make some streams and ground water more vulnerable to contamination than others?*
- *How is water quality changing over time?*
- *At what times of the year are water-quality conditions better or worse?*
- *What contaminants occur in streams and ground water* used as drinking-water sources? What contaminants are found in fish tissue?
- Are contaminants at concentrations of concern for human health and aquatic ecosystems?

NAWQA made considerable progress during its first decade toward assessment of local and national water-quality conditions in streams and ground water. Descriptions of these conditions are presented in hundreds of reports (http://water.usgs.gov/nawqa). Baseline conditions were established, and long-term monitoring was initiated in every basin studied. In the next decade, more than 40 of the major river basins and aquifers will be intensively reassessed, so that 10 years of comparable monitoring data will be available to determine trends at many of the streams and ground-water monitoring sites. The next 10 years of study also will fill in critical gaps in characterizing water-quality conditions, and build upon earlier NAWQA findings that show how natural features and human activities affect the quality of streams, ground water, and ecosystems. NAWQA studies have consistently shown, for example, how concentrations of contaminants vary from season to season and among watersheds because of differences in land and chemical use, land-management practices, degree of watershed development, and natural features such as soils, geology, hydrology, and climate. NAWQA will increase its focus on understanding the key processes that control water-quality conditions in order to establish the links among the sources of contaminants, the transport of those contaminants through the hydrologic system, and the potential effects of contaminants on humans and aquatic ecosystems.

Articles in this issue of *IMPACT* highlight a number of findings and implications for management of water resources at local, regional, and national levels. In addition, several of the articles discuss NAWQA approaches and models designed to help understand and estimate the fate and transport of contaminants over different time frames, geographic areas, and environmental settings. We believe that advances in predictive tools will allow stakeholders at all levels to cost-effectively prioritize, manage, and protect their resources.

The article by Hamilton describes selected findings in major river basins and aquifers across the nation defined as NAWQA "study units." Within these study units, USGS scientists collect and analyze information on water chemistry, hydrology, land use, stream habitat, and aquatic life. Each study-unit assessment is an interdisciplinary

and long-term evaluation of the total resource, rather than a short-term study of a specific geographic area or problem at a single point in time. NAWQA findings thereby describe the general health of water resources in each basin, as well as current and emerging water issues—information that is essential for developing practical water-resource management strategies.

The article by Gilliom and others describes selected findings about water-quality conditions on a national scale. Because each study-unit assessment adheres to a nationally consistent design and sampling and analytical methods, basin findings can be compiled to advance an understanding of the quality of the nation's waters. Comprehensive assessments of pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of study-unit findings. Direct comparisons are made of how human activities and natural processes affect water quality and ecological conditions in the nation's diverse geographic, land-use, and environmental settings.

Wilber and Couch look at NAWQA findings from the perspective of national priorities. These priorities were identified in collaboration with government, research, and interest-group partners following an extensive analysis of national and regional water-resource issues. These "topical studies" are conducted in selected study units that are affected by these issues and that, collectively, represent the geographic distribution of conditions relevant to each topic. The five topical studies are: (1) effects of nutrient enrichment on streams; (2) sources, transport, and fate of agricultural chemicals; (3) transport of contaminants to water supply wells; (4) effects of urbanization on stream ecosystems; and (5) bioaccumulation of mercury in aquatic organisms.

The article by Mueller and others discusses NAWQA's approach to the systematic assessment of long-term trends and changes in the quality of the nation's streams and ground water. Finally, the application of NAWQA results to unmonitored areas is described by Wolock and Kauffman. Effective strategies for managing contaminants and related water-quality issues require far more information than can be measured directly. Moreover, many decisions, such as approving a pesticide for use, require the ability to predict potential effects on water quality and aquatic ecosystems. NAWQA uses statistical tools and computer models to apply the information from direct measurements and the understanding of processes to unmonitored, comparable areas and into the future. NAWQA is exploring the best methods to predict water-quality conditions on the basis of assessments of land use and contaminant sources, natural characteristics of the land, and hydrologic transport processes.

As you read these articles, please note any questions or observations you might have. Let us know how our findings have already served you and your organization, and how we can improve our communication to better serve your needs. We value your input, as it has helped us stay true to our scientific design while remaining responsive to resource management, policy development, and emerging water-quality issues.

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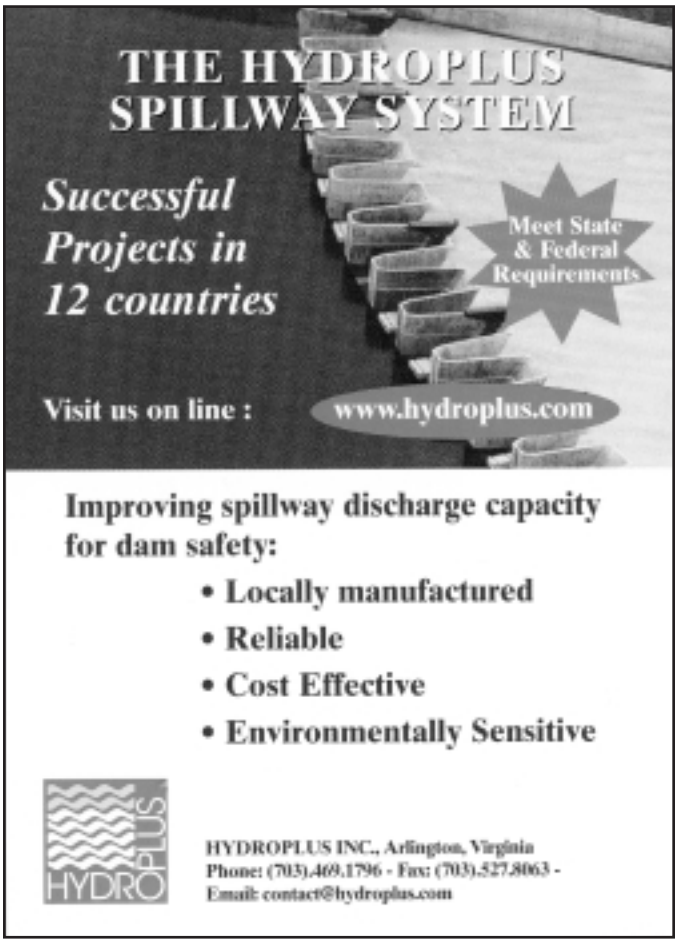


WATER RESOURCES
IMPACT

WATER-QUALITY PATTERNS IN SOME OF THE NATION'S MAJOR RIVER BASINS AND AQUIFERS

Pixie A. Hamilton

INTRODUCTION

In 1991, the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) began evaluating the quality of streams, ground water, and aquatic ecosystems in 51 major river basins and aquifer systems (known as "study units") across the nation. The assessments characterize the ambient water resource – the source of about 60 percent of the nation's drinking water, as well as water for industrial, irrigation, and recreational uses – and thereby complement much of the compliance and regulatory monitoring conducted at the state level and by the U.S. Environmental Protection Agency (USEPA).

NAWQA assesses the total resource, which thereby complements much of the compliance and regulatory monitoring conducted at the state level and by USEPA. For example, the Missouri Department of Natural Resources has incorporated NAWQA stream-quality data into their database for monitoring compliance with USEPA 305(b) water-quality standards. The Department uses the data to describe attainment of beneficial uses, to identify and prioritize problems, to help develop Total Maximum Daily Loads (TMDLs), and to assist in overall natural resource management.

NAWQA assessments describe the occurrence and distribution of pesticides, nutrients, volatile organic compounds (VOCs), metals, dissolved solids, and radon in each basin, as well as the condition of aquatic habitat and fish, insect, and algal communities. Land use, anthropogenic sources of contaminants, and natural factors affect water quality, aquatic life, and stream habitat. The results of these assessments may have implications at the local and state level for drinking-water protection, aquatic ecosystem health, and resource management.

Water quality in each basin is compared to conditions in other geographic regions, providing insight into whether certain types of water-quality issues are isolated or pervasive. The direct comparisons also provide insight into how human activities and natural processes affect water quality and ecological conditions in the nation's diverse geographic and environmental settings.

The design of the NAWQA Program is rotational. Monitoring of the first 20 study units began in 1991, and more than 30 additional study units were phased in by 1997 (Figure 1). About one-third of all study units are intensively investigated at any given time for three to four years, and trends are assessed about every 10 years. In the meantime, low-level monitoring is maintained. A total of 36 river basin and aquifer assessments have been completed and the remaining 15 (study units intensively studied from 1998 to 2001) will be completed in early 2003. Individual basin reports are available on the NAWQA Web site http://water.usgs.gov/nawqa).

ASSESSING THE TOTAL RESOURCE: A CASE "STUDY UNIT"

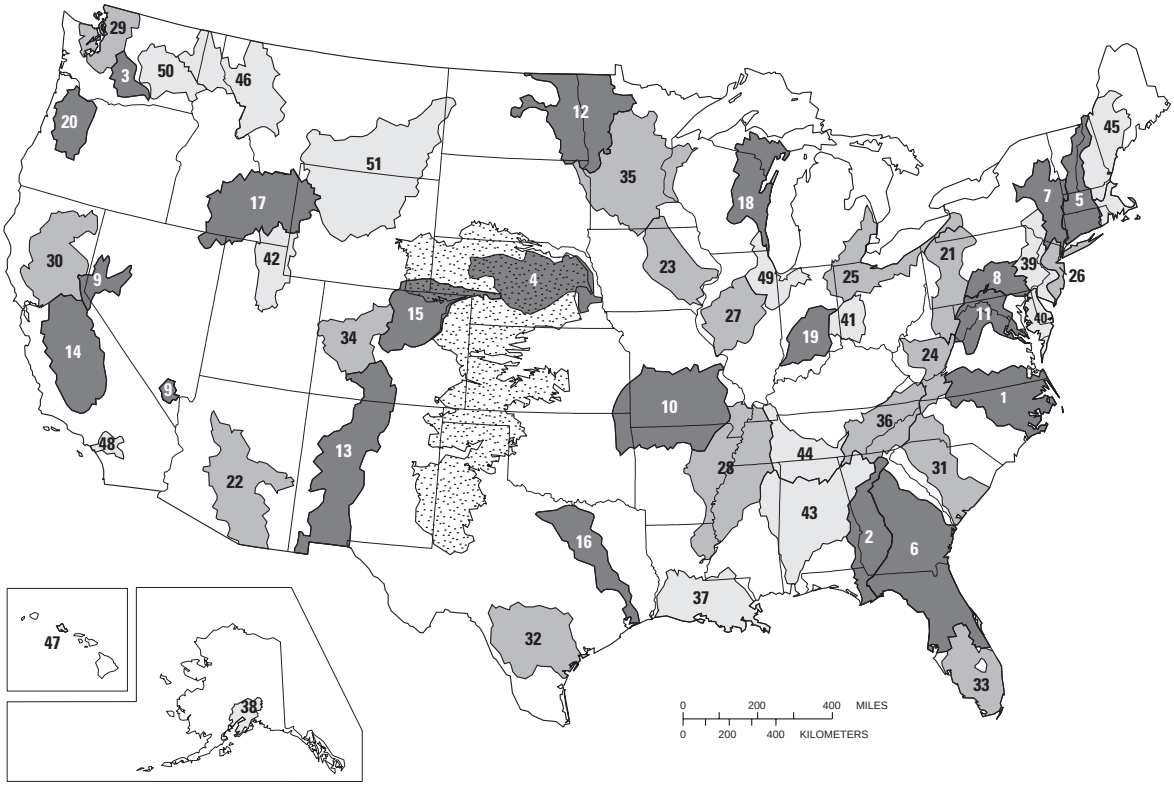
Each assessment is an interdisciplinary and long-term evaluation of the total resource, rather than of a specific geographic area or problem at a single point in time. Therefore, the findings describe the general health of water resources, and reveal current and emerging water issues. For example, a NAWQA assessment in the Sacramento River Basin showed that the Sacramento River and its major tributaries, the Feather and American Rivers, are generally suitable for drinking and irrigation water, recreation, and for sustaining fish and other aquatic life. Fish communities indicated that the ecological system is in relatively good shape – native fish are still common in the streams.

Most of the water in this basin comes from melting snow that accumulates in Sierra, Nevada, mountain reservoirs, which are relatively isolated from sources of urban and agricultural contaminants. Runoff from homes and gardens, however, makes its way to suburban and urban waterways like Arcade Creek, which meanders through neighborhoods in northern Sacramento. The insecticide diazinon was frequently detected in some of these streams, including Arcade Creek (Figure 2). In fact, all of the water samples tested contained concentrations of diazinon that exceeded the guideline for the protection of aquatic life (proposed by the International Joint Commission for the Great Lakes). The concentrations frequently were high enough to be toxic to water insects that are essential food for fish (Domagalski *et al.*, 2000).

Another water issue identified in the Sacramento River Basin is the presence of mercury, which was used in the past as a magnet to collect gold from mountain streams. Throughout the river system, NAWQA scientists found seasonally high mercury concentrations. USGS is continuing to study the sources, occurrence, and transport of mercury throughout the basin.

CLOSE TIES TO LAND AND CHEMICAL USE

In every basin, relationships were seen between land and chemical use in agricultural and urban settings, and the types, mixtures, and concentrations of contaminants in streams and ground water. Some of the highest concentrations of nitrogen and herbicides (such as atrazine, metolochlor, alachlor, and cyanazine) were in stream samples from agricultural areas with the highest chemical use. Concentrations of insecticides in many of the urban water bodies in the basins exceeded at least one guideline established to protect aquatic life. Insecticides – most commonly diazinon, carbaryl, malathion, and chlorpyrifos – were detected more frequently and usually at higher concentrations in urban streams than in



River basin and aquifer assessments, conducted 1991–95

1 Albemarle-Pamlico Drainage Basin
2 Apalachicola-Chattahoochee-Flint River Basin
3 Central Columbia Plateau
4 Central Nebraska Basins
5 Connecticut, Housatonic and Thames River Basins
6 Georgia-Florida Coastal Plain
7 Hudson River Basin
8 Lower Susquehanna River Basin
9 Las Vegas Valley Area and the Carson and Truckee River Basins
10 Ozark Plateaus
11 Potomac River Basin
12 Red River of the North Basin
13 Rio Grande Valley
14 San Joaquin-Tulare Basins
15 South Platte River Basin
16 Trinity River Basin
17 Upper Snake River Basin
18 Western Lake Michigan Drainages
19 White River Basin
20 Willamette Basin

River basin and aquifer assessments, conducted 1994–98

21 Allegheny and Monongahela River Basins
22 Central Arizona Basins
23 Eastern Iowa Basin
24 Kanawha-New River Basins
25 Lake Erie-Lake Saint Clair Drainages
26 Long Island-New Jersey Coastal Drainages
27 Lower Illinois River Basin
28 Mississippi Embayment
29 Puget Sound Basin
30 Sacramento River Basin
31 Santee River Basin and Coastal Drainages
32 South-Central Texas
33 Southern Florida
34 Upper Colorado River Basin
35 Upper Mississippi River Basin
36 Upper Tennessee River Basin

River basin and aquifer assessments, conducted 1998–2001

37 Acadian-Pontchartrain Drainages
38 Cook Inlet Basin
39 Delaware River Basin
40 Delmarva Peninsula
41 Great and Little Miami River Basins
42 Great Salt Lake Basins
43 Mobile River Basin
44 Lower Tennessee River Basin
45 New England Coastal Basin
46 Northern Rockies Intermontane Basins
47 Oahu
48 Santa Ana Basin
49 Upper Illinois River Basin
50 Yakima River Basin
51 Yellowstone River Basin

High Plains regional aquifer assessment, to be completed in 2004

Figure 1. NAWQA Study Units. The NAWQA Program assessed water-quality conditions in 51 major river basins and aquifers from 1991 to 2001. In the next decade, 42 of the 51 basins will be reassessed to fill critical gaps in characterizing water-quality conditions, to identify trends, and to enhance understanding of factors that affect water quality. See USGS Fact Sheet 071-01 "The National Water-Quality Assessment Program – Entering a new decade of investigations" for locations of study units included in the next decade of studies (available on the NAWQA Web site).

agricultural streams. In addition, concentrations of Volatile Organic Carbons (VOCs), such as trihalomethanes, generally were higher in urban streams and ground water than in other land-use settings.

The relation between chemical use and chemical concentrations is demonstrated in some Upper Midwest streams. Concentrations of alachlor and cyanazine – two herbicides commonly used on corn and soybeans – have decreased in the Illinois River and other streams in the Upper Midwest since 1991 following a decrease in use of these herbicides by farmers. Since 1994, farmers have increased use of acetochlor on corn and soybeans. Acetochlor was detected at only trace concentrations during the 1994 growing season in the White River in Indiana, but by 1996, acetochlor was commonly detected in the White River, where a peak concentration of about 2 micrograms per liter was measured (Fenelon, 1998). Close links between chemicals applied and water quality suggest that local and regional management of chemical use can go a long way toward managing water-quality conditions.

