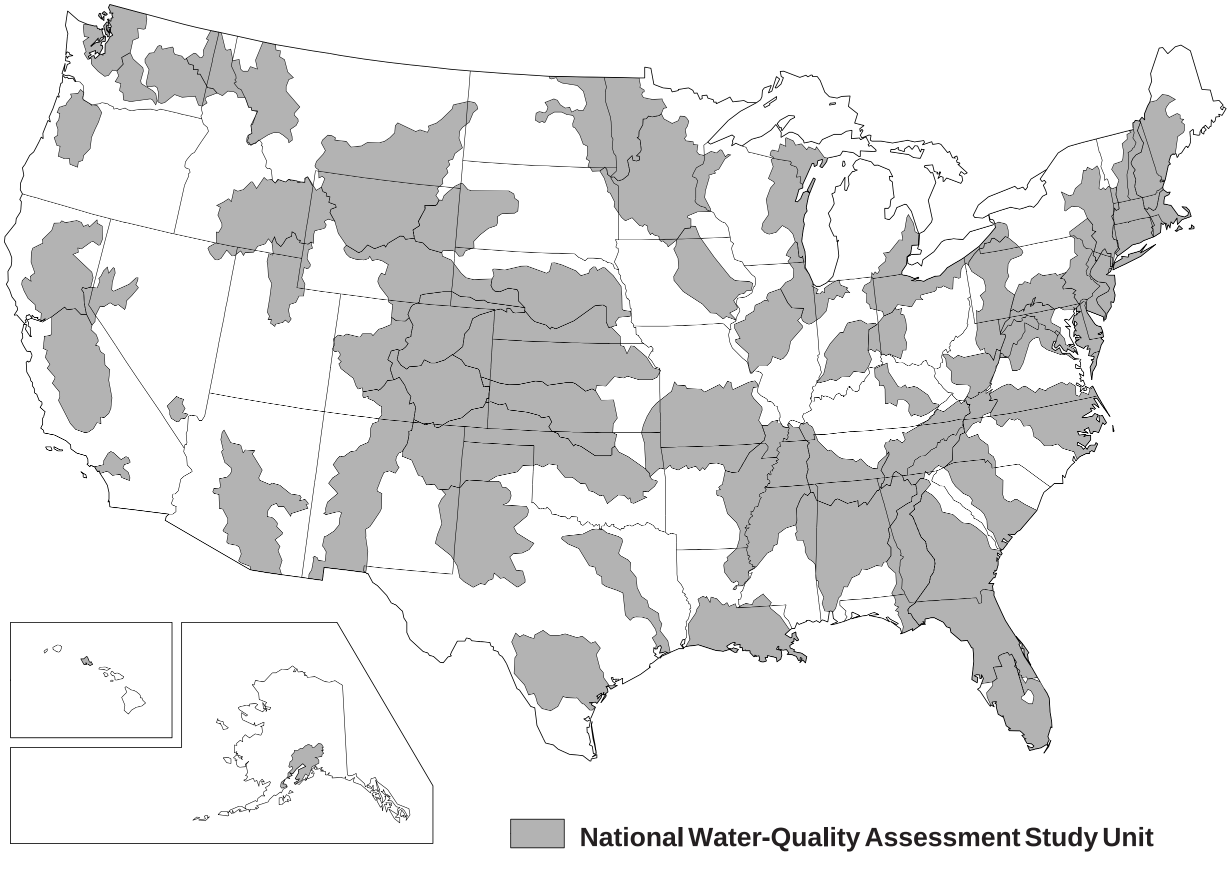
STUDY PLAN FOR URBAN STREAM INDICATOR SITES OF THE NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

U.S. GEOLOGICAL SURVEY

Open-File Report 97-25



NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

STUDY PLAN FOR URBAN STREAM INDICATOR SITES OF THE NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

By Thomas J. Lopes and Curtis V. Price

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Rapid City, South Dakota
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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

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Chief Hydrologist

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GLOSSARY OF NATIONAL WATER-QUALITY ASSESSMENT STUDY COMPONENTS

[Adapted From Gilliom and others, 1995]

Basic Fixed Sites. Sites on streams at which streamflow is measured and data are collected for temperature, salinity, suspended sediment, major ions, nutrients, and organic carbon to assess the broad-scale spatial and temporal character and transport of inorganic constituents of stream water in relation to hydrologic conditions and environmental settings.

Bed-Sediment and Tissue Studies. Assessment of concentrations and distributions of trace elements and hydrophobic organic contaminants in streambed sediment and tissues of aquatic organisms to identify potential sources and assess spatial distribution.

Case Studies. Detailed studies of selected contaminants in selected hydrologic systems to address specific questions that concern the characteristics, causes, and governing processes of water-quality degradation.

Ecological Studies. Studies of biological communities habitat characteristics to evaluate the effects of physical and chemical characteristics of water and hydrologic conditions on aquatic biota and to determine how biological and habitat characteristics differ among Environmental Settings in Study Units.

Environmental Setting. Land areas characterized by a unique, homogenous combination of natural and human-related factors, such as residential land use on glacial-till soils.

Indicator Sites. Stream sampling sites located at outlets of drainage basins with relatively homogeneous land use and physiographic conditions. Basins are as large and representative as possible, but still encompassing primarily one Environmental Setting (typically, 50 to 500 km^2).

Integrator Sites. Stream sampling sites located downstream of drainage basins that are large and complex and often contain multiple Environmental Settings. Most Integrator Sites are on major streams with drainage basins that include a substantial portion of the Study Unit area (typically, 10 to 100 percent).

Intensive Fixed Sites. Basic Fixed Sites with increased sampling frequency during selected seasonal periods and analysis of dissolved pesticides and, at Urban Indicator Sites, volatile organic compounds for 1 year. One or two integrator Intensive Fixed Sites and one to four indicator Intensive Fixed Sites are present in most Study Units.

Land-Use Studies. Investigations of the concentrations and distribution of water-quality constituents in recently recharged ground water (generally less than 10 years old) associated with a particular land use. For each study, usually a combination of 30 shallow existing and observations wells are sampled. Two to four studies typically are completed in each Study Unit during the first cycle of NAWQA.

Occurrence and Distribution Assessment. Assessment of the broad-scale geographic and seasonal distributions of water-quality conditions for streams and ground water of a Study Unit in relation to major contaminant sources and background conditions.

Occurrence Survey. The first phase of study of trace elements and hydrophobic organic contaminants in streambed sediment and tissues of aquatic organisms. The primary objective is to determine which target constituents are common and important to water-quality conditions in each Study Unit.

Retrospective Analysis. The review and analysis of existing water-quality data to provide a historical perspective on the water quality in the Study Unit, to assess the strengths and weaknesses of available information, and to evaluate initial implications for water-quality management and study design.

Spatial Distribution Survey. Extension of the Occurrence Survey for bed sediments and tissues to improve geographic coverage, with particular emphasis on assessment of priority constituents identified in the Occurrence Survey.

