A National Framework for Ground-Water Monitoring in the United States

Prepared by The Subcommittee on Ground Water of The Advisory Committee on Water Information

Approved by The Advisory Committee on Water Information

First Release – June 2009

Revised – July 2013

Cover. A well shelter designed to protect the well, recorder, and transmitting equipment located at the Idaho National Laboratory in Idaho Falls. Big Southern Butte, a well know landmark in eastern Idaho, is in the background. Photograph by Matthew J. Gilbert, U.S. Geological Survey.

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Foreword

The establishment and management of a National Ground-Water Monitoring Network (NGWMN) in the United States would represent a significant achievement in water-resource management. The need for ground-water monitoring focused on the major aquifers and aquifer systems in the USA is increasingly important as a key element of sustainable ground-water resource management and use. The National Framework described in this report provides detailed information and recommendations for developing and operating a national ground-water monitoring network that would provide ongoing data collection on ground-water quantity and quality. These data will be available to the public and will be critical for addressing ground-water management issues at the Federal, State, Tribal and local levels. The data will be particularly useful for "state of the resource" assessments requested by State Legislatures and the U.S. Congress. The National Framework was developed by the Subcommittee on Ground Water (SOGW), an ad-hoc committee under the Advisory Committee on Water Information (ACWI), which is a Department of the Interior Federal Advisory Committee.

Implementation of the NGWMN will require a partnership between State and Federal water-resource management agencies. The monitoring network, as described in this document, is intended to make use of and enhance existing Federal, multi-state, State, and local ground-water monitoring programs. The network will consist primarily of existing wells that are currently being used for regional and statewide ground-water monitoring. As a result it will be necessary to (a) identify wells in existing programs that are suitable for inclusion in the national network, (b) align water-level monitoring frequencies and water-quality analyte lists/sampling frequencies conducted by the source networks with suggested NGWMN frequencies, and (c) add new wells to the network as needed and as funding is available.

Full development and implementation of the NGWMN will require funding and personnel resources. To evaluate and develop meaningful information about the feasibility of the NGWMN concepts and required resources, five pilot studies were conducted in six states. These pilot studies confirmed the feasibility of the NGWMN concepts and provided estimated costs for four major elements of the NGWMN: (1) well network development, (2) field practices, (3) data management, and (4) implementation. These estimated costs, while varying among states, provide guidance on funding requirements associated with implementation of the NGWMN. It is expected that the U.S. Geological Survey (USGS) will provide day-to-day management of the NGWMN. The SOGW will serve in an advisory role to the USGS. It is anticipated that the NGWMN will be incrementally funded and not fully developed for a few years. Thus, it is important to recognize the need for a phased approach to implementation of the network. In the initial phase, the network will not be fully developed. The number and locations of monitoring wells that will be put into the network may not meet all of the desired criteria; however, it is important to get the network started. During a transition phase, the USGS and SOGW will continue to solicit participation in the NGWMN by data providers—mostly states—and provide guidance to state water-resource agencies for adding wells to the NGWMN. The final phase of the network will consist of a long-term ground-water quantity and quality monitoring program, conducted under a scientifically rigorous sampling and analysis plan as well as an interactive data management and retrieval system that would allow for input and use of data by a variety of data users. The time frames associated with these three implementation phases are not known with certainty but are expected to occur over a number of years.

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Executive Summary

Introduction

In 2007, the Subcommittee on Ground Water (SOGW) was commissioned by the Federal Advisory Committee on Water Information (ACWI) to develop a framework that establishes and encourages implementation of a long-term national ground-water quantity and quality monitoring network. This network could provide data and information necessary for planning, management, and development of ground-water resources in a sustainable manner. The SOGW, which together with its working groups, includes more than 70 people representing the private sector and 54 different organizations, including nongovernmental organizations, State and local agencies, Federal agencies, and academia (figure ES-1). The proposed National Ground-Water Monitoring Network (NGWMN) is envisioned as a voluntary, integrated system of data collection, management, and reporting that could provide the data needed to help address present and future ground-water management questions raised by Congress, Federal, State, and Tribal agencies and the public.