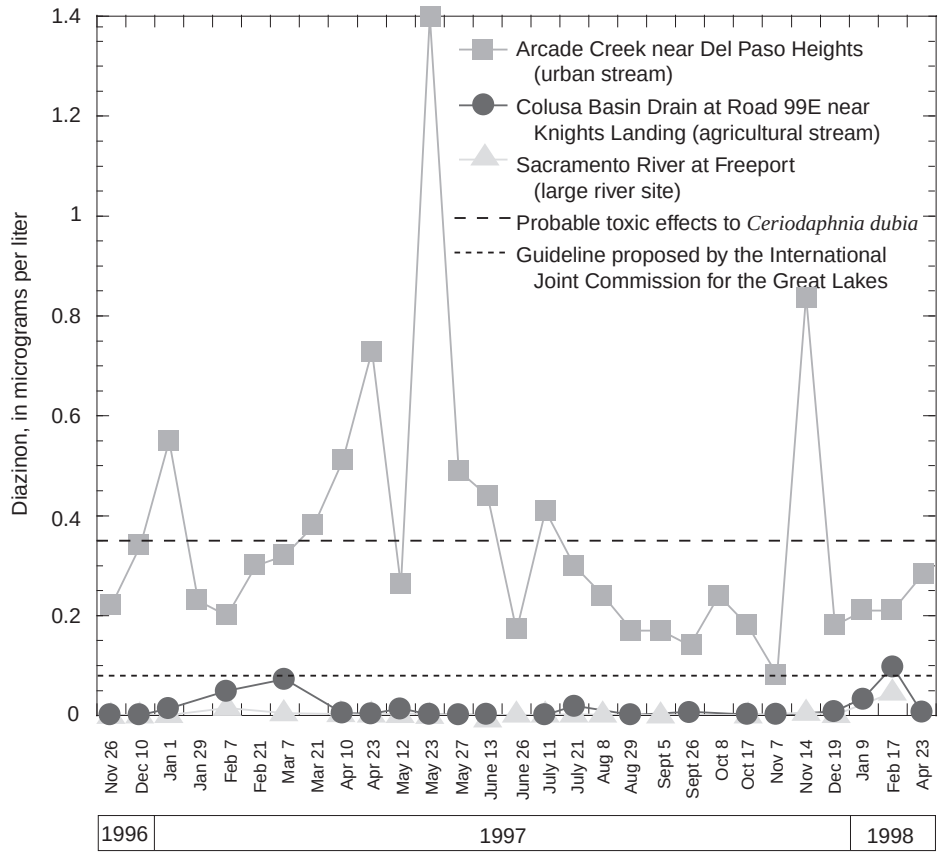


Figure 2. Concentrations of Diazinon in Arcade Creek Near Del Paso Heights, California. All of the water samples collected in Arcade Creek near Del Paso Heights, California, contained concentrations of diazinon that exceeded the guideline for the protection of aquatic life (proposed by the International Joint Commission for the Great Lakes) (Domagalski *et al.*, 2000).

Mixtures and Breakdown Products . . . *In every basin, streams and ground water almost always contain complex mixtures of nutrients, pesticides, and VOCs. These mixtures are composed of chemicals in current use, others that were used historically (such as DDT, which was restricted in the early 1970s), and chemical breakdown products. Mixtures can vary among the different river basins because of land and chemical use unique to each basin. For example, norflurazon and bromacil were found together most frequently in ground water underlying the Southern Florida Drainages because of their relatively local use on citrus crops; atrazine and its breakdown compound, desethylatrazine (DEA), were most commonly found together in all wells sampled throughout the nation.*

Some compounds, such as pesticides, break down into compounds that may be either short-lived or persistent. In many basins, pesticide breakdown compounds were some of the most frequently detected pesticide compounds in streams, and constituted most of the pesticide mass in water samples. For example, herbicide breakdown products commonly were present at 10 times the concentration of parent compounds in the Iowa River, Iowa. On the basis of these findings, local officials in the city of Cedar Rapids, Iowa, require monitoring and analysis of herbicide breakdown products in city water supplies.

LAND-MANAGEMENT PRACTICES

Land-management practices within a basin (including tile drainage, irrigation, and conservation strategies) largely control the movement of chemicals over land to streams and aquifers. For example, conservation tillage practices (whereby farmers maintain a layer of crop residue from the past year's crop) have reduced sediment erosion to streams in northwestern Ohio and northeastern Indiana. During 1993 to 1998, conservation tillage methods were used in more than 50 percent of all crop fields in the Maumee River Basin. Data from previous studies and new data collected by NAWQA at two sites in the Maumee River Basin during 1996 to 1998 showed significant decreases in the amounts of suspended sediment carried by the Maumee River and the Auglaize River, a tributary; these decreases correspond to increases in conservation tillage over time (Myers *et al.*, 2000). In many parts of the Midwest and Southeast, tile drains and ditches are used to drain poorly drained and clayey sediment. This practice effectively "short circuits" the ground-water system by intercepting soil water and shallow ground water and transporting it to streams. As

a result, streams in these areas can have elevated concentrations of agricultural chemicals; seepage into the ground is minimized, thereby resulting in lower concentrations of chemicals in ground water.

THE NATURAL COMPONENT

Anthropogenic factors, such as land-management practices and land and chemical use, are not the sole predictors or controlling factors of water quality. Concentrations of contaminants vary within and among basins despite seemingly similar land uses, types of chemical applications, and management strategies because natural features (including physiography, geology, soils, hydrology, and climate) can affect the movement of chemicals over land to streams and aquifers. For example, after fertilizer management strategies were implemented, concentrations of nitrate decreased significantly in ground water underlying parts of the Central Platte Natural Resources District, Nebraska (from about 18 milligrams per liter in the mid-1980s to less than 2 milligrams per liter in the mid-1990s). Yet, in other parts of the District where similar strategies were implemented, ground-water response was delayed because of differences in local features controlling ground-water flow, such as different soil types and amounts of recharge. Concentrations of nitrate remained greater than two times the USEPA drinking-water standard (10 milligrams per liter) in nearly one-fourth of wells in one area sampled by the District in the mid-1990s (Fuhrer *et al.*, 1999).

The natural environmental setting of a basin also can contribute contaminants to water resources. For example, radon is a naturally occurring radioactive gas that forms during the decay of uranium, which is commonly found in igneous and metamorphic rocks like those in the Blue Ridge physiographic province. The Kanawha-New River Basin had some of the highest concentrations of radon in the nation, exceeding 1,000 picocuries per liter in 30 percent of ground-water samples collected by NAWQA scientists (the USEPA's currently recommended maximum concentration of radon in drinking water is 300 picocuries per liter) (Paybins *et al.*, 2000).

Another example is the sand and gravel aquifers of the Albemarle-Pamlico Drainage Basin in North Carolina, which contribute phosphorus to some streams. Deep ground water underlying parts of the Coastal Plain has relatively high concentrations of phosphorus (a median concentration of 0.25 milligrams per liter), which likely originates from phosphate minerals, such as fluoroapatite, in the Cretaceous-age aquifer sands. Upward discharge of the ground water results in elevated concentrations of phosphorus in streams, particularly in the Tar River and Neuse River drainage basins (analysis indicated a significant correlation for 25 sites sampled during August and September 1995 between concentrations in discharging ground water and in streams) (Spruill *et al.*, 1998). Documentation of this natural source of phosphorus in the Albemarle-Pamlico Drainage Basin has helped water-resource managers to better account for phosphorus sources, and has led to the development of more accurate Total Maximum Daily Loads (TMDLs) in selected streams in North Carolina.

SEASONAL PATTERNS

Seasonal patterns in water quality of streams were observed in most basins. The patterns reflect a combination of the timing and amount of chemical use, the frequency and magnitude of runoff from rainstorms or snowmelt, and specific land-management practices, such as irrigation and tile drainage. Concentrations of nutrients and pesticides were highest during runoff following chemical applications. For example, herbicide concentrations in streams in the Lake Erie-Lake Saint Clair Drainages typically were highest after application and steadily decreased thereafter. Elevated concentrations of the most heavily used agricultural herbicides – atrazine, metolochlor, cyanazine, and acetochlor – were detected for four to six weeks after rainfall and runoff in the spring and early summer (Figure 3; Myers *et al.*, 2000). Pesticides used mostly in urban areas, such as diazinon and prometon, typically are applied in late summer, which is when the highest concentrations were detected in streams (Figure 3). The seasonal nature of chemical use and land-management practices dictates the timing of elevated concentrations in drinking-water sources and aquatic habitats.

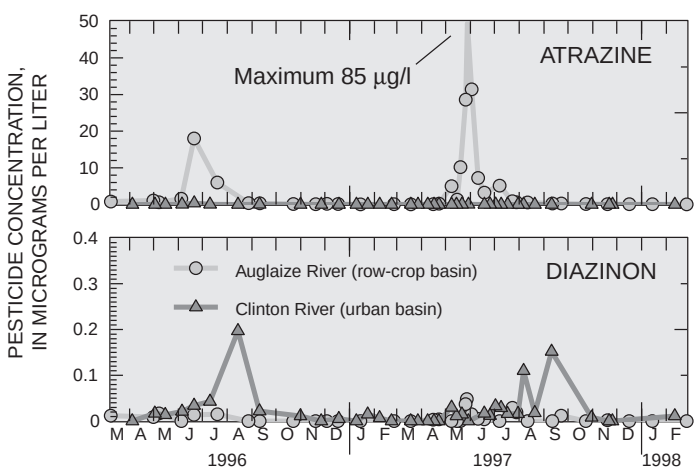


Figure 3. Seasonal Variations in Concentrations of Pesticides. Concentrations of pesticides vary seasonally in the Auglaize River in Ohio and the Clinton River in Michigan, reflecting a combination of the timing and amount of chemical use, the frequency and magnitude of runoff from rainstorms or snowmelt, and specific land-management practices (Myers *et al.*, 2000).

Water and air temperature also can affect the seasonality of the occurrence of compounds in water. For example, VOCs were detected more frequently in stream samples collected during cooler months (October to March) in the Long Island-New Jersey Coastal Drainages than in samples collected in warmer months (April to September). This is most likely because the compounds

are less likely to volatilize in the cooler water. Similarly, concentrations of the VOCs benzene, toluene, methyl *tert*-butyl ether (MTBE), and naphthalene showed seasonality in the Allegheny-Monongahela River Basins. The compounds were present in February, November, and December and absent in July, August, and September. The NAWQA study showed that concentrations of VOCs in water increased by a factor of about three to seven when water temperatures decreased from 25 to 5˚C (Anderson *et al.*, 2000).

CHANGES IN WATER QUALITY OVER TIME

For many basins, it is too early to tell whether conditions are becoming better or worse because historical data are insufficient or too inconsistent to define any trends. In the next decade, more than 40 of the study units will be intensively reassessed, so that 10 years of comparable monitoring data will be available to determine trends at many of the streams and ground-water monitoring sites. To provide immediate measures of long-term water-quality trends for selected metals and organic contaminants since the 1960s or earlier, including many contaminants not historically monitored, NAWQA analyzes sediment cores from lakes and reservoirs. Sediment cores from 14 of the study units were analyzed to determine water-quality changes as watersheds became urbanized.

Sediment washing off the land into lakes and reservoirs contains a complex mixture of "particle-associated contaminants" (those that attach to sediment more readily than dissolve in water). These can include the long-restricted insecticide DDT, polychlorinated biphenyls (PCBs), and lead, as well as polycyclic aromatic hydrocarbons (PAHs), which are formed by the incomplete combustion of fuels. The sediments settle in lakes and reservoirs, forming thick layers and providing a "water-quality history" – a chronicle of chemical changes in nonpoint source pollution as watersheds change over time and as new chemicals are introduced into the environment.

Patterns and trends were identified for some contaminants in the urban areas. For example, analysis of sediment cores from White Rock Lake in Dallas, Texas, indicated that concentrations of lead increased dramatically from the 1940s to the 1970s, and began to decrease rapidly after lead was removed from gasoline (Figure 4). Concentrations, however, are not yet down to background levels. Large decreases also were noted for DDT and PCBs since restrictions on their use were imposed in the 1970s (VanMetre and Callender, 1997).

Sediment-core analysis also indicated that concentrations of PAHs are rapidly increasing since the 1970s (Figure 4). The increases in PAHs are coincident with increases in vehicle use. For example, from 1982 to 1996, PAH concentrations in sediment cores from Town Lake in Austin, Texas, and automobile use (expressed as total miles driven on Austin roads) both increased by about 2.5 times. Most of the growth in Austin has occurred around the fringes of the city and outside the watershed of Town Lake. Such growth patterns have undoubtedly

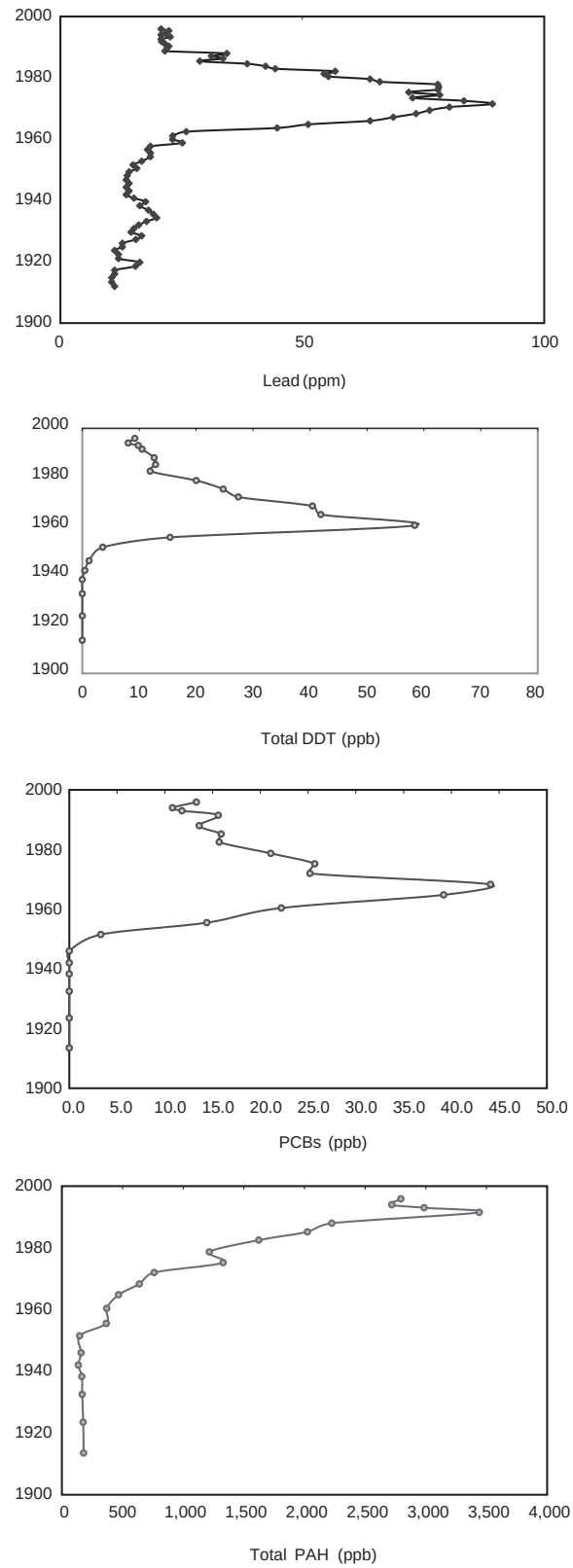


Figure 4. Concentrations of Four Contaminants in Sediment. Lead, DDT, and PCBs show decreasing trends, and PAHs show increasing trends from 1960 to 2000 in White Rock Lake, Dallas, Texas (Modified from VanMetre and Callender, 1997).

contributed to large increases in motor vehicle traffic. This suggests that urban sprawl in outlying areas may affect traffic patterns and water quality in inner cities (VanMetre and Mahler, 1999).

CONCLUSIONS: LOCAL TO NATIONAL CONTEXT

Collectively, NAWQA assessments indicate that the Nation's waters are generally suitable for irrigation, drinking water supply, and other home and recreational use. Major challenges remain in every basin, however, in protecting aquatic resources from nonpoint sources of pesticides, nutrients, metals, VOCs, naturally occurring pollutants, and other contaminants that continue to enter waterways. Comparisons of findings among the basins reveal some common issues, such as the occurrence of complex mixtures and breakdown products in agricultural and urban settings. Comparisons also indicate that contaminant concentrations vary from season to season and among watersheds because of differences in land and chemical use, land-management practices, degree of watershed development, and natural features. Understanding these variations and their causes helps to prioritize issues and implement effective management for water-quality improvement in specific geographic areas (see Figures 5 and 6).