Study Unit. A major hydrologic system of the United States in which NAWQA studies are focused. Study Units are geographically defined by a combination of ground- and surface-water features and usually encompass more than 10,000 km^2 of land area. The NAWQA design is based on an assessment of 59 Study Units, which collectively cover a large part of the Nation, encompass the majority of population and water use, and include diverse hydrologic systems that differ widely in natural and human factors that affect water quality.

Study-Unit Investigation. The systematic study of a NAWQA Study Unit. These investigations consist of four main components: Retrospective Analysis, Occurrence and Distribution Assessment, Trend and Change Assessment, and Case Studies. Study Units are organized into three groups that are studied on a rotational schedule, with 3-year intensive study periods repeated every 9 years.

Trend and Change Assessment. Decadal scale trends and changes in water-quality conditions will be assessed by using a combination of existing historical data, periods of intensive assessments, and selected long-term monitoring strategies.

Water-Column Studies. Assessment of physical and chemical characteristics of stream water, including suspended sediment, dissolved solids, major ions, nutrients, organic carbon, and dissolved pesticides, in relation to hydrologic conditions, sources, and transport.

Water-Column Synoptic Studies. Short-term investigations of specific water-quality conditions during selected seasonal or hydrologic periods to provide improved spatial resolution for critical water-quality conditions compared to fixed-site sampling. For the period and conditions sampled, they assess the spatial distribution of selected water-quality conditions in relation to causative factors, such as land use and contaminant sources, through mass-balance analysis of sources and transport. During the first 3-year intensive study periods, two to three Water-Column Synoptic Studies are included in most Study Unit Investigations.

Study Plan for Urban Stream Indicator Sites of the National Water-Quality Assessment Program

By Thomas J. Lopes *and* Curtis V. Price

ABSTRACT

Urban Indicator Sites are one component of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program. The objectives of monitoring at the Urban Indicator Sites are to: (1) characterize stream quality from drainage basins with predominantly residential and commercial land use, and (2) determine which selected natural and human factors most strongly affect stream quality.

Urban Indicator Sites will be distributed across the United States in settings with statistically different climate and in metropolitan areas that have a population of 250,000 or more. Multiple sites in the same climatic setting will have a range in population density. Ideally, Urban Indicator Sites will monitor drainage basins that have only residential and commercial land use, are 50 square kilometers or larger, are in the same physiographic setting as other Indicator Sites, have sustained flow, and overlap other NAWQA study components. Ideal drainage basins will not have industrial or agricultural land use and will not have point-source-contamination discharges. Stream quality will be characterized by collecting and analyzing samples of streamflow, bed sediment, and tissue of aquatic organisms for selected constituents. Factors affecting stream quality will be determined by statistical analysis of ancillary data associated with Urban Indicator Sites and stream-quality samples.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) Program is a systematic assessment of the quality of the Nation's stream and ground-water resources. The U.S. Geological Survey (USGS) implemented the NAWQA program in 1991 to describe the status and trends in the quality of a large, representative part of the Nation's water resources and to identify the natural and human factors affecting the water quality. Information produced from the NAWQA Program will be useful for policymakers, managers, and the general public at the National, State, and local levels. The basic elements of the NAWQA Program are 59 Study Units that include parts of most of the Nation's major river basins and aquifers (fig. 1). Study Units Investigations were started between 1991 and 1997. Gilliom and others (1995) discuss the overall design of the NAWQA Program in more detail. The glossary at the front of this report includes brief descriptions for many of the study components and key terms used to describe the NAWQA Program. These study components and key terms are highlighted throughout this report with capital first letters.

The emphasis of the NAWQA surface-water design is to monitor the stream quality at Indicator Sites on major streams that drain relatively homogenous land-use and physiographic conditions (Gilliom and others, 1995). Stream quality also is monitored at Integrator Sites on streams that drain mixed land use and at sites on streams that are relatively unaffected by human influences. Streams are monitored for flow, specific conductance, water temperature, and chemical and biological constituents. Urban and agricultural land uses are two of the main land uses being investigated at this time (1997). The objectives of monitoring

Figure 1. Location of National Water-Quality Assessment Program Study Units and their proposed implementation dates (from Gilliom and others, 1995).

at the Urban Indicator Sites are to: (1) characterize stream quality from drainage basins with predominantly residential and commercial land use, and (2) determine which selected natural and human factors most strongly affect stream quality.

This report provides long-term guidance for the distribution of Urban Indicator Sites across the United States; describes the criteria for selecting these sites; provides guidance to Study Units for chemical and biological sampling; and provides guidance for compiling ancillary data that are needed to identify factors affecting stream quality. The guidance provided in this report will foster consistency among Study Units. Consistency is important to understand processes affecting stream quality in urban areas on regional and National scales.

DISTRIBUTION OF URBAN INDICATOR SITES

Urban Indicator Sites will be distributed across the United States on the basis of climate to determine how factors that affect stream quality vary among different regions. Urban stormwater quality was found to be statistically different, at an alpha level of 0.05, among regions of the Nation with different mean annual precipitation (Driver and Tasker, 1990). The amounts and types of precipitation and types of storms affect the occurrence, concentration, temporal distribution, and loads of constituents in streamflow.

Mean annual precipitation, temperature, (National Climatic Data Center, 1996), and snowfall (U.S. Bureau of the Census, 1994a) for 1960 through 1991 were used in a cluster analysis (Davis, 1986) to group 268 metropolitan statistical areas (MSAs) (U.S. Bureau of the Census, 1994b) with populations greater than 50,000 into 17 statistically different climatic settings (figs. 2 and 3; table 1). An MSA is a geographic area that may include several counties and is comprised of a large population nucleus and adjacent communities that have a high degree of economic and social integration with that nucleus; not all cities with a population greater than 50,000 are considered MSAs. The 268 MSAs comprise about 79 percent (196 million) of the U.S. population.

Seventeen climatic settings seem to satisfactorily represent the geographic distribution of climate, even though some anomalies are apparent. For example, Seattle (on the west coast) was grouped into the same climatic setting as New York City (on the east coast). Also, the climate of the Plains, Rocky Mountain, and Great Basin regions are not well represented in the 17 climatic settings because these regions have few MSAs.

NAWQA is targeting large metropolitan areas that have populations greater than 250,000 because in 1990 these large urban areas comprised about 69 percent (171 million) of the U.S. population (U.S. Bureau of the Census, 1992). The incidental or direct release of chemicals in these large urban areas could degrade the quality and the aesthetic and recreational value of urban streams and could affect a large segment of the Nation’s population. Study Unit boundaries include 84 percent (144 million) of the population in MSAs with 250,000 or more. Seventy-three percent (181 million) of the U.S. population is concentrated in 6 climatic settings (4, 9, 11, 15, 16, and 17) which have more than 10 million people in MSAs (fig. 4).