The need for national ground-water monitoring has been recognized by organizations outside government as a major data gap for managing ground-water resources. Our country's communities, industries, agriculture, energy production, and critical ecosystems rely on water being available in adequate quantity and suitable quality. However, it is well established that ground-water quality has been impacted by agricultural pesticide and nutrient use, infiltration of stormwater as a result of best management practices (BMPs), commercial and industrial activities such as cooling water extraction and reinjection causing redistribution of contaminants, energy production, and the effects of artificial recharge and aquifer storage-recovery (AR/ASR) systems that may be using treated potable water, reclaimed water, or raw surface water or stormwater.

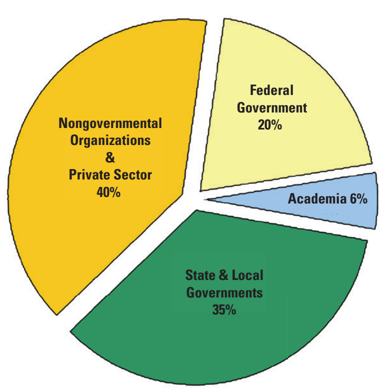

Figure ES-1 Organizational distribution of Subcommittee on Ground Water membership and work group participants.

Ground water is the source of drinking water for 130 million Americans each day and provides 42 percent of the Nation's irrigation water (Hutson and others, 2004). Ground-water levels and ground-water quality have changed across the Nation in response to this water use and activities at land surface. Because surface water is fully allocated in many parts of the Nation, increased ground-water demand is expected in all sectors of water use, including the heavy use sectors of irrigation and public supply. New factors exacerbate these trends. Biofuel production likely will increase ground-water irrigation demand and the potential for contamination from agrichemical applications. Proposals for geologic sequestration of carbon dioxide to mitigate climate change present the potential to acidify ground water used for drinking water and other purposes if migration of the carbon dioxide to overlying aquifers occurs. Increased activities in the oil and gas sector to enhance natural gas production through hydraulic fracturing to meet ever growing energy demands use more water and may raise ground-water vulnerability risks. Additionally, brackish and saline ground water may now be used after treatment in water-deficient areas and may compete as locations for carbon sequestration.

All of these activities threaten actively used aquifers and the baseflow of the streams they support. Not only may baseflow and ground-water dependent ecosystems be threatened, but ground water that has become contaminated often discharges to surface-water bodies, demonstrating how monitoring of ground-water quality is a critical component for understanding, restoring, and managing surface-water quality.

Current Ground-Water Monitoring Efforts

Ground-water level monitoring has been conducted for many decades in many States. Data from these networks have been used to help identify, develop, and manage ground-water supplies. Ground-water quality monitoring programs have been developed more recently in response to the focus on water quality that resulted from passage of the Safe Drinking Water Act; the Clean Water Act; the Comprehensive Environmental Response, Compensation, and Liability Act; and other environmental laws. As of 2007, thirty-seven States operated statewide or regional ground-water level monitoring networks, and 33 States have at least one active statewide or regional ground-water quality monitoring program. The State monitoring networks are funded by a combination of State and Federal funds. The networks are operated by a variety of State agencies, many of them in cooperation with the U.S. Geological Survey (USGS).

Interstate aquifer management is complicated by differing State objectives and reporting protocols for ground-water monitoring networks and ground-water use. This circumstance precludes regional or national evaluations of ground-water availability, rates of use, and sustainability. Because many aquifers support multiple jurisdictions, a focus on monitoring at the aquifer level rather than at a political subdivision is critical to facilitate sustainable ground-water use.