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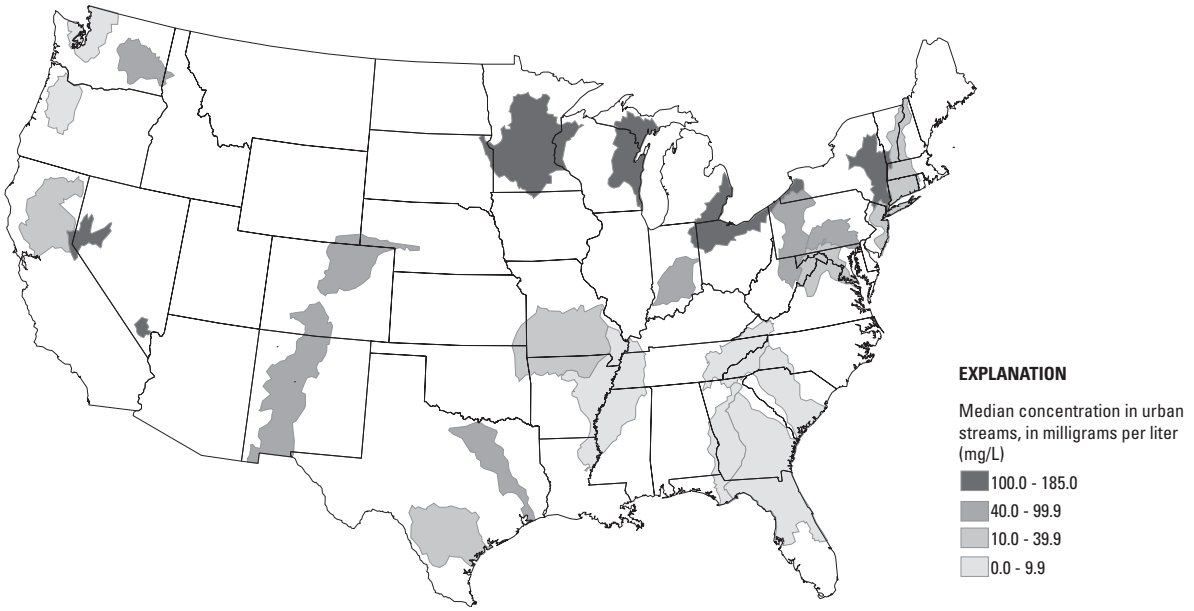

Figure 5. Concentrations of Chloride in a National Context. Median concentrations of chloride were highest in urban streams in the Upper Mississippi River Basin and other study units in the north-central and northeastern parts of the U.S. because of runoff of de-icing chemicals applied to roads and highways. Findings for Shingle Creek and 13 other major streams in the Minneapolis metropolitan areas indicate significant relations between chloride concentrations and impervious surfaces and snowmelt. The information, placed in the context of other sampled urban watersheds, particularly in the north-central and northeastern United States, helped to demonstrate to the Shingle Creek Watershed Management Commission that elevated chloride in Shingle Creek was not a local stockpile issue. The Commission has since recommended a metropolitan approach to assess current practices of road salt use, which is leading to improved strategies needed to meet Minnesota water-quality standards (Stark *et al.*, 2000).

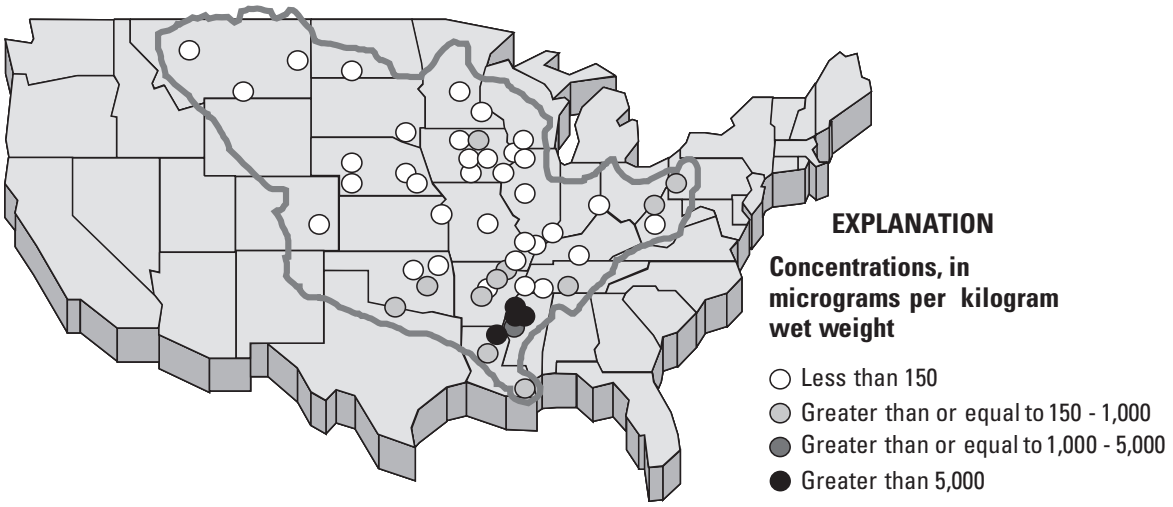

Figure 6. DDT in Fish Tissue in the Mississippi River Valley. Concentrations of DDT in streams and rivers were often higher in the Mississippi River Embayment than national norms. Specifically, fish collected in 1995 during an interdisciplinary USGS study found that the highest total DDT concentrations in the Mississippi River Valley were measured in the Mississippi Embayment NAWQA study unit. These results have contributed to decisions by the State of Mississippi to establish fish-consumption advisories for selected organochlorine compounds and other contaminants (Kleiss *et al.*, 2000).

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A NATIONAL LOOK AT WATER QUALITY

Robert J. Gilliom, David K. Mueller, John S. Zogorski, and Sarah J. Ryker

INTRODUCTION

Most water-quality problems we face today result from diffuse "nonpoint" sources of pollution from agricultural land, urban development, forest harvesting and the atmosphere (U.S. Army Corps of Engineers *et al.*, 1999). It is difficult to quantify nonpoint sources because the contaminants they deliver vary in composition and concentrations from hour to hour and season to season. Moreover, the nature of the contamination is complex and varied. When Congress enacted the Clean Water Act 30 years ago, attention was focused on water-quality issues related to the sanitation of rivers and streams – bacteria counts, oxygen in the water for fish, nutrients, temperature, and salinity. Now, attention is turning to the hundreds of synthetic organic compounds like pesticides used in agricultural and residential areas, volatile organics in solvents and gasoline, microbial and viral contamination, and pharmaceuticals and hormones.

Although a complete national picture of these complex water-quality issues is not yet possible, the first decade of studies (1991 to 2001) by the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program provides significant new findings about the quality of our nation's water resources. Comprehensive assessments of pesticides, nutrients, volatile organic compounds (VOCs), trace metals, and aquatic ecology are developed at the national scale through synthesis and analysis of findings in NAWQA study units (see article by Hamilton). A summary of findings in 36 of the 51 study units is included in this article. These 36 study units were intensively investigated from 1992 to 1996 and from 1996 to 1998. Comprehensive syntheses that include findings from the remaining 15 study units will be available in 2003. (Refer to Figure 1, pg. 6, in the article by Hamilton for locations of study units.)

WATER QUALITY IN AGRICULTURAL AREAS

Assessments of more than 100 agricultural watersheds and shallow ground-water systems in the 36 study units indicate widespread nonpoint source contamination of our streams and ground water. For example, nitrogen and phosphorus commonly were found at concentrations that contribute to excessive plant growth in streams. In nearly 80 percent of streams sampled, average annual concentrations of phosphorus were greater than the U.S. Environmental Protection Agency (USEPA) desired goal for preventing nuisance plant growth, which can lead to dissolved oxygen levels that are low enough to be harmful to fish and other aquatic life.

Nitrate is prevalent in shallow ground water (less than 100 feet below land surface) beneath agricultural areas, where about 20 percent of samples exceeded the USEPA drinking-water standard for nitrate (10 milligrams per liter as nitrogen). This is a key issue in areas where shallow wells are used for domestic supply. Domestic wells are not regulated and owners often do not know the quality of their well water or whether their wells are vulnerable to contamination.

Nitrate most often is elevated in karst (carbonate) areas or where soils and aquifers consist of sand and gravel. These natural features enable rapid infiltration and downward movement of water and chemicals. Some of the more vulnerable areas of the nation are the Central Valley of California, and parts of the Pacific Northwest, the Great Plains, and the Mid-Atlantic region. In contrast, contaminants are barely detectable in ground water underlying farmland in parts of the upper Midwest, despite similar high rates of chemical use. In these areas ground-water contamination may be limited because of relatively impermeable, poorly drained soils and glacial till that cover much of the region, and because tile drains provide quick pathways for runoff to streams.

Detectable concentrations of pesticides are widespread. At least one pesticide was detected in more than 95 percent of stream samples and in more than 60 percent of shallow wells sampled in agricultural areas. A relatively small number of these chemicals, specifically the herbicides atrazine (and its breakdown product desethylatrazine), metolachlor, cyanazine, and alachlor, accounted for most detections. The occurrence of these commonly detected pesticides is related to their use; they are in the top five in national herbicide use for agriculture.

Insecticides that were used in the past still persist in agricultural streams and sediment. DDT was the most commonly detected organochlorine compound, followed by dieldrin and chlordane. Their uses were restricted in the 1970s and 1980s, and yet, more than 20 years later, one or more sediment-quality guidelines for these compounds were exceeded at more than 20 percent of agricultural sites.

WATER QUALITY IN URBAN AREAS

Nonpoint chemical contamination is not just an agricultural problem. A synthesis of findings in 35 urban watersheds and shallow ground-water systems ("urban" refers primarily to residential and commercial development over the last 50 years) indicates that water in urban areas has a characteristic chemical "signature" that is closely linked to the chemicals used in the watersheds. Insecticides – such as diazinon, carbaryl, chlorpyrifos, and malathion – were detected more frequently and usually at higher concentrations in urban streams than in agricultural streams. All urban streams sampled had concentrations of insecticides that exceeded at least one guideline established to protect aquatic life. Herbicides

also are widespread – detected in 99 percent of urban stream samples and in more than 50 percent of sampled wells. The most common herbicides in urban streams and ground water were simazine and prometon.

Concentrations of total phosphorus are as high in urban streams as in agricultural ones, and exceeded guidelines in 70 percent of sampled streams. Nitrate, however, is less prevalent in shallow ground water beneath urban areas, where less than 3 percent of samples exceeded the USEPA drinking-water standard for nitrate.

Concentrations of selected trace elements, such as cadmium, lead, zinc, and mercury, are elevated above background levels in heavily populated urban settings, most likely a consequence of emissions from industrial and municipal activities and motor vehicles. Sediment cores from streambeds and reservoirs, which can be used to track changes over long time periods, indicate that lead increased from 1940s to the 1970s, and began to decrease after it was removed from gasoline. Concentrations, however, are not yet down to background levels.

VOCs, which are used in plastics, cleaning solvents, gasoline, and industrial operations, are prevalent in shallow urban ground water. Some of the most frequently detected compounds were the commercial and industrial solvents trichloroethene (TCE) and tetrachloroethene (PCE); the gasoline additive methyl *tert*-butyl ether (MTBE); the gasoline hydrocarbon methylbenzene (toluene); and the solvent and disinfection-by-product of water treatment, trichloromethane (also known as chloroform).

Sediment in urban streams is more likely to be contaminated with the historically used pesticides DDT, chlordane, and dieldrin than sediment in agricultural streams. Sediment-quality guidelines for organochlorine pesticides were exceeded at 36 percent of sampled urban sites. Moreover, these compounds, as well as PCBs, were found in fish tissue from urban water bodies, usually at higher concentrations than in sediment. One or more organochlorine compounds were detected in 97 percent of whole fish samples collected at urban sites, and PCBs were detected in more than 80 percent of whole fish samples. Concentrations of organochlorine compounds exceeded guidelines to protect wildlife at more than 10 percent of urban sites; wildlife guidelines for PCBs were exceeded at nearly 70 percent of urban sites. These findings have contributed to decisions by some states to issue fish-consumption advisories.

Biological communities that inhabit streams draining urban areas indicated degraded water quality more frequently than those communities in streams draining forested or undeveloped areas. Pollution-tolerant algae and aquatic invertebrates (such as worms and midges), as well as omnivorous fish communities, prevailed at the degraded sites. Deteriorated water quality and sediment, as well as habitat disturbances, contribute to the degraded biological communities. The greatest effects were seen in areas with the highest human population densities and watershed development.

The Occurrence of Methyl Tert-Butyl Ether (MTBE) . . . *A unique characteristic of the NAWQA Program is its ability to sample and analyze at very low concentrations (down to parts per trillion) for selected trace elements, more than 80 different pesticides, and more than 80 different VOCs. Thus, chemicals can be detected at concentrations that are 10 to 1,000 times lower than the standards set by USEPA and many states. The low-level analysis identifies the chemicals that are present, and whether concentrations are increasing or decreasing over time. This methodology also identifies "emerging" contaminants that might not otherwise be targeted for analysis – such as methyl tert-butyl ether (MTBE), the gasoline additive used to decrease vehicular carbon monoxide emissions and ozone levels in the atmosphere. An unintended consequence of MTBE use is its widespread occurrence in ground water because of its tendency to persist in ground water for years, even decades, and its ability to migrate long distances.*

MTBE was detected in about 5 percent of the ground-water samples collected by NAWQA across the nation. The concentrations typically were low, well below the USEPA drinking-water consumer advisory concentration of 20 to 40 parts per billion, which is based on taste and odor thresholds. MTBE was most frequently detected in ground water underlying urban areas in comparison to agricultural and mixed land-use settings (detected in about 14 percent of wells sampled in urban areas). In addition, MTBE was detected about 4 to 6 times more frequently in high-use areas, such as in Reformulated Gasoline (RFG) areas, where gasoline contains 11-percent MTBE by volume.

NAWQA works in partnership with the USEPA, the Metropolitan Water District of Southern California, Oregon Graduate Institute of Science and Environmental Engineering, and the American Water Works Association Research Foundation to assess MTBE concentrations associated with drinking-water supplies. A study on drinking water from selected communities in 12 states in the Northeast and Mid-Atlantic Regions showed that MTBE was detected in 9 percent of community water systems; less than 1 percent of the systems, however, exceeded the USEPA consumer advisory concentration for MTBE. A study including about 1,000 water utilities showed that the frequency of detecting MTBE increases with larger community water systems. Specifically, MTBE was detected in about 4 percent of community water systems serving less than 10,000 people, and in nearly 15 percent of systems serving more than 50,000 people. Access to supporting technical information, references, and raw data is at http://www.sd.cr.usgs.gov/nawqa/vocns/.

LAY OF THE LAND MATTERS

Understanding how natural features and land-management practices affect water quality can help improve watershed management. Natural features – topography, geology, soil type, hydrology, and climate – and land-management practices – tile drainage and irrigation and conservation strategies – make some areas more vulnerable to contamination. For example, regression models showed that basin size, soil permeability, and runoff characteristics are significant factors in explaining stream concentrations of atrazine and four other commonly used herbicides. Annual agricultural use is the most important factor. NAWQA studies showed that elevated concentrations of nitrogen and phosphorus in streams are common in two types of settings: (1) arid or semiarid areas with moderate to steep slopes where

vegetation is likely insufficient to slow runoff or take up all available nutrients, and (2) flat areas with poorly drained soils where artificial drains and ditches provide quick pathways for runoff to streams.

NATURALLY OCCURRING CONTAMINANTS

Some contaminants in water are not derived from human activities associated with agricultural lands and urban development, but occur naturally in the environment. NAWQA studies the occurrence of, and factors controlling, the distribution of 31 trace elements, such as selenium, chromium, uranium, radon, and arsenic. For example, USGS assessments indicated that concentrations of arsenic in more than 31,000 potable untreated water samples were almost always lower than the previous USEPA drinking-water standard of 50 parts per billion (Welch *et al.*, 2001). Concentrations in about 10 percent of the samples, however, exceeded 10 parts per billion, a provisional limit set by the World Health Organization and the new USEPA drinking-water standard (November 2001) (Figure 1). The concentrations of naturally occurring arsenic in ground water vary from region to region because of a combination of natural features, including geologic features and ground-water chemistry. Widespread elevated concentrations of arsenic in ground water were found in drinking-water aquifers in the West, Great Lakes region, and New England. Moderate to high concentrations were found in parts of the central and southern United States. Elevated concentrations were least frequent in the Southeast.