Climatic settings 1 and 3 do not have MSAs with a population greater than 250,000. Climatic setting 10 has a population of 1.5 million and 2 MSAs (Grand Rapids-Muskegon-Holland, Michigan, and Binghamton, New York) with more than 250,000 people. However, less than 10 percent of the population in climatic setting 10 is within Study Unit boundaries (fig. 4). Four climatic settings (5, 7, 12, and 14) only have one MSA with a population of 250,000 or more that is within Study Unit boundaries.

Ideally, each climatic setting will have at least three Urban Indicator Sites with relatively low, medium, and high population densities to determine how human-related factors affect stream quality. Other factors, such as impervious area and chemical use, may correlate with population density. Urban Indicator Sites with different population densities do not have to be in the same MSA or Study Unit. Each of the six climatic settings that have a population of more than 10 million (fig. 4) will require more than three Urban Indicator Sites to adequately represent the settings. This matrix of climatic settings and population density provides long-term guidance for prioritizing and selecting MSAs that will represent different regions of the Nation.

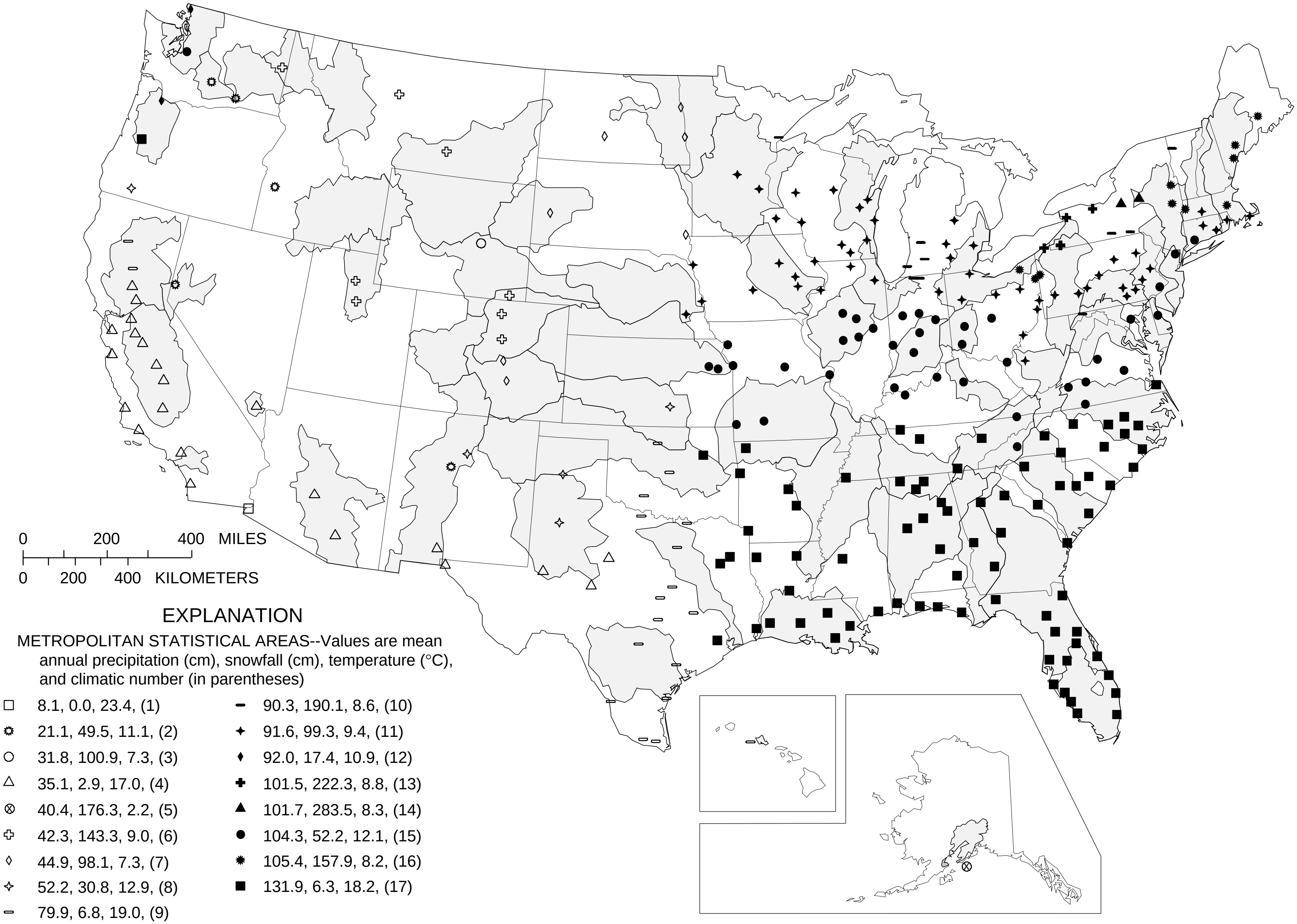

Figure 2. Locations of metropolitan statistical areas (U.S. Bureau of Census, 1994b) grouped into climatic settings with similar annual precipitation, snowfall, and temperature, 1960-91. NAWQA Study Units are shaded.