Description of the Proposed National Ground-Water Monitoring Network (NGWMN)

The proposed NGWMN may be thought of as a compilation of selected wells across the Nation that can be used to enhance existing State and Federal monitoring efforts. The NGWMN is not intended to replace existing State or Federal monitoring networks, nor is it intended to address local issues. The network is designed to focus on monitoring ground water from the Nation's most productive aquifers and aquifer systems. The USGS defines a Principal aquifer as a regionally extensive aquifer or aquifer system that has the potential to be used as a source of potable water over broad areas. Other important aquifers, as identified by States or Tribes, also will be included in the network. The focus of the network will be on assessing the baseline conditions and long-term trends in water levels and water quality. Final designs for the monitoring network for each Principal aquifer will differ depending on a number of factors, including aquifer lithology, thickness, degree of aquifer confinement, degree of aquifer development (i.e., pumping), climate, potential for adverse impacts to water quality, and other hydrogeologic factors. The final network design for each aquifer or aquifer system likely will be an approach that specifies a minimum number of monitoring sites for a given aquifer/aquifer system and that determines the number of monitoring sites required for an aquifer/aquifer system to achieve a predetermined sampling density.

The NGWMN will include three well classification subnetworks: a Background Subnetwork, a Suspected Changes Subnetwork, and a Documented Changes Subnetwork. Network monitoring will include three different categories: trend monitoring, surveillance monitoring, and special studies monitoring. Any given monitoring location could be included in one or more categories. Frequency of monitoring for any given aquifer/aquifer system will be determined on the ability of the measurement schedule to adequately detect short-term and seasonal changes and to discriminate between the effects of short- and long-term hydrologic stresses. For water-quality monitoring, the analytes to be sampled are based on the subnetwork, the monitoring category, and the monitoring frequency. Detailed information contributed to the NGWMN about a monitoring site and the contributing aquifer will be a critical component for management and subsequent analysis of data. The national framework also recognizes that selected ancillary information will be required to answer important water-management questions. Common data-collection techniques will be established to ensure comparability of data that will be provided by a wide variety of Federal, Tribal, State, and local organizations. The NGWMN recognizes that new technologies for collecting samples, making measurements, and analyzing data will continue to be developed and improved. These new technologies may result in significant cost savings for ground-water monitoring programs and will be incorporated into the NGWMN as appropriate.

Ground-Water Data Management

Another essential part of the proposed NGWMN is a data-management system designed to access and disseminate network data. Data systems in the United States exist at many organizational levels (local, State, national, academic, and private sector), but because of many factors, including historical differences in purpose, the data cannot easily be shared and compared, which results in inefficient use of the data and higher overall costs. To overcome this problem, several national, private, and governmental organizations have evolved data standards and a common vocabulary to facilitate data sharing. As new databases are developed and old systems are updated, the standards gradually are being incorporated into these systems. Agencies and academia will continue to improve technology and software for the collection, retrieval, display, and interpretation of data. As a result, the focus of the NGWMN data-management system will be on developing applications that facilitate the retrieval of and access to data on an as-needed basis from multiple, dispersed data repositories The applications will allow the data to continue to be housed and managed by the data provider while being accessible for purposes of a national monitoring program. A Web-based portal will allow the diverse network stakeholders to search and retrieve data needed to address the many questions related to the monitoring of the Nation's ground-water resources (figure ES-2).

Benefits of a National Ground-Water Monitoring Network

The NGWMN will provide an improved foundation and context, at the national and regional multistate scale, within which to interpret data from various data-collection efforts. The network will generate an ongoing time series of ground-water levels and water-quality data necessary to evaluate the status and trends of the Nation's ground-water resources. The network will provide data that can be used to answer questions at a variety of scales, though the primary focus will be on national or regional interstate scales. Because the