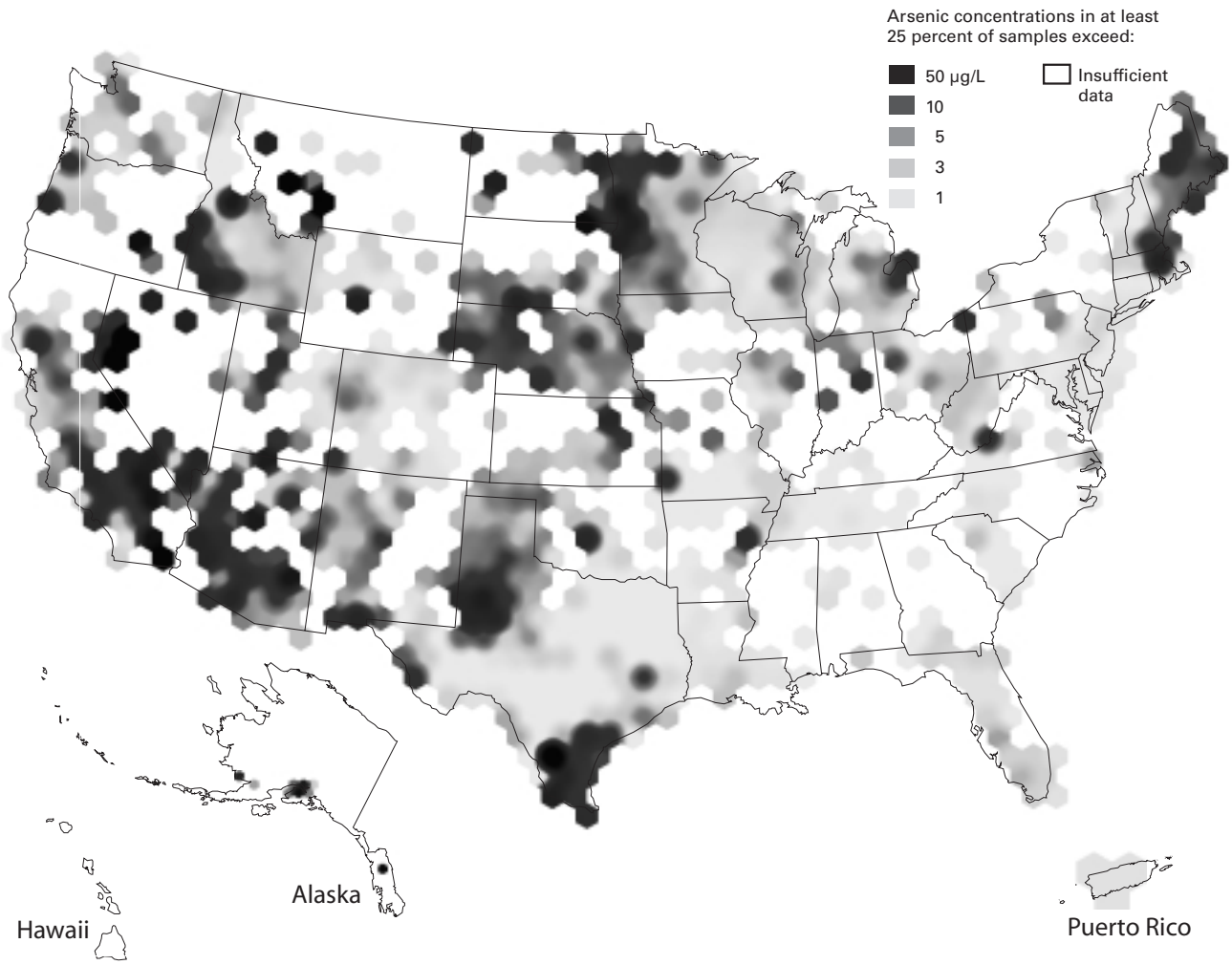

Figure 1. A National Look at Arsenic Concentrations. Arsenic concentrations in potable untreated ground water generally were highest in the West and lowest in the Southeast, but elevated concentrations were found locally within each physiographic province because of geochemical conditions. The data, representing 31,350 samples, were collected between 1973 and 2001 by USGS (20,050 samples) and the States of Minnesota, Texas, and Wisconsin. *Note that this map was not intended to be used to identify high arsenic at an individual well or water system. Concentrations can be locally variable because of well type, well depth, aquifer type, geology, and other factors.* Access to supporting technical information and raw data is at http:/water.usgs.gov/nawqa/trace/.

CONSIDERATIONS FOR HUMAN HEALTH AND AQUATIC ECOSYSTEMS

Contaminants were found at concentrations below current USEPA drinking-water standards and guidelines in most samples of streams and ground water, but U.S. and Canadian aquatic-life guidelines were exceeded in many streams. For example, concentrations of insecticides exceeded at least one guideline established to protect aquatic life in every urban stream sampled.

The actual risks to humans and aquatic life, however, are only partially addressed by comparing measured concentrations to established standards and guidelines. For example, individual compounds seldom occur alone; more than 70 percent of stream samples collected in agricultural and urban areas contained five or more pesticides. Existing standards and guidelines do not address whether exposure to contaminant mixtures, even at low concentrations, may have adverse cumulative effects. In addition, chemical breakdown products, which can have similar or even greater toxicities than parent compounds, are often as common in the environment as parent compounds. Thus, standards and guidelines for individual parent compounds may sometimes underestimate risk.

In addition, USEPA standards have not been established for many individual contaminants and their breakdown products; only about half of the pesticides and VOCs measured in these NAWQA investigations have standards. Furthermore, even for compounds that have standards, the potential impacts on the reproductive, nervous, and immune systems of aquatic organisms have not been tested. Many of the 20 most frequently detected pesticides may have the potential to affect reproduction or development of aquatic organisms or wildlife by interfering with natural hormones.

The timing of exposure to contaminants is another factor in assessing potential effects on humans and aquatic life. Typically, lengthy periods of low concentrations of contaminants are punctuated by seasonal pulses of much higher concentrations. USEPA standards for drinking water are based on long-term average concentrations.

The USEPA integrates findings from the NAWQA Program into management and regulatory considerations, such as pesticide registration and drinking-water protection. USGS and USEPA frequently exchange information and develop collaborative studies. For example, in 1999, NAWQA and USEPA initiated a two-year monitoring program for assessing pesticide concentrations in drinking water. In support of the USEPA's responsibility under the Food Quality Protection Act of 1996, the program is a first step towards a long-term goal of characterizing human exposure to pesticide residues in drinking water derived from surface-water sources. Reservoirs were selected for sampling because they are important sources of drinking water and because they integrate pesticide loadings from their watersheds. A total of 116 of 186 pesticides and breakdown products were detected in at least one sample of raw or finished water. Many of the compounds, however, were detected in fewer than 5 percent of the samples and at concentrations very near the analytical-reporting levels—often 10 to 1,000 times lower than USEPA standards and health advisories. Access to supporting technical information and raw data is at http://md.water.usgs.gov/nawqa.

"The USEPA has been required to factor potential exposures to pesticides through drinking water into already complex procedures used to set pesticide "tolerance levels" in foods…We do not have all the answers yet by any means, but we in the USEPA who are charged with implementing this part of the new Food Quality Protection Act (passed in August 1996) are greatly impressed with the knowledge and expertise contributed by NAWQA Program scientists and managers to assist the USEPA in addressing the questions." (Joseph Merenda, Office of Pesticide Programs, USEPA).

CONCLUSIONS

The NAWQA Program has assessed and documented major patterns of contamination in the nation's streams and ground water—patterns that have important implications for water-quality management and policy. Policies that take advantage of these science-based insights will help to (1) improve water-quality management and regulations so that they better reflect the complexities of contaminant occurrence, (2) identify key sources of nonpoint pollution, and (3) improve investments in monitoring and management across the nation's diverse landscapes. For example, water-quality standards and guidelines need to address the occurrence of contaminant mixtures, breakdown products, and seasonal pulses of contaminants. Monitoring programs cannot rely on one or two samples per year and should be designed to simultaneously measure streamflow and multiple compounds in one sample. In addition, not all water resources are at equal risk of contamination. Controlling nonpoint source pollution may, therefore, require targeted actions based on local and regional vulnerability rather than uniform treatment of contaminant sources. This approach requires knowledge of chemical use, contaminant occurrence, and local and regional effects of land-management practices and natural features.

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ASSESSING FIVE NATIONAL PRIORITIES IN WATER RESOURCES

William G. Wilber and Carol A. Couch

INTRODUCTION

In 2001, the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) began its second decade of studies. A total of 42 study units (major river basins and aquifers across the nation) will be reassessed in three groups of 14 on a rotating schedule. Each group of study units will be studied intensively for three years, followed by six years of low-intensity assessment.

One of the primary goals in the second decade is to improve understanding of the key processes that control water-quality conditions in order to establish the links among the *sources* of contaminants, their *transport* through the hydrologic system, and the *effects* of contaminants and physical alterations on stream biota and ecosystems and on the quality of drinking water. An improved understanding of these links will provide the basis for predicting water-quality conditions in unmonitored areas and for predicting the likely effects of contemplated changes in land- and water-management practices.

TOPICAL STUDIES

The NAWQA Program, in collaboration with government, research, and interest-group partners, has selected five topics of regional and national importance for initial study. The five "topical studies" and defining questions are:

Effects of Nutrient Enrichment of Streams (Figure 1a) – How do biological communities (including algae, macrophytes, and invertebrates) and associated community functions (for example, those related to stream metabolism and nutrient uptake) respond to varying levels of nutrient enrichment in agricultural streams in different environmental settings?

Sources, Transport, and Fate of Agricultural Chemicals (Figure 1b) – How do environmental processes and agricultural practices (for example, tile drains, irrigation, and buffer strips) affect the transport and fate of chemicals in the hydrologic systems of nationally important agricultural settings? What are the effects on the quality of streams and ground water?

Transport of Contaminants to Water Supply Wells (Figure 1c) – What are the primary sources and transport mechanisms that affect the occurrence of natural and anthropogenic contaminants in ground water tapped by drinking-water supply wells? What are the important transformation processes (for example, those related to the degradation of pesticides and volatile organic compounds)? What effects do well location, well depth, and pumping rates have on transport and transformation of selected contaminants?

Effects of Urbanization on Stream Ecosystems (Figure 1d) – How do stream ecosystems respond to land-use changes associated with urbanization? How do these responses vary across different environmental settings?

Bioaccumulation of Mercury in Aquatic Organisms (Figure 1e) – What are the environmental and biological factors that govern the transformation of mercury into methyl-mercury in aquatic food chains? What are the most important sources of mercury?

Each of the topical studies will provide information on the implications of scientific findings for land and water management. Management issues addressed include the development of regional nutrient criteria for streams; implementation of agricultural management practices and their effects on the natural hydrology and transport of chemicals; protection of source waters and drinking water; restoration of streams; development of fish advisories; and, management of ecosystems.

The five topical studies, which vary in scope and complexity, are the starting point for assessments of national priority issues that will continue throughout the second decade of the NAWQA Program. As the topical studies progress through the rotating groups of study units, relative emphasis on topics may shift and new topics may be added. Implementation of four of the first five topical studies began in 2001; the study on urbanization and its effects on stream ecosystems began in 1999, and preliminary findings are provided below.

Effects of Urbanization on Stream Ecosystems

This investigation was initiated in 1999 in the metropolitan areas of Anchorage, Alaska; Birmingham, Alabama; Boston, Massachusetts; Chicago, Illinois; Cincinnati-Dayton, Ohio; Los Angeles, California; Philadelphia, Pennsylvania-Trenton, New Jersey; and Salt Lake City, Utah. Additional studies began in 2001 in Atlanta, Georgia; Reno-Sparks, Nevada; Dallas-Fort Worth, Texas; Denver, Colorado; Raleigh-Durham-Chapel Hill, North Carolina; Milwaukee, Wisconsin; and Portland-Salem-Eugene, Oregon (Figure 2). In all of these studies, urbanization is defined as the conversion from rural land uses to residential and commercial uses that are typical of recent, generally sprawling, urban-growth patterns. Specific questions addressed by all studies include:

- *How do stream hydrology, water chemistry, habitat, and biological communities change as watersheds are urbanized? Are there threshold levels of watershed urbanization, which if exceeded, result in significant degradation of stream ecosystems?*

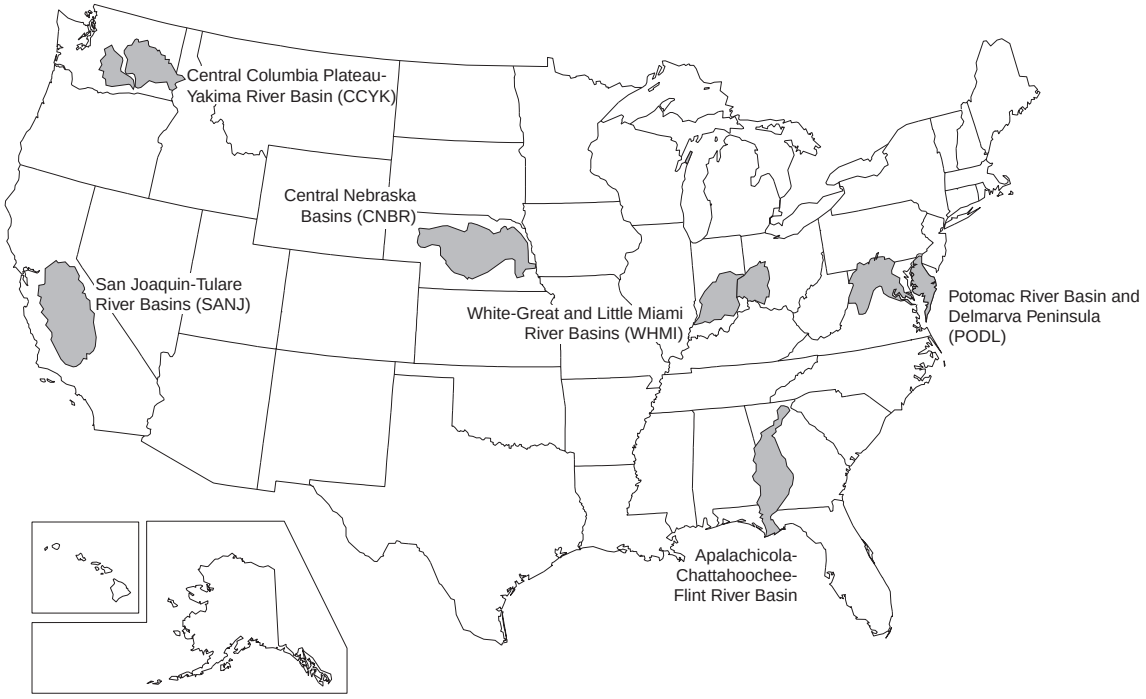

Figure 1a. Study Units Assessing the Effects of Nutrient Enrichment of Streams, 2001 to 2004.

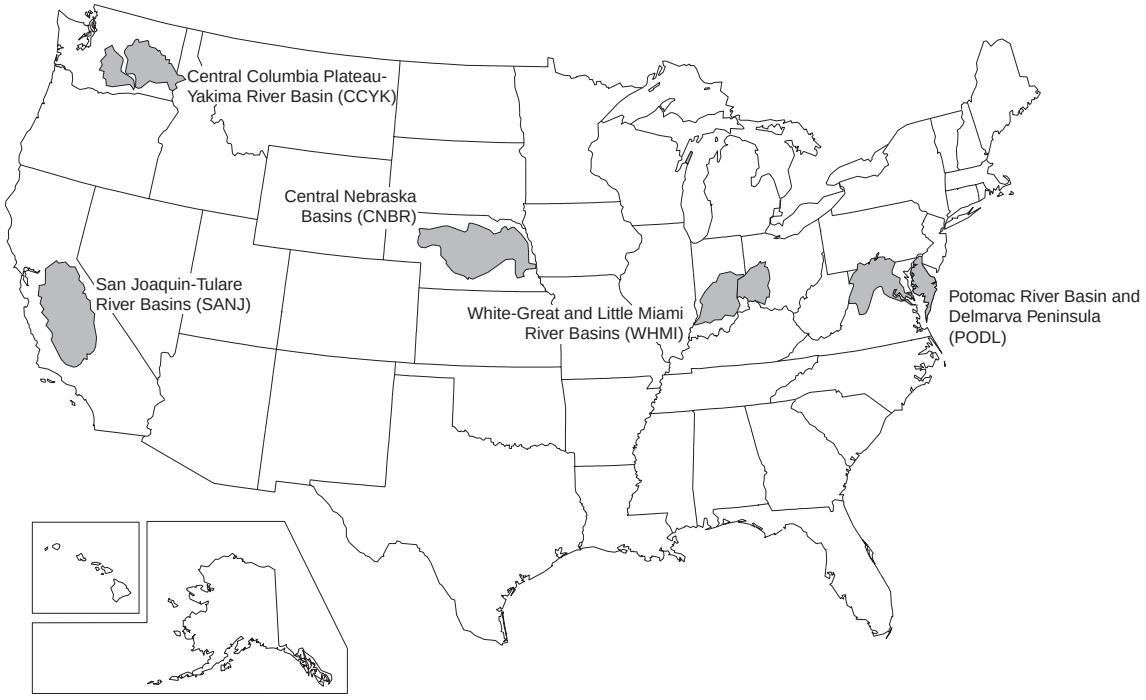

Figure 1b. Study Units Assessing Sources, Transport, and Fate of Agricultural Chemicals, 2001 to 2004.