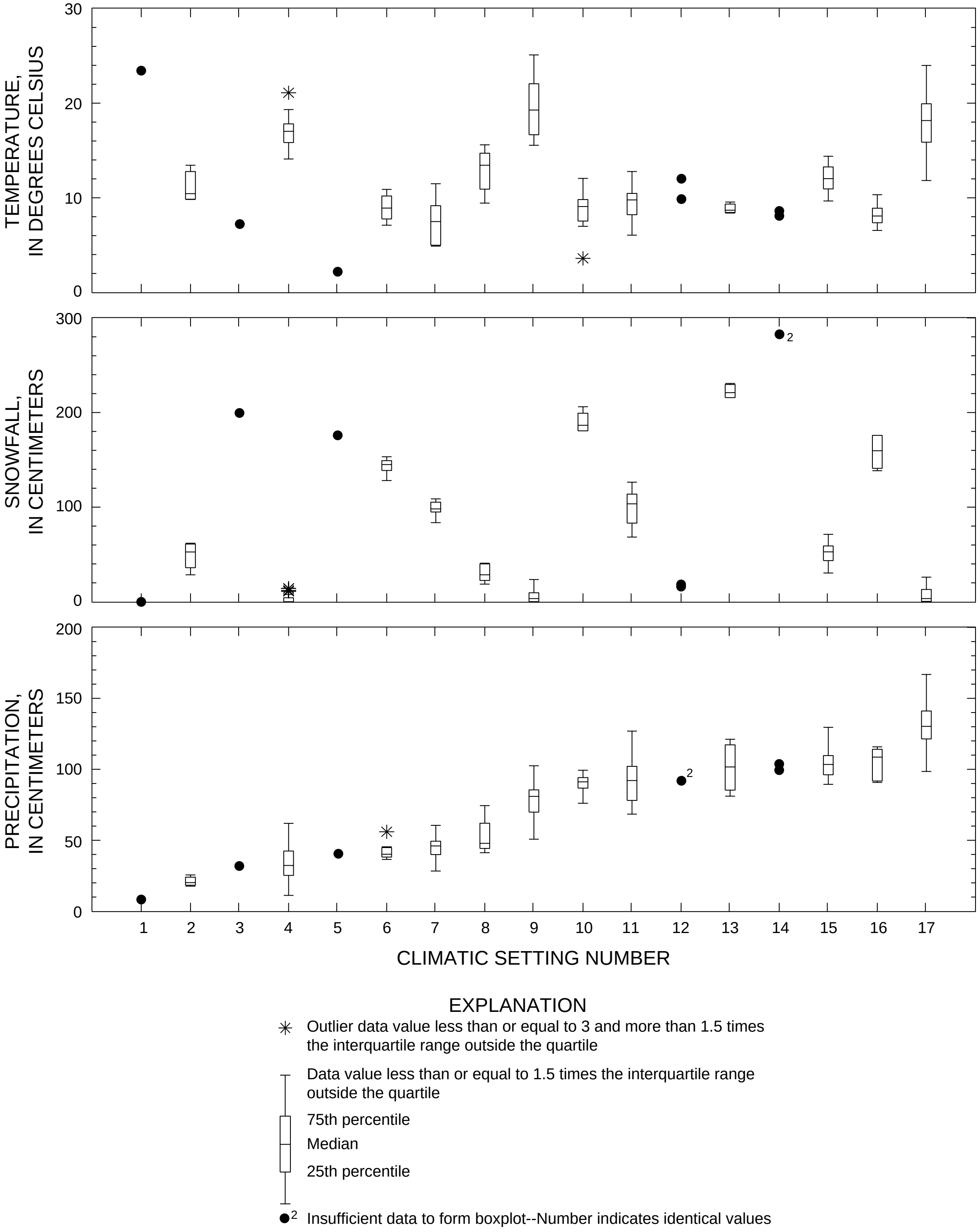

Figure 3. Mean annual precipitation, snowfall, and temperature (1960-91) of metropolitan statistical areas within different climatic settings.

Table 1. Metropolitan statistical areas, by climatic setting, that have a population greater than 250,000 and are within a Study Unit boundary of the National Water-Quality Assessment Program

[The precipitation and snowfall values, in centimeters, and temperature, in degrees Celsius, are mean annual values for the climatic setting. N, number of metropolitan statistical areas in each cluster. **Bold**, Land-Use Study is possible, planned, or completed; (1991) year Study Unit started; *, has an Urban Indicator Site. Metropolitan statistical areas that have potential for Land-Use Studies are listed first and ranked by population. Other metropolitan statistical areas are ranked by population. Metropolitan Statistical Areas from U.S. Bureau of the Census (1994b)]

Climatic Setting 1: Precipitation (8.1) Snowfall (0.0) Temperature (23.4) N = 1					
No metropolitan statistical areas represented					
Climatic Setting 2: Precipitation (21.1) Snowfall (49.5) Temperature (11.1) N = 5					
Albuquerque, NM (1991)	**Reno, NV (1991)**				
Climatic Setting 3: Precipitation (31.8) Snowfall (199.9) Temperature (7.3) N = 1					
No metropolitan statistical areas represented					
Climatic Setting 4: Precipitation (35.1) Snowfall (2.9) Temperature (17.0) N = 22					
Los Angeles-Riverside, Orange Co., CA (1997)	**Sacramento-Yolo, CA (1994)***	**Las Vegas, NV (1991)**	**Fresno, CA (1991)**	**Stockton-Lodi, CA (1991)**	**Modesto, CA (1991)**
Visalia, Tulare, Porterville, CA (1991)	El Paso, TX (1991)	Phoenix-Mesa, AZ (1994)	Tucson, AZ (1994)	Bakersfield, CA (1991)	
Climatic Setting 5: Precipitation (40.4) Snowfall (176.3) Temperature (2.2) N = 1					
Anchorage, AK (1997)					
Climatic Setting 6: Precipitation (42.3) Snowfall (143.3) Temperature (9.0) N = 8					
Denver-Boulder-Greeley, CO (1991)*	**Salt Lake City-Ogden, UT (1997)**	**Spokane, WA (1997)**	**Provo-Orem, UT (1997)**		
Climatic Setting 7: Precipitation (44.9) Snowfall (98.1) Temperature (7.3) N = 7					
Colorado Springs, CO					
Climatic Setting 8: Precipitation (52.2) Snowfall (30.8) Temperature (12.9) N = 5					
Wichita, KS (1997)	Lubbock, TX (1997)				
Climatic Setting 9: Precipitation (79.9) Snowfall (6.8) Temperature (19.0) N = 19					
Dallas-Fort Worth, TX (1991)*	**San Antonio, TX (1994)***	**Honolulu, HI (1997)**	Corpus Christi, TX (1994)	Oklahoma City, OK	
Climatic Setting 10: Precipitation (90.9) Snowfall (190.1) Temperature (8.6) N = 10					
No metropolitan statistical areas represented					
Climatic Setting 11: Precipitation (91.6) Snowfall (99.3) Temperature (9.4) N = 52					
Detroit-Ann Arbor-Flint, MI (1994)*	**Minneapolis-St. Paul, MN-WI (1994)***	**Harrisburg-Lebanon-Carlisle, PA (1991)***	**Appleton-Oshkosh-Neenah, WI (1991)**	Chicago-Gary-Kenosha, IL-IN-WI (1997)	Pittsburgh, PA (1994)*
Milwaukee-Racine, WI (1991)	Hartford, CT (1991)	Providence-Fall River-Warwick, RI-MA (1997)	Toledo, OH (1994)	Allentown-Bethlehem-Easton, PA (1997)	Springfield, MA (1991)
Fort Wayne, IN (1994)	Lancaster, PA (1991)	York, PA (1991)	Reading, PA (1997)	Charleston, WV (1994)	New London-Norwich, CT-RI (1991)
Johnstown, PA (1994)					

Table 1. Metropolitan statistical areas, by climatic setting, that have a population greater than 250,000 and are within a Study Unit boundary of the National Water-Quality Assessment Program—Continued