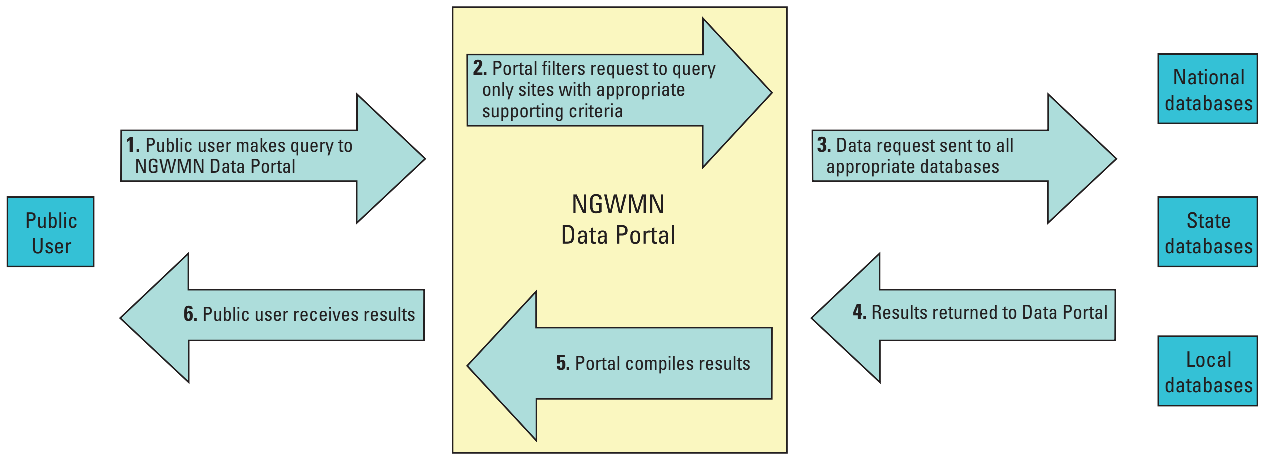

Figure ES-2 Steps taken and information flow from a public data request to the proposed National Ground-Water Monitoring Network data portal.

individual monitoring programs may have differing objectives and produce data not sufficiently compatible for aggregation into a national dataset, establishment of a consistent national design and standards for ground-water monitoring will allow selected wells in many of these monitoring programs to be included in a national program that does have consistent goals, procedures, and data-quality standards. A set of metrics will be developed to track the success of the NGWMN. These metrics would be based on NGWMN goals of (a) full participation by the principal ground-water data producers in the United States, (b) full acceptance by these producers of the NGWMN goals and recommendations, and (c) inclusion of an adequate number and distribution of monitoring locations so that meaningful interpretations can be made regarding the status and trends for ground-water levels and quality. The NGWMN management will include strategies for assuring adequate communication, coordination, and collaboration with all Federal, State, Tribal, and local stakeholders. To implement these strategies, a network management structure will be developed, and adequate funding will be required. To support an efficient implementation of a NGWMN, pilot projects were conducted in selected areas of the country to incorporate parts of existing State ground-water monitoring programs into a national network (Subcommittee on Ground Water, 2011).

Recommendations of the Subcommittee on Ground Water

On the basis of the work completed by the Subcommittee on Ground Water, the following recommendations are presented for consideration by the Advisory Committee on Water Information:

1. **Establish a National Ground-Water Monitoring Network, according to the design parameters in this Framework Document, to include**

   a. **A network management structure,**

   b. **A national ground-water data portal, and**

   c. **Data collected and contributed from a variety of providers including States, Federal agencies, regional entities, and other organizations.**

A three-tiered structure is recommended (figure ES-3): (1) continue the Subcommittee on Ground Water to serve as an interface between the ACWI and the NGWMN on Federal issues and to identify directions and priorities for the NGWMN, (2) establish a Management and Operations Group

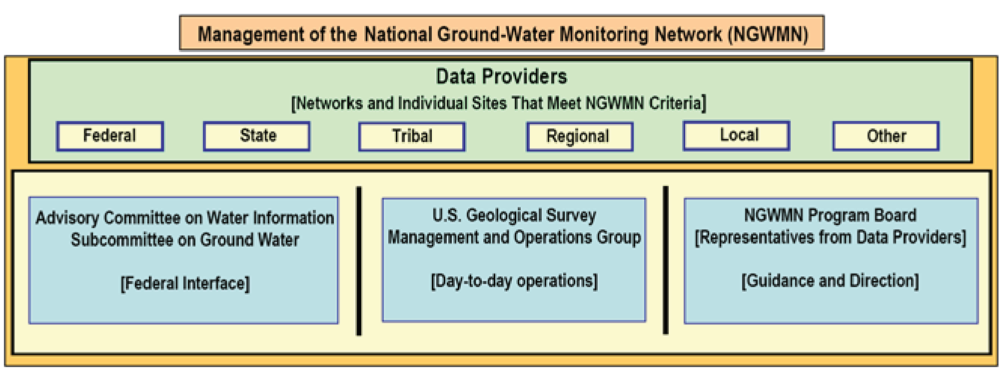

Figure ES-3 Management of the proposed National Ground-Water Monitoring Network.

in the U.S. Geological Survey to handle day-to-day administration of the NGWMN, and (3) establish a Program Board to provide guidance and input regarding scope, priorities, and overall direction to the Management and Operations Group. Members will consist of NGWMN data providers.