Figures 1a through 1e. Locations of Study Units Involved in Topical Studies. Topical studies are conducted in selected study units that are affected by the issues. Collectively, the coordinated set of studies helps to demonstrate how controls on water quality vary across the country in different natural and land-use settings.

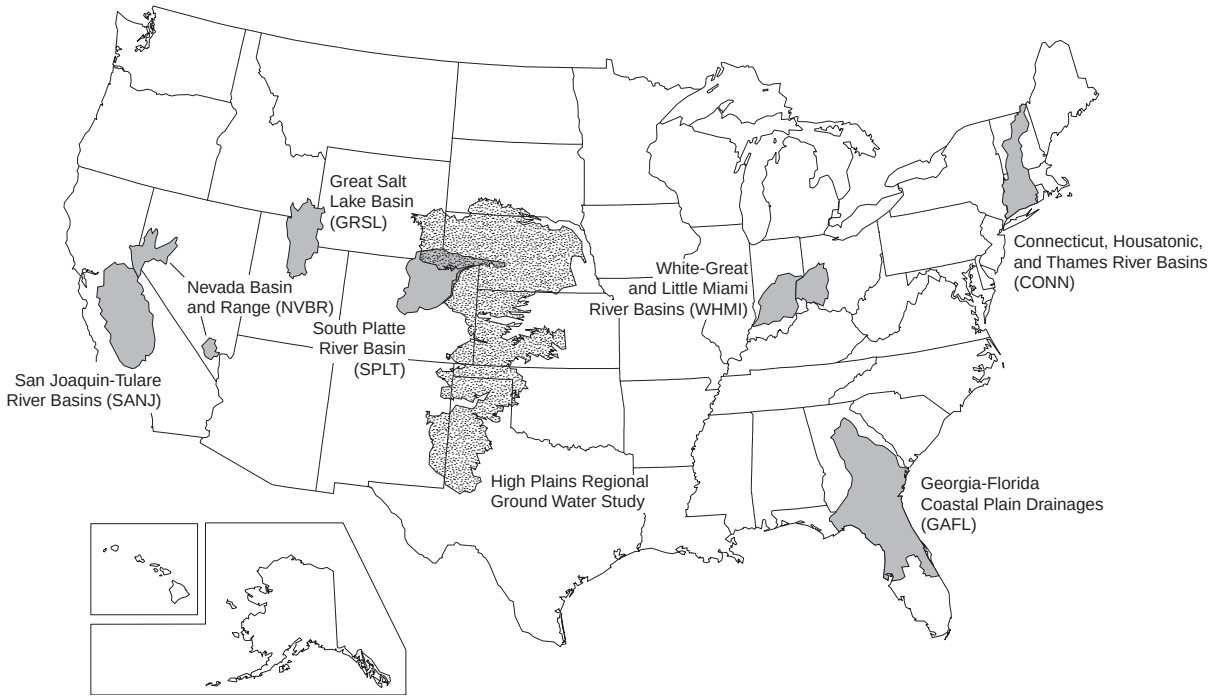

Figure 1c. Study Units Assessing Transport of Contaminants to Water Supply Wells, 2001 to 2004.

Figure 1d. Study Units Assessing Effects of Urbanization on Stream Ecosystems, 2001 to 2004.

Figures 1a through 1e (cont'd). Locations of Study Units Involved in Topical Studies. Topical studies are conducted in selected study units that are affected by the issues. Collectively, the coordinated set of studies helps to demonstrate how controls on water quality vary across the country in different natural and land-use settings.

Figure 1e. Study Units Assessing Bioaccumulation of Mercury in Aquatic Organisms, 2001 to 2004.

Figures 1a through 1e (cont'd.). Locations of Study Units Involved in Topical Studies. Topical studies are conducted in selected study units that are affected by the issues. Collectively, the coordinated set of studies helps to demonstrate how controls on water quality vary across the country in different natural and land-use settings.

Figure 2. Fifteen Metropolitan Areas Where NAWQA is Studying the Effects of Urbanization on Stream Ecosystems.

- *What watershed characteristics, such as basin slope, geology, and soils, are most important in governing the hydrologic, chemical, and biological responses to urbanization?*

- *How do biological responses to urbanization vary among the diverse environmental settings of these metropolitan areas?*

- *What are the susceptibilities of specific aquatic organisms to water-quality degradation caused by urbanization?*

- *What are the best measures for monitoring water quality in watersheds that are becoming increasingly urbanized?*

Data from the 1999 studies are being compiled and interpreted; findings will be reported in journals and USGS reports in 2003. Preliminary analysis indicates that:

- Rapid degradation of stream ecosystems occurs early in the process of watershed urbanization. For example, in Anchorage, invertebrate communities that are sensitive to pollution and habitat modifications declined when about 5 percent of land cover in the watershed was converted to "impervious area," such as roads, parking lots, and houses.

- Early, rapid degradation is associated with deforestation and other processes that alter hydrology, stream temperature, and habitat. In some areas, these physical factors severely degrade biological communities before nutrients and other contaminants from nonpoint sources reach concentrations that may further degrade the communities.

- The magnitude of stream ecosystem response generally is greater when forests or rangeland are urbanized than when agricultural areas planted in row crops are urbanized.

Studies in the 15 metropolitan areas will better define the interrelationships among water quality, stream hydrology and habitat, and ecosystems. In addition, these studies will lead to improved and comparable techniques for biological monitoring, and to the development of key indicators of the effects of urbanization on environmental quality. Information on the magnitude and pattern of degradation of stream ecosystems will help urban planners and other stakeholders prioritize streams for restoration. Understanding the effects of habitat disturbance, in addition to chemical contamination, within a given setting will help clarify the most appropriate strategy for managing, protecting, and restoring urban streams.

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CHANGES IN WATER QUALITY OVER TIME

David K. Mueller, Wayne W. Lapham, Martin E. Gurtz, and Peter C. VanMetre

INTRODUCTION

Water quality is constantly changing, from season to season and from year to year. It is sometimes difficult to distinguish these short-term fluctuations from long-term trends. For many chemicals, it is too early to tell whether concentrations have increased or decreased because historical data are insufficient or too inconsistent to define any trends.

Despite these challenges, some trends in water quality were evident during the first decade of studies of river basins and aquifers (referred to as "study units") across the nation by the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program (1991 to 2001). Some of the trends were determined through analysis of lake and reservoir sediment cores, which provide a "water-quality history" or chronicle of chemical changes as watersheds change over time and as new chemicals are introduced into the environment. The cores indicated dramatic improvements in water quality for regulated contaminants including lead, DDT, and polychlorinated biphenyls (PCBs). Conversely, the same cores indicated significant declines in water quality as watersheds urbanized. The largest increases in concentrations were noted for polycyclic aromatic hydrocarbons (PAHs). The increases most likely relate to increasing motor vehicle traffic in watersheds (VanMetre *et al.*, 2000)

Decreases in concentrations in whole fish of organochlorine insecticides, such as DDT, dieldrin, and chlordane, also were identified through comparison of NAWQA biological data with historical data collected by other monitoring programs. Just as notable as these decreases, however, is that these long-restricted insecticides still are found at elevated concentrations in fish and streambed sediment in many agricultural and urban areas across the nation. For example, sediment-quality guidelines for organochlorine pesticides were exceeded at 36 percent of sampled urban sites (U.S. Geological Survey, 2001).

NAWQA findings, along with historical data, also showed changes in nutrient concentrations over the past 20 years in rivers downstream from wastewater treatment plants. In the Trinity River downstream from Dallas, Texas, improved treatment processes resulted in decreased concentrations of ammonia and phosphorus despite urban population growth. As concentrations of ammonia decreased, however, concentrations of nitrate increased because ammonia is converted to nitrate during the sewage treatment process. Concentrations of total inorganic nitrogen thereby remained the same. The discharge is less toxic to fish because of the lower ammonia concentrations; however, the potential for excessive plant growth in streams due to total inorganic nitrogen was not reduced.

Two of the most important contributions during the first decade of studies have been the establishment of baseline conditions for comparison to results of future assessments, and the initiation of long-term monitoring in every basin. Evaluation of trends will be a major focus during the second decade of studies (2001 to 2011) when streams and aquifers will be intensively reassessed in 42 NAWQA study units. As the program progresses, 10 or more years of comparable data will be available for an increasing number of stream and ground-water sampling sites. These data will be used to evaluate long-term trends and changes in the quality of water at sites that represent a large proportion of the nation's water resources. To the extent possible, identified trends will be related to probable causes. Typical questions to be addressed include:

- *Have concentrations of selected chemicals changed in aquifers used for drinking-water supply, and in recently recharged ground water upgradient of those principal aquifers?*

- *Have concentrations of chemicals and the condition of aquatic communities and ecosystems changed in streams representative of different hydrologic landscapes, ecoregions, and land uses?*

- *Has the quality of ground water or streams (including stream ecosystems) changed in response to urbanization or in response to changes in agricultural management practices, such as tillage methods, chemical use, or crop patterns?*

TRENDS NETWORKS

Sampling networks for determining trends have been established for (1) surface water, focusing on the chemical, physical, and biological quality of rivers and streams; (2) ground water, focusing on the chemical and physical quality of principal aquifers and shallow ground water; and, (3) sediment, focusing on trace elements and organic contaminants in lakes and reservoir bed sediment.

Surface-Water Network

The surface-water trends network is composed of 137 sites on streams and rivers that were sampled during the first decade of the NAWQA Program. In addition, 21 new sites will be included by 2009. Sites largely representing a single upstream land use are known as "indicator sites;" sites representing multiple-land-use settings are known as "integrator sites" (Figure 1).

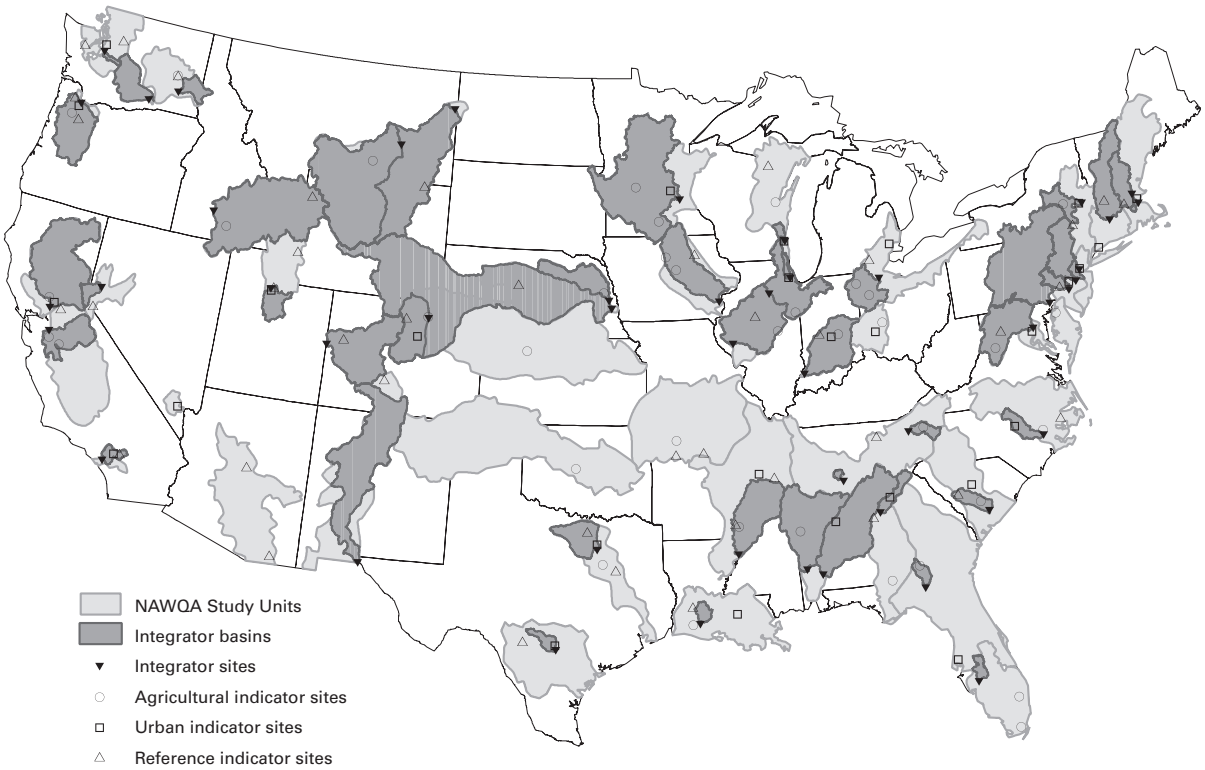

Figure 1. Surface-Water Trends Network. The surface-water trends network is composed of sampling sites on streams and rivers that represent important urban, agricultural, and reference land uses.

Agricultural indicator sites were selected to provide proportional coverage of the most important agricultural settings in the nation, defined by a combination of crop type, physiography, and climate. The network includes 33 sites previously sampled by NAWQA and nine new sites in 34 different agricultural settings. Urban indicator sites are located in 28 of the nation's 50 largest metropolitan areas. These sites are located downstream from recent residential and commercial development and in areas expecting substantial growth in the near future. Reference indicator sites are located in relatively undeveloped and minimally disturbed areas in environmental settings similar to the agricultural and urban indicator sites. In addition, a few reference sites are located downstream from relatively pristine areas, such as in national parks. The network includes 36 reference sites, five of which are new sites added in 2002.

Each of the indicator sites is nested within one of the larger integrator basins, which represent large river networks that integrate the mix of land uses and human activities. The integrator sites generally are located at the most downstream point of a basin. The network includes 47 integrator sites in 39 study units; monitoring at two additional sites is planned in 2009.

All surface-water trends sites have continuous monitoring of streamflow and specific conductance. Periodic samples are collected for analysis of nutrients (nitrogen and phosphorus), suspended sediment, organic carbon, and water-soluble pesticides. Volatile organic compounds (VOCs) also are sampled at urban sites. Samples are collected monthly or bi-monthly, depending on data requirements for trend evaluation. In addition, each site will be more intensively sampled (up to about 25 samples per year) during a two-year period on a rotational basis. Biological sampling is done once a year at about 90 percent of the sites. Sampling includes algal, invertebrate, and fish community measurements and characterization of physical habitat conditions.

Ground-Water Network

The ground-water trends network builds on results from 225 studies, each of which included sampling of about 25 to 30 wells during 1993 to 2001. These studies assessed water quality in selected major aquifers and in shallow ground water beneath agricultural, urban, and other land-use settings. A total of 69 of these study areas will be reassessed to determine ground-water quality trends (Figure 2). In addition, 22 new studies will be added by 2009.