Climatic Setting 12: Precipitation (92.0) Snowfall (17.4) Temperature (10.9) N = 2					
Portland-Salem, OR-WA (1991)*					
Climatic Setting 13: Precipitation (101.5) Snowfall (222.3) Temperature (8.8) N = 4					
Buffalo-Niagara Falls (1994)	Erie, PA (1994)				
Climatic Setting 14: Precipitation (101.7) Snowfall (283.5) Temperature (8.3) N = 2					
Utica-Rome, NY (1991)					
Climatic Setting 15: Precipitation (104.3) Snowfall (52.2) Temperature (12.1) N = 40					
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA (1994)*	**Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD (1997)**	**Seattle-Tacoma-Bremerton, WA (1994)***	**Cincinnati-Hamilton, OH-KY-IN (1997)**	**Bridgeport, CT (1991)***	**Indianapolis, IN (1991)***
Dayton-Springfield, OH (1997)	**Peoria-Pekin, IL (1994)**	Washington-Baltimore, DC-MD-VA-WV (1991)*	Johnson City-Kingsport-Bristol, TN-VA (1994)	Lexington, KY (1994)	Springfield, MO (1991)
Climatic Setting 16: Precipitation (105.4) Snowfall (157.9) Temperature (8.2) N = 10					
Boston, MA-NH (1997)	**Albany-Schenectady-Troy, NY (1991)***	Cleveland-Akron, OH (1994)	Portland, ME (1997)		
Climatic Setting 17: Precipitation (131.9) Snowfall (6.3) Temperature (18.2) N = 79					
Atlanta, GA (1991)*	**Tampa-St. Petersburg-Clearwater, FL (1991)**	**Orlando, FL (1991)**	**Memphis, TN-AR (1994)***	**Jacksonville, FL (1991)**	**West Palm Beach-Boca Raton, FL (1994)**
Baton Rouge, LA (1997)	**Columbia, SC (1994)***	**Melbourne-Titusville-Palm Bay, FL (1991)**	**Daytona Beach, FL (1991)**	**Lakeland-Winter Haven, FL (1994)**	**Lafayette, LA (1997)**
Fort Myers-Cape Coral, FL (1994)	**Huntsville, AL (1997)**	**Macon, GA (1991)**	**Eugene-Springfield, OR (1991)**	**Savannah, GA (1991)**	**Fort Pierce-Port St. Lucie, FL (1994)**
Tallahassee, FL (1991)*	New Orleans, LA (1997)	Charlotte-Gastonia-Rock Hill, NC-SC (1994)	Raleigh-Durham-Chapel Hill, NC (1991)	Birmingham, AL (1997)	Greenville-Spartanburg-Anderson, SC (1994)
Knoxville, TN (1994)	Charleston-North Charleston, SC (1994)	Little Rock-North Little Rock, AR (1994)	Mobile, AL (1997)	Chattanooga, TN (1994)	Montgomery, AL (1997)
Hickory-Morganton, NC (1994)	Columbus, GA-AL (1991)	Miami-Fort Lauderdale, FL (1994)	Tulsa, OK		

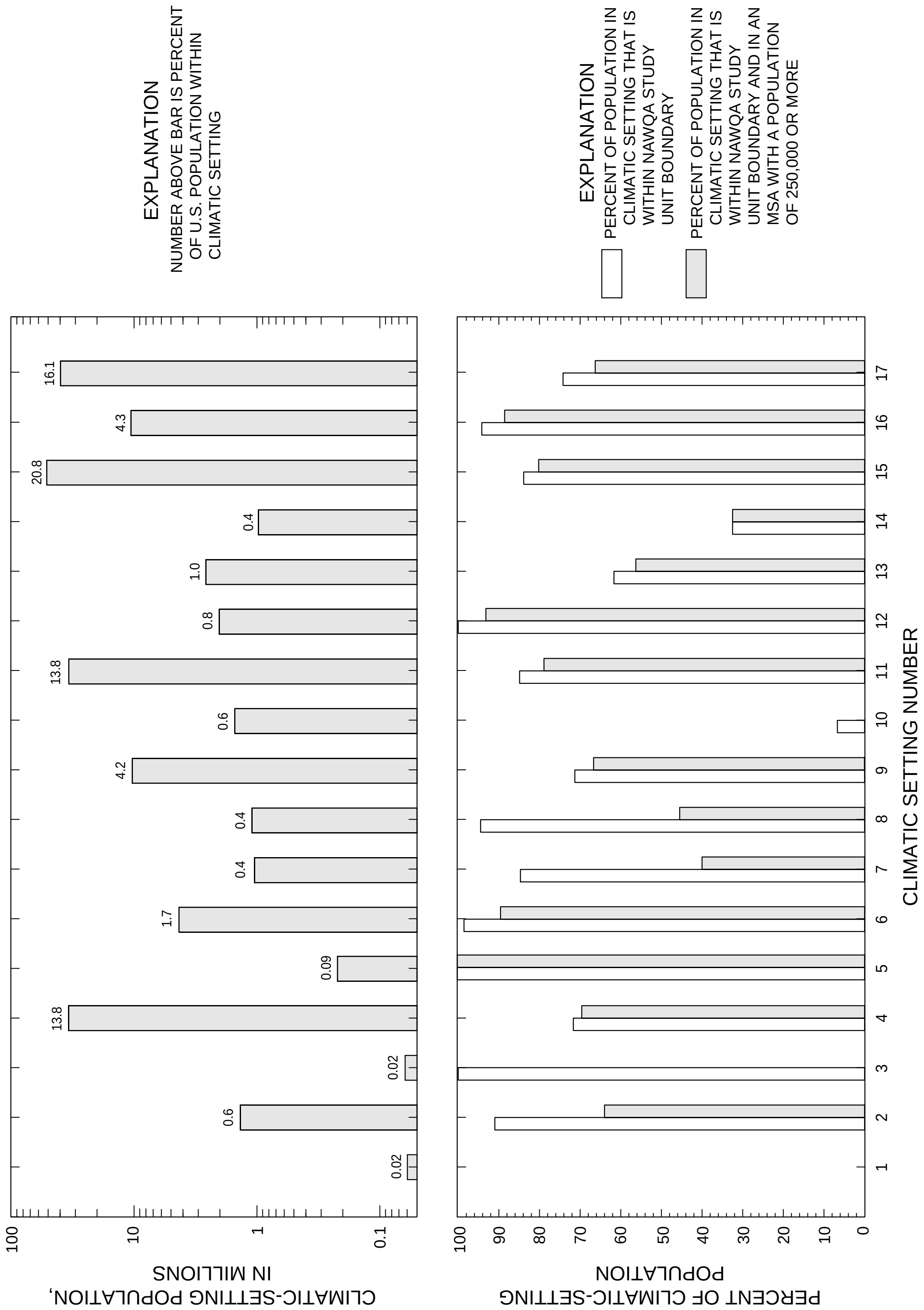

Figure 4. Populations of metropolitan statistical areas within different climatic settings.

SELECTION OF URBAN INDICATOR SITES

Study Units should select Urban Indicator Sites that meet certain criteria to assure consistency in data that will be used for regional and national comparisons. Criteria for selecting Urban Indicator Sites are similar but not identical to the criteria for Urban Land-Use Studies (Squillace and Price, 1996). To the extent possible, select drainage basins that overlap other NAWQA study components to attain a more comprehensive understanding of hydrologic, chemical, and biologic processes in urban environments. For example, Bed-Sediment and Tissue Studies, Ecological Studies, Indicator and Integrator Sites, Land-Use Studies, and Water-Column Synoptic Studies could all be located within an urban area.

Urban Indicator Sites, like Urban Land-Use Studies, are targeting residential/commercial land use. Although they are difficult to find, ideal drainage basins will have only residential/commercial land use because a small amount of industrial and agricultural land use can have a large effect on stream quality. If industrial or agricultural land uses cannot be avoided, then computer programs and regression equations may be used to estimate the affect of those areas on stream quality and decide if the effect will be significant. Also, it may be possible to use gages upstream and downstream of the urban area to segregate the contributions of contaminants from different land uses.