Sites used to sample shallow ground water were selected, in part, on the basis of the aquifer's importance either as a source for drinking water or because it is hydraulically connected to a deeper aquifer used for

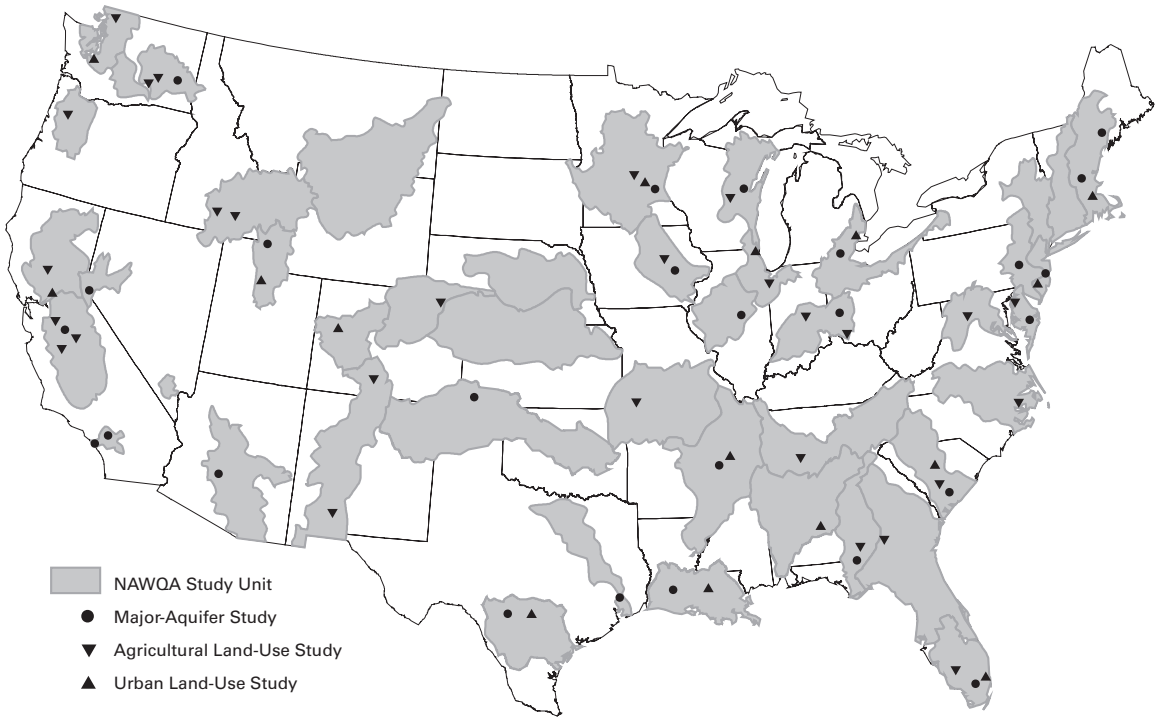

Figure 2. Ground-Water Trends Network. The ground-water trends network is composed of sampling sites in principal aquifers and shallow ground water underlying agricultural, urban, and undeveloped land-use settings.

drinking-water supply. In addition, the sites were selected on the basis of the aquifer's vulnerability to contamination from the land surface, as measured by anthropogenic and natural controls, such as fertilizer and herbicide use, population density and growth, soil texture, aquifer permeability, climate, and irrigation intensity.

Sites used to sample deeper ground water (refer to Major Aquifer Studies, Figure 2) were selected, in part, because the aquifers serve as drinking-water supplies. In addition, the sites are representative of 16 principal aquifers across the nation: Glacial Deposits across the north-central and northeastern U.S.; Mississippi Embayment-Texas Coastal Uplands; High Plains; Basin and Range in Nevada and parts of California and Arizona; Floridan; Coastal Lowlands along the Gulf of Mexico; Piedmont and Blue Ridge; North Atlantic Coastal Plain; Cambrian-Ordovician in the Upper Midwest; Coastal Plain Surficial; Edwards-Trinity in Texas; New York and New England crystalline-rock; Columbia Plateau; Central Valley of California; California Coastal Basins; and the Biscayne in southern Florida.

During the first year of sampling, one sample will be collected from each of the wells. Samples will then be collected biennially in about five wells in each ground-water study to help determine trends. Chemical analysis includes major ions, nutrients, organic carbon, pesticides, VOCs, trace elements, and microbes.

Sediment Network

NAWQA began analyzing sediment cores in 1996 in 45 lakes and reservoirs in and around 14 urban areas (including Anchorage, Atlanta, Boston, Chicago, Dallas, Denver, Las Vegas, Los Angeles, Minneapolis, Newark/New York, Orlando, Salt Lake City, Seattle, and Washington, D.C.). In the second decade of NAWQA studies, sediment cores will be analyzed to assess changes in contaminants associated with urban, agricultural, and reference settings (Figure 3). Particle-associated contaminants analyzed by NAWQA include major and trace elements (such as arsenic, lead, mercury, and zinc), organochlorine pesticides (such as DDT, chlordane, and dieldrin), PCBs, and PAHs. These contaminants are toxic to aquatic life and thus have sediment-quality guidelines. In addition, some are of concern because they accumulate in fish and other wildlife or occur in drinking water. In fact, particle-associated contaminants were the cause of more than 2,800 fish-consumption advisories in the United States in 2000.

The primary focus of the sediment trends network is to:

- Assess the dramatic changes occurring in urban areas (for example, will PAHs continue to rise with traffic?), and link those changes with sources and controlling factors (as represented by 16 sites in 12 major urban areas).

Figure 3. Sediment Trends Network. Sediment cores will be analyzed to assess changes in contaminants associated with urban, agricultural, and reference settings.

- Determine chemical response to changes in agricultural land use (as represented by 18 sites in 16 different study units).

- Assess reference conditions (for example, what are the "pre-industrial" concentrations of trace elements) and atmospheric contributions (of trace elements such as mercury) in selected regions of the nation (as represented by 14 sites in 14 study units).

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ESTIMATING WATER-QUALITY CONDITIONS IN UNMONITORED WATER RESOURCES

David M. Wolock and Leon K. Kauffman

INTRODUCTION

Ideally, direct measurements of contaminant concentrations in streams and ground water would be available to characterize the exposure of aquatic organisms or the potential exposure of humans to contaminants in waters used as sources of drinking water. Because of the costs of such measurements, however, this is possible for a relatively small number of streams or wells. In addition, many strategies and challenges in water-resource management are related to predicting water-quality conditions in the future. Thus, concentrations of contaminants often must be indirectly estimated for unsampled locations and times using statistical and simulation models.

MODELING AND ANALYSIS

During its second decade of studies (2001 to 2011), the National Water-Quality Assessment (NAWQA) Program will emphasize the development and use of explanatory and predictive tools. Statistical analyses, geographic information systems (GIS), and process-oriented simulation models will be used to extrapolate information gained from direct measurements to unmonitored, comparable water resources and into the future. NAWQA is exploring the best methods – generally represented by a mix or hybrid of the statistical, GIS, and simulation techniques – to predict water-quality conditions on the basis of assessments of land use and land-management strategies, contaminant sources, natural characteristics of the land, and hydrologic transport processes. These methods will provide cost-saving tools for stakeholders at all levels to prioritize, manage, and protect their resources.

The modeling and analysis are used to improve understanding of the *sources* of contaminants; the *transport* of water and contaminants from the land surface to the stream, in the stream, and in the saturated and unsaturated zones as controlled by hydrologic features, watershed characteristics, and land-management strategies; and, the *effects* on aquatic ecosystems and drinking-water supplies. Results from the different model simulations and analyses will be synthesized on a national scale by "hydrologic landscape regions." These regions are similar in climate, geology, and topography. They provide a nationally consistent framework for synthesis and integration of data collection and modeling results from across the nation, and help delineate the role of hydrologic characteristics that affect contaminant transport and fate on the national scale.

CASE STUDIES

This article contains several examples of model development and analysis from the first decade of NAWQA studies. For the most part, model development has relied heavily on statistical regression in combination with GIS technology. This approach allows investigation of relations between concentrations of compounds and watershed and landscape characteristics, and, in large part, uses correlations to rank the likelihood and risk of contamination. The first case study, from the State of Washington, demonstrates the benefits of the use of regression and GIS analysis to assess the vulnerability of public-supply wells to pesticide contamination.

The second case study uses regression and GIS technology to assess risks of nitrate contamination of shallow ground water on a national scale. The results of these studies are used as a resource by the Office of Ground Water and Drinking Water of the USEPA, which sets standards for drinking-water contaminants and protects sources of drinking water.

The third case study uses regression and GIS analysis of selected herbicides in streams, in conjunction with a simulation model known as TOPMODEL. TOPMODEL is used to quantify the percentages of overland flow (runoff) and ground-water discharge to streamflow. The transport of contaminants, such as herbicides, can differ substantially in the different flow systems; therefore, the relative percentages of overland and ground-water flow in total streamflow is an important component in understanding the occurrence and fate of contaminants in streams.

The fourth case study demonstrates how USGS scientists used the regression model known as SPARROW (for SPAtially-Referenced Regression On Watershed attributes) to better understand the links between sources of contaminants and transport in some of the nation's major river basins (like the Mississippi). SPARROW analyses are used by states, federal agencies, and other watershed stakeholders to identify significant watersheds and sources contributing nitrogen to coastal systems, like the Gulf of Mexico, and to target nutrient-reduction areas (Priority Nutrient Reduction Areas) in Chesapeake Bay.

The final case study demonstrates the use of a process-oriented simulation model to predict changes in nitrate concentrations in streams and wells over time given various hypothetical changes in nitrogen use in Glassboro, New Jersey. Process-oriented simulation, in combination with statistical regression and GIS technology, will be emphasized in the NAWQA Program during the next decade in study-unit assessments, topical studies, and analysis of trends. The integration of these tools will allow predictions of effects of various land-management practices and land-use changes on water-quality conditions over time.

Pesticides in Ground Water in Washington State

In 1996, NAWQA scientists worked with the Washington State Department of Health to assess the vulnerability of public water-supply wells to pesticide contamination (Ryker and Williamson, 1996). Statistical analysis indicated that pesticide detection frequencies could be correlated with three factors: land use (predominantly agricultural and urban); well depth (less than 125 feet); and nitrate concentration (greater than 2.7 milligrams per liter). Using this analysis, the health department was able to identify wells having low vulnerability to contamination and thus obtain waivers for quarterly monitoring required under the Federal Amendments to the Safe Drinking Water Act, 1996. Thus, Washington State was able to protect drinking-water sources while saving at least $6 million in additional monitoring costs. This is an annual savings of as much as $70 per household on small public supply systems that were granted full monitoring waivers.

Estimating Risks of Nitrate Contamination to Shallow Ground Water Across the Nation

In collaboration with the Office of Ground Water and Drinking Water of the USEPA, the NAWQA Program developed a regression model and national map showing the patterns of risk for nitrate contamination of shallow ground water (Nolan *et al.*, 2002). The regression model integrates nitrogen inputs and aquifer susceptibility by use of GIS technology. Nitrogen inputs are estimated from commercial fertilizer application rates, percent cropland and pasture near a well, and population densities (the latter representing residential and urban nitrogen sources, such as septic systems, fertilizers, and domestic animal waste). Aquifer susceptibility is represented by soil-drainage characteristics – the ease with which water and chemicals can seep to ground water – depth to the seasonally high water table, and the presence or absence of unconsolidated sand and gravel aquifers.

Nitrate concentrations measured in NAWQA studies generally conform to the patterns of risk shown on the national map. Nitrate concentrations are expected to be lowest in areas shown by the lightest shade, where nitrogen inputs and aquifer susceptibility are lowest; and highest in the areas mapped with the darkest shade, which represent regions where nitrogen inputs and aquifer susceptibility are highest (Figure 1). Once ground water is contaminated, it is expensive and, in many cases, virtually impossible to clean up. By identifying regions with the highest risk of nitrate contamination, managers can more effectively target areas for pollution-prevention programs and long-term monitoring. Using risk guidelines to locate areas for pollution prevention also can result in cost-effective management.

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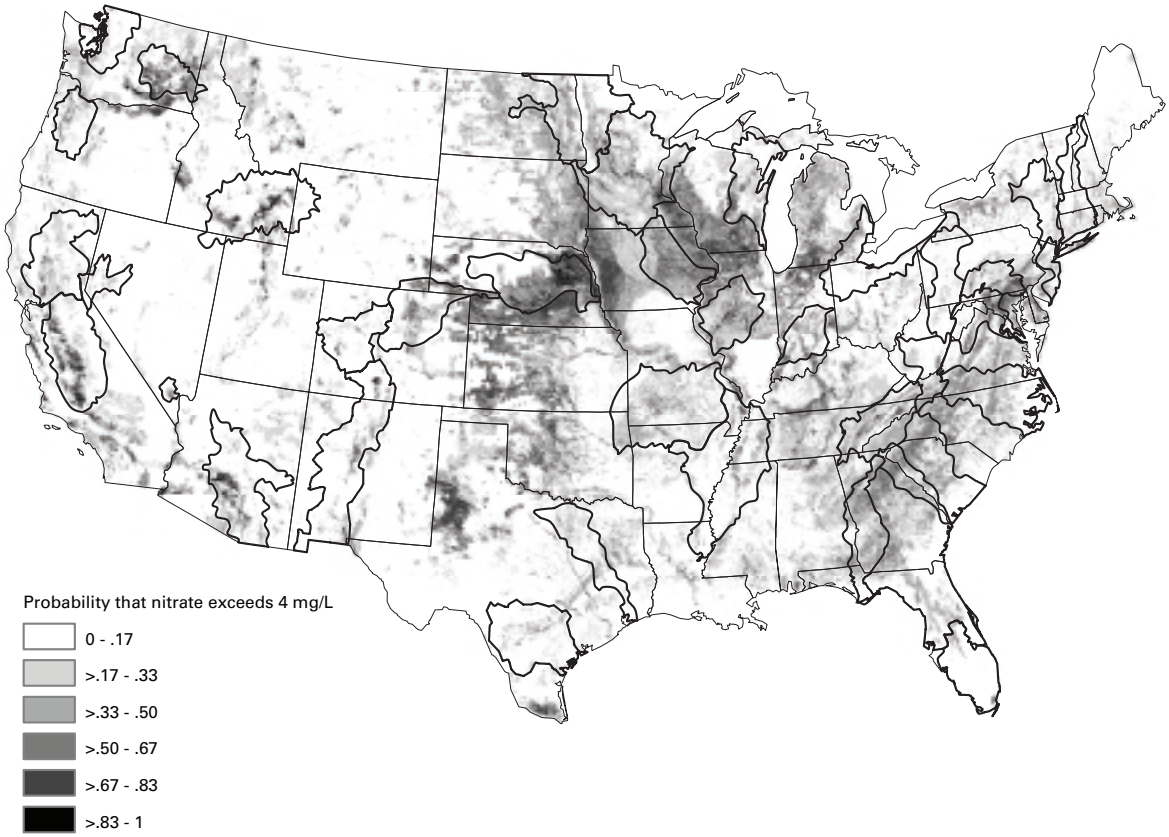

Figure 1. Concentrations of Nitrate in Shallow Ground Water. Areas with the highest risk for contamination of shallow ground water by nitrate generally have high nitrogen inputs to the land and well-drained soils overlying unconsolidated, coarse-grained deposits. *Use of this map to identify ground-water contamination in individual wells or aquifers is not advised because of the effects of local variations in land use, irrigation practices, aquifer type, and rainfall* (Nolan *et al.*, 2002).

Estimating Herbicide Concentrations in U.S. Streams from Watershed Characteristics

Regression models were developed to estimate concentrations of the herbicides alachlor, atrazine, cyanazine, metolachlor, and trifluralin in streams. The models integrate data on herbicide use and watershed characteristics (Larson and Gilliom, 2001). Concentrations were determined from samples collected from 45 streams throughout the nation during 1993 to 1995. Agricultural use of the herbicides in the watershed was a significant predictor in nearly all of the model simulations. Several hydrologic and soil parameters, such as basin size, runoff characteristics, and soil permeability, also were useful in explaining the variability in concentrations of herbicides among the streams. Most of the regression model simulations for estimation of concentration percentiles (10th, 25th, 50th, 75th, 90th, and 95th) and annual mean concentrations accounted for 50 to 90 percent of the variability among streams. Predicted concentrations were nearly always within an order of magnitude of the measured concentrations for the model-development streams, and predictions of concentration distributions reasonably matched the actual distributions in most cases. Although further validation is needed, the results for the five herbicides are promising and suggest that the regression approach developed on the basis of concentration data obtained from monitored resources may be useful for application to other pesticides and for estimation of pesticide concentrations in unmonitored streams.

An important component in the regression analysis was the application of TOPMODEL – a topography-based watershed model – to estimate the percentages of overland flow (runoff) and ground-water discharge to streamflow. The model is useful for integrating physical hydrology of surface water and ground water as it relates to influences on contaminant transport and water quality, including the influence of hydrologic factors on stream ecology. TOPMODEL simulation results are directly applied in the regression analysis.

Predicting Delivery of Nitrogen to the Gulf of Mexico

A mass-balance, regression model known as SPARROW is used to estimate nitrogen flux through the interior watersheds of the Mississippi basin (Alexander *et al.*, 2000). The method correlates nitrogen flux in streams with nitrogen inputs (fertilizer use, manure, and atmospheric deposition) and factors controlling nitrogen transport in watersheds, including physical characteristics of the landscape (such as soil permeability) and aquatic systems (such as channel size and water velocity). Simulation results – based on data from 374 monitoring stations, including 123 along the 6 largest tributaries to the Mississippi – showed that nitrogen loss is inversely related to channel size (that is, nitrogen removal in streams declines rapidly with increasing channel size as in-stream processes become progressively less effective at removing nitrogen with increases in channel depth). The proximity of nitrogen sources to large streams and rivers, therefore, increases the ultimate transport of nutrients to the Gulf of Mexico. Despite the long travel times, many watersheds located along large rivers more than 2,500 kilometers from the Gulf of Mexico deliver significantly larger fractions of nitrogen to coastal waters than watersheds located on smaller streams less than a few hundred kilometers from the Gulf (Figure 2). This finding has important implications for nutrient management in the Mississippi River basin, and more generally, in large coastal watersheds. The delivery of nitrogen to coastal systems from point and nonpoint sources is not a simple function of the distance of these sources from coastal waters. Instead, the proximity of sources to large streams and rivers, as measured by the length of time that surface waters travel through smaller tributaries, is a major determinant of the downstream transport of nitrogen. Information on nitrogen delivery and transport to coastal watersheds may assist in evaluations of efficient nutrient control strategies, including efforts to identify the most significant watersheds and sources contributing nitrogen to coastal systems.