Ideal drainage basins should be 50 km^2 (square kilometers) or larger and similar in size and physiographic setting to other Indicator Sites, so data are comparable. Minimally, drainage basins should be 25 km^2 or larger. Drainage basins should have sustained flow and well-defined drainage-basin boundaries so that accurate ancillary information can be compiled. Sampling reaches should be located so that riparian and channel conditions are representative of the urban setting. No significant geomorphic modifications or tributaries should be between the Ecological Studies sampling reach and the location where streamflow and chemical samples are monitored. Drainage basins with sustained flow that convey urban stormwater, have channels suitable for Ecological Studies, and have streamflow and water-quality records are ideal for Urban Indicator Sites.

The population density should be typical of residential/commercial areas in the MSA so that constituent concentrations, frequency of occurrence, loads, and yields are representative. Study Units that have more than one Urban Indicator Site should select drainage basins with a range in population density to determine how the intensity of urbanization affects stream quality.

Age of urban development should be known, but age is not a selection criterion because development within a drainage basin typically occurs over extended periods. Stormwater quality also is related more to current activities rather than previous land use, except for persistent chemicals such as organochlorine pesticides. This criterion differs from Urban Land-Use Studies (Squillace and Price, 1996), which select residential/commercial areas developed between about 1970 and 1990.

Streams in urban drainage basins have a variety of beneficial uses. For example, the drinking-water supply in New Jersey is partly dependent on streamflow from urban basins. Urban streams may be tributary to large rivers, such as the Ohio, Tennessee, and Mississippi Rivers, and downstream municipalities use these large rivers for their water supply. Some urban streams in Minneapolis/St. Paul are designated fisheries and recreational areas. Urban drainage basins are being restored across the Nation to improve the aesthetic quality of the streams and to restore the ecosystems that once thrived in these basins. Because the beneficial use of urban streams is variable, basin selection is not based on a specific type of use. This also differs from the Urban Land-Use Studies (Squillace and Price, 1996), which select urban areas overlying aquifers that are used, have the potential to be used, or may affect drinking water supplies.

Drainage basins should not have point sources and large industrial and agricultural areas because these sources may have large contaminant concentrations that would mask the effects of residential/commercial land use on stream quality. If point sources cannot be avoided, then discharge from the point source should comprise a few percent of the low-flow discharge and should not have measurable concentrations of constituents that will be analyzed. Reconnaissance sampling may be needed to help select sites if point sources cannot be avoided. Wide transportation corridors, such as rail yards and limited-access highways, also should be avoided or minimized. Golf courses, parks, roadways, and business highways are considered part of the residential/commercial land use. Light industry that is mixed with commercial areas may be very difficult to avoid but should be minimized.

CHARACTERIZING STREAM QUALITY IN RESIDENTIAL/COMMERCIAL AREAS

Residential/commercial land use comprises the largest land use within metropolitan areas and, therefore, could contribute a large proportion of the contaminant loads to urban streams. It is important to understand the effect of this land use on streamflow in order to protect stream quality, aquatic habitats, and biology. Residential areas also are important because contamination in shallow ground water has been correlated to population density (Eckhardt and Stackelberg, 1995). Recharge from urban stormwater in high-density residential areas could be one source of this contamination. Point-source discharges and large industrial areas will not be investigated at Urban Indicator Sites because Federal and State regulations require municipal and industrial dischargers to limit their effect on streams. In comparison, there are few regulations to control the quantity and quality of stormflow to streams in residential/commercial areas. Study Units may use Water-Column Synoptic Studies to investigate point sources and industrial areas where these sources are important issues.

Questions to be Answered

Questions regarding contaminants in urban streams will be answered using data from Urban Indicator Sites. Some of these questions are: What contaminants are commonly found in streamflow from residential/commercial land use? What is the range in concentrations? What is the frequency of occurrence and temporal distribution of contaminants in urban streams? Are frequently detected chemicals of ecological concern due to their bioaccumulation, toxicity, or endocrine disruption? How do the frequency of occurrence and concentrations vary across the Nation? Do regional patterns exist that could be used to establish regional water-management strategies? How do contaminant yields from urban drainage basins compare to those from other types of land use? Are constituents found in streamflow the same constituents found in ground water? Is infiltration of stormwater in areas with residential/commercial land use a source of ground-water contamination?

Work Elements

Locate Data Sets Needed for Drainage Basin Delineation

Geographic Information Systems (GIS) is a valuable tool that can help locate drainage basins that meet the selection criteria. Land-use, land-cover, hydrographic, and aerial-photography data are available from many sources and will be needed to locate drainage basins. The only national data base of land use is the land-use and land-cover digital data from 1:250,000- and 1:100,000-scale maps that were developed from aerial photography from the 1970's to mid-1980's (U.S. Geological Survey, 1990). Study Units may use a modified version of the land-use data that delineates new growth areas (Hitt, 1994). Local information also may be used, especially for pre-1970 information, but should be checked for accuracy and inconsistencies. Some useful Federal, State, and local government data sets and services include:

1. USGS 1:250,000-scale Geographic Information Retrieval and Analysis System (GIRAS) data, updated using census population (U.S. Geological Survey, 1990; Hitt, 1994).
2. Land cover based on satellite remote-sensing data.
3. USGS 1:100,000-scale Digital Line Graph (DLG) transportation data.
4. U.S. Bureau of Census Topologically Integrated Geographic Encoding Reference (TIGER) data (similar to 1:100,000-scale DLG data).
5. USGS digital orthophoto quadrangles (DOQ's). DOQ's are aerial photographs registered to a map base. They are available for limited areas from USGS and State or local agencies.
6. USGS provides an aerial-photography search service at its Earth Science Information Centers. The archives includes references to aerial photography from many agencies other than the USGS, for example, aerial photography from the U.S. Department of Agriculture/National Resources Conservation Service. Aerial photography also is available from State and local agencies and businesses.
7. Other land-use/land-cover mapping and local zoning maps.

Select Drainage Basins

The following GIS processing steps are suggested to identify potential drainage basins using nationally available GIS data sets. If available, more detailed local GIS information should be used in place of the nationally available data sets.

1. Obtain updated 1990 GIRAS land-use/land-use change coverage (see Hitt, 1994).
2. Obtain coverages of drainage-basin boundaries and hydrography including wetlands and, if available, stormwater controls such as storm sewers, retention and detention basins, and dry wells (consult local flood-control agency). Information on stormwater controls will be useful in determining the contributing area and where stormflows enter the stream.
3. Create a coverage of transportation areas, such as railways and non-business, limited-access highways, from 1:100,000-scale DLG data (U.S. Geological Survey, 1989).
4. Obtain a coverage of known point sources of contamination (consult State or local environmental agency).
5. Overlay the land-use, hydrography, stormwater controls, transportation, and point-source coverages to identify drainages with desired characteristics for size, residential/commercial land use, and minimal point sources.
6. Visit each drainage basin; determine if streamflow from the basin can be gaged.
7. Consult with agencies who are familiar with local issues and projects that are planned in the basins. Select the basins that best meet the criteria for Urban Indicator Sites.

Install Streamflow-Gaging Station

Streamflow-gaging stations should be constructed to meet standard USGS requirements for monitoring streamflow (Rantz and others, 1982) if the selected site does not have an existing gage. Large gage houses are not needed if Study-Unit personnel manually collect discrete samples during high flows. However, it is recommended that the gage house be large enough for at least one automatic-pumping sampler along with other equipment. Automatic samplers are very useful in collecting high-flow samples from flashy urban streams. Room for two automatic samplers will be needed if the Study Unit uses an ISCO 6100 to collect high-flow samples for volatile organic compounds (VOCs). The intake of the automatic sampler should be as close as possible to where samples will be manually collected so that data are comparable. Urban Indicator Sites should have rain gages, but rain gages are not required to characterize rainfall amounts and distributions for the entire drainage basin. Rain gages should be accurate to 0.01 inch and be able to record at 15-minute intervals. Rainfall intensity, as well as amounts, were shown to correlate with constituent loads (Driver and Tasker, 1990). Previously existing rain gages operated by other Federal, State, and local agencies may be suitably distributed in the drainage basin to better characterize sampled storms.

Sample Streamflow

The source of contaminants affects the occurrence and temporal variation of concentrations in streamflow. Contaminants found in streams from residential/commercial areas can originate from the atmosphere, solid material and spills on impervious surfaces that are flushed into storm sewers, chemicals applied to lawns and gardens, and contaminated ground water that discharges to streams. For example, VOCs in the atmosphere can partition into precipitation; the occurrence of VOCs in stormwater from this source is expected to be fairly constant during high flows. Flushing of contaminants accumulated on impervious surfaces, however, can result in incidental occurrence and high concentrations in the initial flow from a storm due to the flush-off effect and relatively low concentrations during the remainder of the high flow. The occurrence of contaminants and temporal variation of concentrations also are affected by the characteristics of the basin, such as land slope and distance between sources and the sample location.

Two sampling strategies will be used to obtain data sets that characterize annual and seasonal occurrence and ranges in contaminant concentrations. The sampling strategy used depends on whether an indicator site is a Basic Fixed Site (BFS) or Intensive Fixed Site (IFS) (Gilliom and others, 1995); most Urban Indicator Sites are IFSs. BFSs and IFSs are operated for at least 2 years and may be operated for a third year if unusual hydrologic conditions occur during the first 2 years. More data are collected at the IFS than at the BFS during 1 of the 2 years; the IFS is operated as a BFS during the other year.

Basic Fixed Site Sampling Strategy

The BFS sampling strategy is designed to characterize (1) general water-quality conditions in streamflow, (2) periodic variations that are due to storms and seasons, and (3) variations between years. BFS sampling is comprised of continuous monitoring, fixed-interval sampling, and extreme streamflow sampling (Gilliom and others, 1995). Continuous monitoring will include streamflow, specific conductance, and water temperature at all Urban Indicator Sites. Fixed-interval samples will be manually collected at Urban Indicator Sites at least monthly during BFS sampling (table 2). Equal-width increment sampling is the recommended method for collecting fixed-interval samples (Shelton, 1994).

Table 2. Basic Fixed Site fixed-interval and high-flow sampling frequency for Urban Indicator Sites

[Months with three samples are the recommended months when high-flow samples should be collected. High-flow samples could be collected at other times depending on the climate and periods of chemical use in the Study Unit. Samples should be analyzed for major ions, nutrients, suspended sediment, dissolved solids, and suspended and dissolved organic carbon]

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
3	1	1	1	1	3	3	1	1	1	1	3

Samples should be collected eight times per year during high-flow conditions resulting from storms or snowmelt. Minimally, one manually collected discrete sample should be collected during the rising stage or at the peak of the streamflow when contaminants are most likely to be detected in urban streams. Point sampling at the centroid of the stream should be used during high flows because stage can change too quickly in urban streams to collect an equal-width increment sample. Preferably, several manually collected samples will be collected during high flows to calculate high-flow loads and yields. Samples should be analyzed for major ions, nutrients, suspended sediment, dissolved solids, and suspended and dissolved organic carbon. Refer to a U.S. Geological Survey memorandum (Tim Miller, U.S. Geological Survey, written commun., May 15, 1996, Reston) for guidance on collecting quality-control samples.

Automatic samplers should collect flow-weighted composite samples during high-flow conditions and the results used to calculate stormflow loads and yields. Loading of contaminants into large river systems was decided to be of greater national importance than determining the time-weighted concentration to which aquatic organisms are exposed during high flows. Automatic samplers may be activated at specified volumes of streamflow by a data logger that has been programmed with a regression equation for the stage-discharge relation. The data logger can calculate the volume of streamflow during a storm and activate the sampler when the volume of streamflow exceeds a volume specified in the program. Try to avoid sampling at a specified volume that is too low and would fill the automatic sampler before the flow recession stage. The data logger also can record ancillary data, such as the time at which a sample was successfully collected. A large, glass bottle can collect sample water for nutrients and suspended sediment.

Field measurements should include specific conductance, pH, water temperature, dissolved oxygen, and alkalinity for fixed-interval and high-flow samples, and notes should indicate whether urban stormwater contributed to streamflow. Analysis of bacteria (fecal coliform, fecal streptococci, or E. coli) is not required. Synoptic studies, however, could provide valuable information on the sources of bacteria and should be done for urban streams that are used for recreation and when there is partial-body contact.

Intensive Fixed Site Sampling Strategy

The IFS sampling strategy is designed to collect detailed data on the occurrence of contaminants listed in table 3 at fixed intervals and during high flows for 1 year, after which sampling will return to the BFS sampling strategy. Trace elements also may be sampled, but are not required. The proportion of urban stormwater in streamflow is likely to be a primary factor affecting the detection of contaminants, so the emphasis of the intensive sampling strategy is to collect samples during high flows when pesticides and VOCs are likely to occur. The periods of high-frequency fixed-interval sampling should be during the wet seasons when pesticides are frequently used and when detection of VOCs is expected to be highest, such as during a temperature inversion during cold months. Discrete samples that are collected manually during high flows should be from the centroid of the stream on the rising stage or peak of high flows (table 4). Contaminants, especially VOCs, may not be present at detectable concentrations during flow recession. Automatic samplers with a large, glass bottle can be used to collect sample water for pesticides. The ISCO 6100 should fill three vials for each VOC sample. Tables 3 and 4 list the sampling frequencies for urban IFSs. Study Units may sample at higher frequencies at urban IFSs and for the same constituents at other Indicator Sites for comparison.