A similar modeling approach (using SPARROW) also is applied to the Chesapeake Bay watershed. The information is being used by the USEPA Chesapeake Bay Program to target nutrient-reduction areas (Priority Nutrient Reduction Areas) and to design nutrient-load reduction plans that are specific to each tributary (Tributary Strategies) (Preston and Brakebill, 1999).

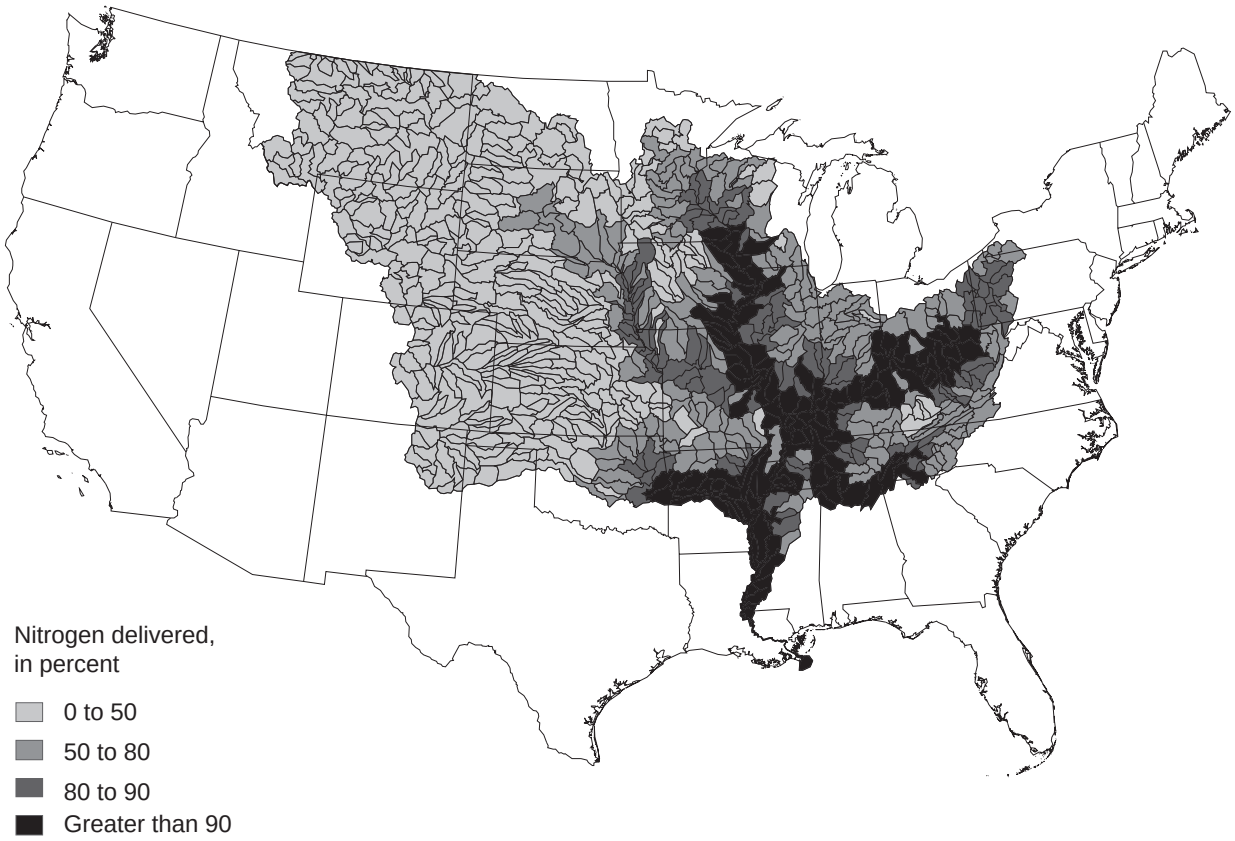

Figure 2. Percent of Nitrogen Delivered to the Gulf of Mexico. A considerable amount of total nitrogen delivered to the Gulf of Mexico originates from watersheds in the Mississippi River Basin very distant from the Gulf. (modified from Alexander *et al.*, 2000).

Predicting Changes in Nitrate Concentrations in Streams and Wells in Glassboro, New Jersey

A three-dimensional ground-water-flow model was developed to simulate the movement of nitrate from the water table, through the surficial aquifer system, to streams and public-supply wells in the surficial aquifer system near Glassboro, New Jersey (Kauffman *et al.*, 2001; Ayers *et al.*, 2000). The model integrates the hydraulic properties of the aquifer with changes in land use and use of nitrogen (manure and nitrogen-based fertilizers) over time to simulate nitrate concentrations at discharge points (streams and wells).

Simulated nitrate concentrations generally matched concentrations measured in samples from public-supply wells in the study area, verifying that nitrate moves conservatively (that is, persists without being sorbed or chemically degraded) through the aquifer system. Simulated nitrate concentrations in three streams during base flow over a nine-year period, however, had to be multiplied by 0.6 to obtain a match with measured nitrate concentrations. Because nitrate appeared to move conservatively to wells, the apparent loss of nitrate in streams indicates that about 40 percent of the nitrate in aquifer recharge is removed by denitrification in the aquifer near the streams and (or) by in-stream processes. This finding is corroborated by the findings that median concentrations of nitrate in shallow ground water were consistently greater than those in streams draining similar land-use settings.

The use of manure and nitrogen-based fertilizers has steadily increased from 1950 to 2000 (Modica *et al.*, 1998). The model was used to evaluate the effects of hypothetical changes in the use of nitrogen on nitrate concentrations in streams and public-supply wells. Three scenarios were used in the model: (1) nitrogen use remains unchanged from that in 2000, (2) nitrogen use is reduced at a constant rate to zero in 2050, or (3) nitrogen use is instantly reduced to zero (Figure 3).

The model shows that the response time of nitrate concentrations in streams and public-supply wells differs depending on the nitrogen-use pattern; in each case, however, the response time will not be immediate, primarily because of the amount of time required for water to move through the aquifer system and discharge to a stream or well. In fact, if nitrate concentrations in recharge remain unchanged from 2000 (scenario 1), the concentration of nitrate in streams and public-supply wells will continue to increase for several decades before stabilizing at a concentration corresponding to the amounts of nitrogen applied to urban, agricultural, and undeveloped lands in recharge areas.

Even if nitrate concentrations in recharge are reduced at a constant rate to zero by 2050 (Scenario 2), nitrate concentrations in streams and public-supply wells will continue to increase for 5 to 10 years. This lag in response is equivalent to the average age of water discharging to streams and public-supply wells. Because public-supply wells sampled for this study are screened near the bottom of the aquifer system, they withdraw water that is, on average, older than water discharging to streams. Thus, streams will respond faster to changes in land use or chemical use than will public-supply wells.

Finally, if the concentration of nitrate in recharge were to be immediately reduced from the 2000 level to zero (Scenario 3), the concentration of nitrate in streams and public-supply wells would begin to decrease as the result of the influx of younger ground water. However, reducing the 2000-level concentration in streams and public-supply wells by half would still take 10 or more years because of the amount of time required for water introduced before 2000 to move through the aquifer system and discharge to a stream or well.

In addition to predicting changes in the concentration of nitrate in streams and public-supply wells over

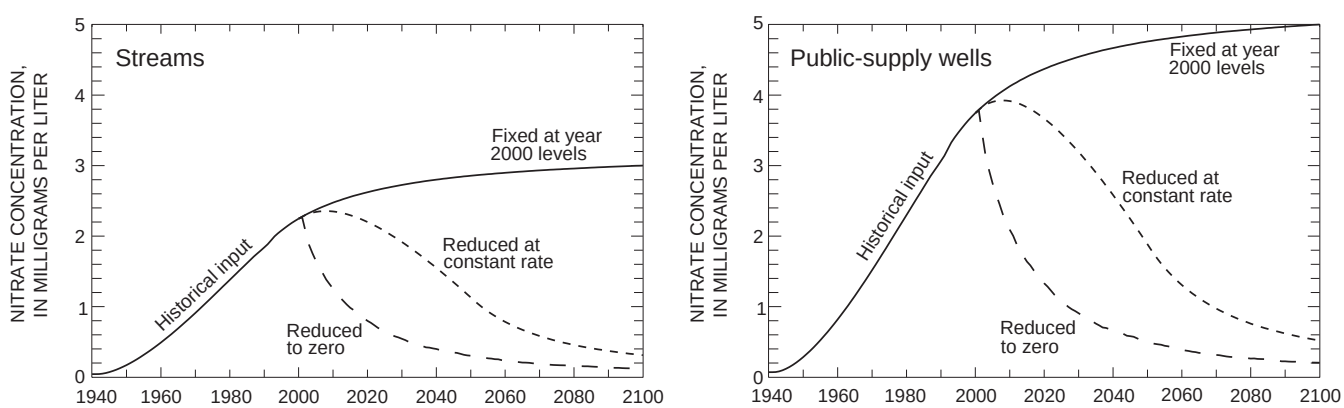

Figure 3. Simulated Concentrations of Nitrate in Streams and Public-Supply Wells for Three Scenarios Involving Different Nitrogen-Use Patterns in Glassboro, New Jersey. Model simulations show that concentrations of nitrate in streams and public-supply wells will not decline immediately because of the amount of time required for water introduced before 2000 to move through the aquifer system (Ayers *et al.*, 2000).

time, the model also was used to predict changes in nitrate concentrations at a typical depth (90 to 100 feet below land surface) for many domestic wells in the study area. Model simulations showed that nitrate concentrations at this depth will increase over the next 50 years and will likely exceed the USEPA drinking-water standard for nitrate (10 milligrams per liter as nitrogen) in those areas where nitrogen fertilizer use is most intensive. This simulation assumes nitrate input remains unchanged from 2000.

CONCLUSIONS

As the NAWQA Program shifts its emphasis from assessing and documenting water-quality conditions and cause-and-effect factors (during the first decade of studies) to achieving a better understanding of sources and transport of contaminants, and critical processes controlling water quality (during the second decade), predictive models will play a vital role in both analysis and water-management applications. NAWQA also will continue to provide water-management agencies with systematic, high-quality data that can be used to develop and test predictive models for hydrologic systems throughout the nation. Water-quality models have been in use for many years, but their utility depends on how well they represent actual conditions. Without demonstrated reliability based on comparisons to measured conditions, it is difficult to have confidence in a model, and its usefulness in decision-making, especially in controversial situations, is limited.

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David M. Wolock oversees the modeling and other hydrologic systems applications for the NAWQA Program. His technical interests include the study of how watershed topography, climate, and soils affect hydrologic processes at different spatial and temporal scales. Please access the NAWQA Web site for publications and additional information on modeling approaches and case studies http://water.usgs.gov/nawqa.

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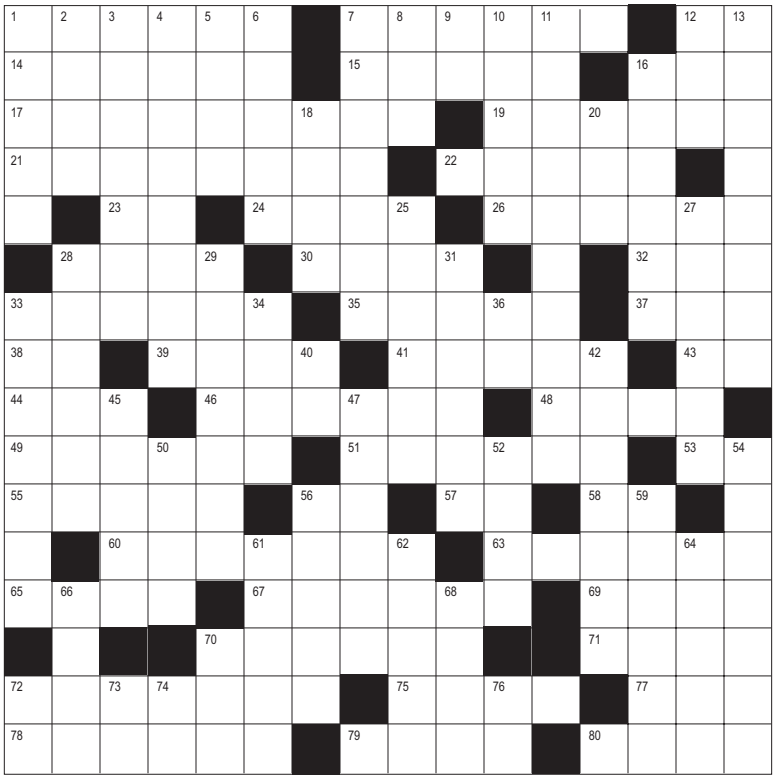
▲ Water Resources Puzzler (answers on pg. 33)



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1 vodka and orange juice
7 river in California
12 civil service job classification
14 escapeway
15 perfect
16 Red or Black
17 Louisville and Nashville and Sante Fe
19 unit of weight
21 pertaining to a kitchen
22 sway
23 not out
24 matches
26 followed by heat or period
28 ancient Greek colonade
30 word from a history course
32 architects' group
33 maxim
35 spokes of a wheel?
37 deface
38 football score
39 trig function
41 execs ride in these
43 a pronoun
44 "_____ to Billy Joe"
46 cotton cloth
48 Cleo's river
49 flat
51 one who acts in self interest
53 period of time (abbr.)
55 exposure to risk
56 location of Juniata River
57 mother's command to child
58 professor's helper
60 illegal drug sellers
63 river in England
65 ascend
67 a blood deficiency
69 not any
70 dealer
71 Peter _____ of TV fame
72 extremely cold
75 hydraulic grade _____
77 hard _____ to crack
78 a drinking spree
79 American auto pioneer
80 Redding or Skinner

DOWN

1 Air or magnetic
2 Hawaiian feast
3 type of bill
4 tributary of the Mississippi River
5 Laura or Bruce
6 ermine
7 June and July
8 Koch and Asner
9 memo heading
10 Suez or Erie
11 map features
12 prefix for hydrology
13 hygenic
16 a small river
18 lacking water
20 followed by blanket or cell
25 German prisoner-of-war camp
27 city on the Niger River
28 followed by shoe or soap
29 60s rock group: "The _____"
31 part of TAE
33 cork or plug
34 growl
36 contraction
40 "Mister _____" of TV fame
42 river in Burma
45 Virgil and Wyatt
47 brought up
50 "Savage Island"
52 Greek letter
54 offends
56 followed by code or service
59 quantity
61 Ethiopian province
62 one of the senses
64 boredom
66 _____ of Man
68 any plant belonging to the iris family
70 neckware
72 location of 63 across (abbr.)
73 symbol for actinon
74 bank purchase
76 Canadian province

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▲ President's Message

Kenneth J. Lanfear, AWRA President, 2002

NAWQA MOVES INTO A NEW PHASE

First of all, let me disclose that my "day job" is with the U.S. Geological Survey, and that I was involved in some of the early planning to select study units for the NAWQA program. I will also note that one of the benefits of being AWRA President is that I get to write these *IMPACT* messages as the President of AWRA, not as a USGS employee. Thus, I can say what Pixie Hamilton and Tim Miller are too modest to say: by just about any objective measure, NAWQA is an extremely successful Federal program. Take a look, for example, at the 142-page bibliography of NAWQA publications available at <http://water.usgs.gov/nawqa/bib.html>.NAWQA has created an incredible knowledge base about water quality in the United States, founded on solid, peer-reviewed methodology and documented data. AWRA is proud to have presented many NAWQA articles in *JAWRA* and our conference proceedings over the past 10 years. We are awaiting the opportunity to publish more of these fine works as NAWQA moves into its next phase of intensively reassessing basins.