Table 3. Intensive Fixed Site fixed-interval sampling frequency for Urban Indicator Sites

[VOCs, volatile organic compounds]

Constituent	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Nutrients	2	2	2	4	4	4	4	4	1	2	2	2
VOCs	2	2	2	1	1	1	1	1	1	2	2	2
Pesticides	1	1	1	4	4	4	4	4	1	1	1	1
Suspended sediment and dissolved solids	2	2	2	4	4	4	4	4	1	2	2	2
Suspended and dissolved organic carbon	2	2	2	4	4	4	4	4	1	2	2	2

Table 4. Intensive Fixed Site high-flow sampling frequency for Urban Indicator Sites

[Deviation from the recommended sampling periods may be required depending on the climate and periods of high chemical use in the Study Unit. VOCs, volatile organic compounds]

High-flow event	Nutrients	VOCs	Pesticides	Suspended sediment
Winter frontal storm (about Oct. 1 to Mar. 31)	3	3	0	3
Thunderstorm (about June 1 to Sept. 1)	3	3	[1]4	3
Snowmelt	2	2	0	2

[1] Pesticide samples should be collected between April 1 and September 1.

Sample Bed Sediment and Tissue

The occurrence and concentration of trace elements and hydrophobic organic contaminants is best characterized by analyzing samples of streambed sediment and tissue of aquatic organisms because these contaminants typically are associated with the solid phase and accumulate in tissues of aquatic organisms. Bed-Sediment and Tissue Studies should be done at all Urban Indicator Sites to assess the occurrence of these contaminants in urban environments. Sampling should be done near the reach where stream samples are collected and during summer or autumn low streamflow to collect recently deposited sediment and reduce seasonal streamflow variability (Gilliom and others, 1995). Methods described by Shelton and Capel (1994) for collection of bed sediment and by Crawford and Luoma (1993) for collection of tissue should be used.

DETERMINING FACTORS AFFECTING STREAM QUALITY IN RESIDENTIAL/ COMMERCIAL AREAS

Identifying sources of contaminants and understanding processes affecting their transport in urban streams are critical to protect the water resources in urban environments. Past urban investigations focused primarily on characterizing constituent concentrations in streamflow; relatively little work was done to identify sources of contamination. Statistical analysis of detailed ancillary data collected at Urban Indicator Sites will help explain the occurrence of contaminants.

Natural and human factors affect the chemistry of streamflow. Natural factors, such as soil type, may affect the amount of suspended sediment and naturally occurring constituent concentrations. Human factors, such as use of a particular herbicide with a certain type of landscaping, may explain the presence of contaminants at a particular location. Many potential sources of contaminants exist in residential/commercial areas, but a limited number of land-use activities could be the major contributors of contaminants to streamflow. This knowledge will be useful for effectively managing development in urban areas.

Questions to be Answered

Factors affecting the stream quality must be identified to answer questions of local and national importance. What natural and human factors most strongly explain the presence or absence of contaminants in streamflow? In which Environmental Setting(s) are certain contaminants most commonly detected? Are previous land uses a factor in the types of contaminants found in streamflow, bed sediments, and tissues? What are the possible anthropogenic sources of contamination in urban streamflow? Is the atmosphere a predominant source of VOCs?

Work Elements

Define Stormflow Characteristics

Stormflow characteristics for sampled high flows should be defined to help explain the occurrence and concentration of contaminants and to estimate loads and yields of selected constituents. The peak flow, volume of storm runoff, and flow-weighted percent of stormwater in streamflow when samples were collected should be determined. Streamflow, percentage of stormwater in streamflow, and sampling time should be plotted to show when samples were collected during the high flow. If rainfall data are available, storm characteristics should include amount of rainfall, maximum 15-minute rainfall intensity, antecedent dry days, and distribution of rainfall in the drainage basin. The 15-minute streamflow data and hydrograph- and storm-characteristic data should be saved in Relational Data Base (RDB) files for storage in the national NAWQA data base.

Compile Ancillary Data

The following ancillary data associated with Urban Indicator Sites are needed to determine factors affecting stream quality. Much of the ancillary data also are needed for the ground-water components of the urban studies. Ancillary data beyond that listed below may be needed; additional ancillary data should be gathered by Study Units when other factors could affect stream quality at Indicator Sites.

1. Current, surrounding, and previous land-use history—Use GIS to calculate the percentages of current land use in the drainage basin and the type of land use surrounding the urban area. Check with other government agencies for the availability of land-use information in GIS format. Determine if the population in the basin is stable or changing; if rapidly increasing, periodically measure the percentage of urban area and land uses in the drainage basin. Use GIS, aerial photographs, or other sources to document the history of land use in the basin to the greatest extent possible. Urban areas commonly encroach on land that was previously used for agriculture, and residue from the previous land use could affect streamflow quality. Persistent pesticides, used extensively after World War II, are the most likely residue that could affect stream quality. It may not be necessary to document land use prior to 1945.
2. Drainage basin—Use census data to obtain population, population density, and socio-economic factors such as mean income because chemical use may be associated with an affordability index. Traffic density and potential point-source-contamination data (for example gas stations, dry cleaners, auto-repair shops) may be available from city, county, or State agencies. Percentage of impervious area associated with specific land uses may be available from local flood-control agencies, and soil types in the drainage basin may be available from the Natural Resources Conservation Service or local universities. Determine if combined sewers, point sources of contamination, flood-control structures (for example, retention/detention ponds, dry wells), and rain gages are in the basin. Make contacts to get information on distribution of rainfall for sampled storms. Aerial photography is useful for identifying features in the study area.
3. Monitored stream—Determine if sustained low-flow is from ground water, point-source discharges, or a combination of sources. Depth to water in nearby wells can be used to help determine which sections of the stream are gaining or losing. Streamflow measurements can be made at selected reaches during low flow to estimate base flow or infiltration rates. Discharge from storm drains and point sources can be measured during low streamflow to determine the contribution from these sources. Additional information on streamflow and stream quality in the basin may be available from other agencies and consulting firms.
4. Climate—Obtain information on mean annual precipitation, percentage of precipitation as snow, and percentage of annual precipitation for each month using climatic data for 1960-91. Compare climatic variables of the sampling period to the mean values and determine if typical or unusual climatic conditions occurred.
5. Atmosphere—Determine if the U.S. Environmental Protection Agency has classified the MSA as a nonattainment area for air quality, if and when reformulated fuels are used, the mean wind velocity and direction, and if prevailing upwind sources of atmospheric contaminants exist. Contact State and local agencies for air-quality monitoring data

that may exist. Determine how long the air monitoring has been in place, the location of monitoring stations, methods of data collection, constituents that are analyzed, and obtain data collected concurrently during the study period.

6. Toxic Release Inventory (TRI)—Use GIS and TRI data (U.S. Environmental Protection Agency, 1995) to estimate the annual release of constituents, unit-area releases (kilograms per square kilometer), and proportion of releases to the atmosphere, land, and streams in the urban area.
7. Additional sources—Obtain information on chemical releases from other sources that may exist such as Federal, State, or municipal toxic release and point-source inventories (for example, U.S. Environmental Protection Agency's Permit Compliance System data base).

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