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Solution to Puzzle on pg. 32

▲ Water Resources Continuing Education Opportunities

MEETINGS, WORKSHOPS, SHORT COURSES

JULY 2002

23-26/Joint Conf. on Integrated Transboundary Water Mgmt. Traverse City, MI. **Contact** (http://www.iwr.msu.edu/ucowr/)

28-31/EWRI-IAHR Hydraulic Measurements & Experimental Methods Conf. (HMEM). Estes Park, CO **Contact** (http://www.ewrinstitute.org/hmem/)

28-Aug. 1/2nd Federal Interagency Hydrologic Modeling Conf. Las Vegas, NV. **Contact** Don Frevert, Co-Tech. Prog. Chair, USBR, P.O. Box 25007, M/C D-8510, Lakewood, CO 80225 (303/445-2473; f: 303/445-6351; e: dfrevert@do.usbr.gov)

29-Aug 2/Hydrovision 2002. Portland OR. **Contact** Hydrovision 2002, 410 Archibald St., Kansas City, MO 64111 (816/931-1311; web: http://www.hcipub.com)

AUGUST 2002

4-10/132nd American Fisheries Society Meeting. Baltimore, MD. **Contact** Betsy Fritz (301/897-8616; e: bfritz@fisheries.org)

11-17/12th Stockholm Water Sym: Balancing Competing Water Uses – Present Status and New Prospects. Stockholm, Sweden. **Contact** Stockholm Intern'l. Water Inst., Stockholm Water Sym., Sveavagen 59, SE-113, Stockholm, Sweden. (+46 8 552 139 61; e: sympos@siwi.org)

12-15/StormCon™ – The North American Surface Water Quality Conf. & Exposition. Marco Island, FL. **Contact** Janice Kaspersen (805/681-1300 x12; e: sweditor@forester.net)

18-22/132nd American Fisheries Society Annual Meeting. Baltimore, MD. **Contact** Betsy Fritz (301/897-8616, x212; e: bfritz@fisheries.org)

SEPTEMBER 2002

3-6/Second International Sym. on GIS/Spatial Analyses in Fishery and Aquatic Sciences. Brighton, UK. **Contact** Michael Porter (e: cus@fisheries.org; web: www.esl.co.jp/Sympo/sympo10.htm)

17-18/AWRA Water Resources Policy Dialogue. Washington, DC. Contact AWRA, 4 West Federal St., P.O. Box 1626, Middleburg, VA 20118-1626 (540/687-8390; f: 540/687-8395; e: info@awra.org)

18-21/5th RNRF Congress: Non-Point Source Water Pollution: Exploring a Last Frontier. Baltimore, MD. **Contact** RNRF (301/493-9101; web: www.rnrf.org)

22-26/Rocky Mountain Summit: Sustaining Ecosystems & their People. Whitefish, MT. **Contact** RMS 2002, Attn: Julia Rodriguez, 130 Mumford Hall, Columbia, MO 65211-6200 (573/882-7458; f: 573/884-2199; e: CARES@Missouri.edu; w: www.cares.missouri.edu/rms2002

25-27 / National Clean Marina Workshop. Mystic, CT. **Contact** David G. White, NY Sea Grant, SUNY Oswego, Oswego, NY 13126 (315-312-3042; f: 315-312-2954; w: www.nyseagran.org)

30-Oct. 4/6th Intern'l. Conf. on Diffuse Pollution. Amsterdam, The Netherlands. **Contact** www.nva.net/agenda/conference.htm or Govert Verstappen at G.G.C.Verstappen@riza.rws.minvenw.nl or r.r.kruize@inter.nl.net

OCTOBER 2002

8-10/Changing Faces of Conservation & Agriculture: The Future of Working Lands. Moline, IL. **Contact** Chris Murray (e: chrism@agribiz.org)

13-17/Hydrologic Extremes: Challenges for Science & Mgmt. AIH 2002 Annual Meeting. Portland, OR. **Contact** AIH, 2499 Rice St., Ste. 135, St. Paul, MN 55113 (651/484-8169; f: 651/484-8357; e: AIHydro@aol.com; w: www.aihydro.org)

27-30 / California and the World Ocean '02. Santa Barbara, CA. **Contact** Orville Magoon, Honorary Conf. Chair, P.O. Box 279, 21000 Butts Canyon Rd., Middletown, CA 95461 (707/987-0114; f: 707/987-9351; e: CWO2002@coastalzonefoundation.org; w: resources.ca.gov/ocean)

NOVEMBER 2002

3-6 / Watersheds Across Boundaries: Science, Sustainability, Security. Stevenson, WA. **Contact** Chuck Slaughter, WMC Conf. Chair (208/364-4069; f: 208/387-1246; e: cslaugh@uidaho.edu)

3-7/AWRA's Annual Water Resources Conf. Philadelphia, PA. Contact AWRA, 4 West Federal St., P.O. Box 1626, Middleburg, VA 20118-1626 (540/687-8390; f: 540/687-8395; e: info@awra.org)

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▲ AWRA Future Meetings

2003 MEETINGS

SEPTEMBER 17-18, 2002 • WASHINGTON, D.C.
AWRA WATER RESOURCES POLICY DIALOGUE

NOVEMBER 3-7, 2002 • PHILADELPHIA, PENNSYLVANIA
AWRA's ANNUAL WATER RESOURCES CONFERENCE

2003 MEETINGS

MAY 12-14, 2003 • KANSAS CITY, MISSOURI
AWRA's SPRING SPECIALTY CONFERENCE

JUNE 30-JULY 2, 2003 • NEW YORK, NEW YORK
AWRA's SUMMER SPECIALTY CONFERENCE

NOVEMBER 3-6, 2003 • SAN DIEGO, CALIFORNIA
AWRA's ANNUAL WATER RESOURCES CONFERENCE

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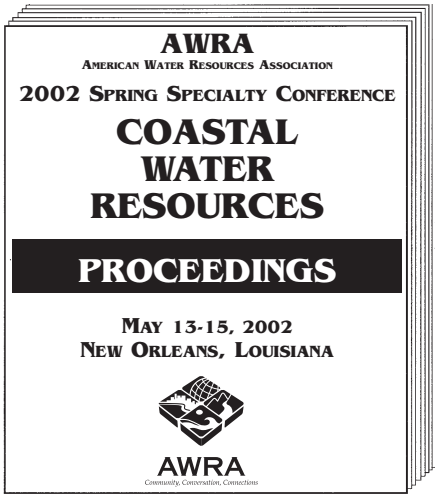

Back in the late 1960s, most water resources professionals were focused on the traditional aspects of hydrology, hydraulics, and ground water. They were worried about flood control, hydropower, irrigation, and water supply. Relatively few people were systematically considering water quality and how it relates to the environment. Below the head of the tide, another smaller group of engineers and scientists were working on coastal problems. They focused on wave mechanics, shoreline and harbor protection, beachfills, and the behavior of tidal inlets. A few people were trying to model estuarine circulation in response to the budding national flood insurance program s need for better tools to predict hurricane surge elevations. Here, again, the emphasis was on the built environment, with little emphasis on the preservation of natural systems.

Fast forward to now and the whole world has changed. Knowledge in all technical fields has increased exponentially. Successful professionals are now more highly specialized in narrow disciplines. On the other hand, we have learned that natural systems are infinitely more complex and interesting than once was widely understood. Therefore, our trend towards fragmented knowledge works against the critical need for a broad, multidisciplined approach to solving real problems. It was fortuitous that New Orleans was the site of AWRA s 2002 Spring Specialty Conference. Nearly 80 percent of the total U.S. wetland losses are occurring nearby. The underlying causes involve a complex combination of coastal and hydrologic factors, including loss of sediment supply, barrier island erosion, saltwater intrusion, and diminished freshwater inputs to the estuarial system. Most of the problems are man-made. Solving the challenges will require integrated approaches that go far beyond the tools available to either water resource or coastal professionals taken alone.

This published proceedings represents a good sampling of presentations made throughout the conference. Author contact information appears on the first page of each paper and will allow interested readers to followup directly with authors, thereby propagating the dissemination of information beyond the conference and this published volume. Papers are included on the following topics: • Coastal Resources Management; • Habitat Restoration; • Shoreline Erosion/Regional Sediment Management; • Puget Sound Naval Shipyard Environmental Investment Project (ENVEST); • Water Quality; • Hydraulic and Water Quality Modeling; • Coastal Ground Water; and several special Poster papers and abstracts.

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CARDHOLDER'S NAME _____

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➤ Your Primary Reason For Joining? (check one)

- ❑ To Receive Information Through JAWRA and Impact
- ❑ Networking Opportunities
- ❑ Technical Committee Interactions
- ❑ Conference Discount
- ❑ Employment Opportunities
- ❑ Other: _____

➤ How Did You Learn Of AWRA? (check one)

- ❑ Promotional Mailing
- ❑ Internet Search
- ❑ Journal (JAWRA)
- ❑ IMPACT
- ❑ Boss/Friend/Colleague
- ❑ Email Received
- ❑ Other: _____

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DEMOGRAPHIC CODES

(PLEASE LIMIT YOUR CHOICE TO ONE IN EACH CATEGORY)

JOB TITLE CODES

JT1	Management (Pres., VP, Div. Head, Section Head, Manager, Chief Engineer)
JT2	Engineering (non-mgmt.; i.e., civil, mechanical, planning, systems designer)
JT3	Scientific (non-mgmt.; i.e., chemist, biologist, hydrologist, analyst, geologist, hydrogeologist)
JT4	Marketing/Sales (non-mgmt.)
JT5	Faculty
JT6	Student
JT7	Attorney
JT8	Retired
JT9	Computer Scientist (GIS, modeling, data mgmt., etc.)
JT10	Elected/Appointed Official
JT11	Volunteer/Interested Citizen
JT12	Non-Profit
JT13	Other_____

EMPLOYER CODES

CF	Consulting Firm
EI	Educational Institution (faculty/staff)
ES	Educational Institution (student)
LR	Local/Regional Gov't. Agency
SI	State/Interstate Gov't. Agency
IN	Industry
LF	Law Firm
FG	Federal Government
RE	Retired
NP	Non-Profit Organization
TG	Tribal Government
OT	Other _____

EDUCATION CODES

HS	High School
AA	Associates
BA	Bachelor of Arts
BS	Bachelor of Science
MA	Master of Arts
MS	Master of Science
JD	Juris Doctor
PhD	Doctorate
OT	Other _____

WATER RESOURCES DISCIPLINE CODES

AG	Agronomy	GI	Geographic Information Systems
BI	Biology	HY	Hydrology
CH	Chemistry	LA	Law
EY	Ecology	LM	Limnology
EC	Economics	OE	Oceanography
ED	Education	PS	Political Science
EG	Engineering	OT	Other
FO	Forestry		
GR	Geography		
GE	Geology		

_____

PLEASE NOTE YOUR SELECTED CODE NUMBERS FROM ABOVE

JOB TITLE CODE ..... ❑
❑
EMPLOYER CODE..... ❑
WATER RESOURCES DISCIPLINE CODE..... ❑

▲ June 2002 JAWRA Papers (Vol. 38, No. 3)

RIPARIAN ECOLOGY AND MANAGEMENT IN MULTI-LAND USE WATERSHEDS-Part II

- Relationships Between Flood Frequencies and Riparian Plant Communities in the Upper Klamath Basin, Oregon
- Forest-River Interactions: Influence on Hyportheic Dissolved Organic Carbon Concentrations in a Floodplain Terrace
- Effects of Prescriptive Riparian Buffers on Landscape Characteristics in Northern Minnesota, USA
- Assest to Move Watershed Councils From Assessment to Action

TECHNICAL PAPERS

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- Selected Nutrients and Heavy Metals in Sewage Sludge From New Jersey POTWs
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- A Monte Carlo Test of Load Calculation Methods, Lake Tahoe Basin, California-Nevada
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- Optimizing Well Placement in a Coastal Aquifer: Outer Cape Cod, Massachusetts
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- Water Quality Modeling of Alternative Agricultural Scenarios in the U.S. Corn Belt
- Virginia USA Water Quality, 1978 to 1995: Regional Interpretation
- Evaluating the Influence of Source Basins on Downstream Water Quality in the Mississippi River
- A Long-Term, Watershed-Scale, Evaluation of the Impacts of Animal Waste BMPs on Indicator Bacteria Concentrations
- Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts
- Spatial Variability in Water-Balance Model Performance in the Conterminous United States
- Quantification of Incised Channel Evolution and Equilibrium

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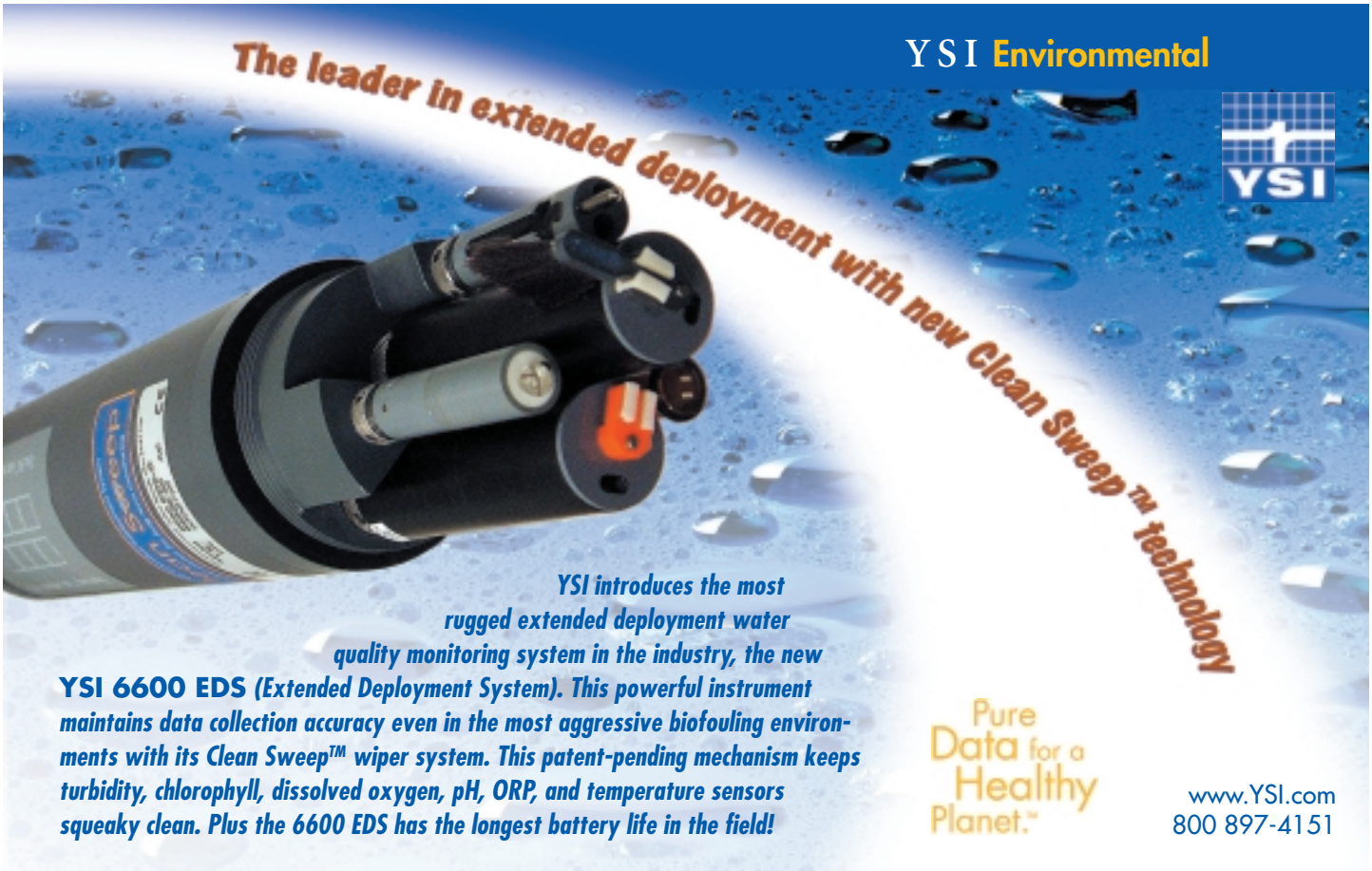

Questions???
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(540) 687-8395

By E-Mail
info@awra.org

Check Out Our Home Page Atwww.awra.org

WATER POLICY DIALOG
Your Opportunity To Be Heard On Important Water Policy Issues

AWRA is sponsoring a "Water Resources Policy Dialogue." September 17-18, 2002, in Washington, D.C., that will focus on six key water resources policy issues presently facing our nation. The issues are: Restoring and Protecting the Environment: Water Resources Infrastructure: Safety and Security of Water Resources: Managing Watersheds Holistically: Sustainable Water Use and Drought Management: and Flood Plain and Coastal Zone Management. These issues will be explored by three keynote speakers, by panels comprised of well-known water resources experts, and most importantly in discussion groups on each issue that allow every participant in the Dialogue an opportunity to register their opinions. **Attendance at the Dialogue is by invitation and is on a first-come/first-serve basis. Be apprised that the registration fee is $295.00. If you are interested in participating and would like to receive an invitation, please e-mail Richard Engberg, AWRA Technical Specialist, at <dick@awra.org>.**

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