The NGWMN will consist of two components—a ground-water level network and a ground-water quality network. Each network will make available internally consistent data and information for planning, management, and development of ground-water resources at the regional and national scale to meet current and future water needs. The NGWMN would include three well classification subnetworks—a Background Subnetwork, a Suspected Changes Subnetwork, and a Documented Changes Subnetwork.

2. **Explore and facilitate Federal funding opportunities, cooperative agreements, and any and all feasible options to help support the NGWMN.**

Possible funding models include one or more of the following: Federal Monitoring Programs and Federal-to-Federal collaboration; the U.S. Geological Survey Cooperative Program; a modified USGS-STATEMAP program; and U.S. Environmental Protection Agency grants that support monitoring.

3. **Use the information from the completed Pilot Projects to**

    a. **Implement the National Ground-Water Monitoring Network concepts and**

    b. **Aid in its full-scale implementation.**

A test of the SOGW's comprehensive design plan for a NGWMN was needed before pursuit of network implementation. Five State- and aquifer-based volunteer pilots—Montana, Texas, Minnesota, Illinois-Indiana, and New Jersey—began in January 2010 to test the proposed network design and implementation concepts. These pilots have completed their 1 year volunteer pilot projects and have successfully demonstrated the feasibility of a collaborative national ground-water monitoring network that would provide information necessary for the planning, management, and development of ground-water supplies to meet current and future water needs.

The NGWMN Internet data portal was a key element to the success of a NGWMN. A pilot NGWMN portal was developed using state-of-the-art informatics processes to unify data provided from nine disparate data systems. Site data and measurements from NGWMN sites were unified and available through the network data portal, in many cases on-the-fly using Web services. The pilot portal effort found that even though States recorded data differently and used different database platforms, States typically included nearly all of the data needed for comparable reporting in their existing databases, and making adjustments in those systems was not foreseen as a major obstacle. Thus, the SOGW template for reporting provided a consistent approach for integrating the State data and mapping those data to the portal.

The pilot projects identified some changes to the NGWMN Framework Document that would improve the clarity of the guidance in the document and make participation by NGWMN data providers easier. The SOGW will use this information to move forward with full implementation.

Chapter 1 – Introduction

Water is one of the Nation's most essential natural resources. Our country's communities, industries, agriculture, energy production, and critical ecosystems rely on water being available in adequate quantity and suitable quality. Ground water is the source of drinking water for more than 130 million Americans each day and provides about 42 percent of the Nation's irrigation. Although overall water use has been relatively steady for more than 20 years, ground-water use has continued to increase, primarily for public supply and irrigation. Of the 83,300 million gallons per day (Mgal/d) of ground water used in 2000, 68 percent was used for irrigation, about 23 percent was used for public supply and domestic use, 4 percent for industrial use, and the remainder for livestock, aquaculture, mining, and power generation (Hutson and others, 2004). In addition to human uses, many ecosystems are dependent on direct access to ground water or on ground-water discharge to streams, lakes, and wetlands.

The Nation's ground water is under stress and requires immediate attention at the local, State, interstate, and national level. State and Federal agencies have measured ground-water level declines in nearly every State. Ground-water quality changes from chemical use and waste disposal have occurred in all States. Climate change through increased flooding may significantly affect ground-water quality and through drought may significantly affect ground-water levels. Because surface water is fully allocated to existing uses in many parts of the Nation, increased ground-water demand is expected in all sectors of water use, including the heavy use sectors of irrigation and public supply. Energy and biomass production for biofuels likely will increase stress on ground water used for growing crops and producing and refining fuels. Associated increases in agrichemical application and residuals disposal also may have a deleterious effect on ground water. Proposals for geologic sequestration of carbon dioxide to mitigate climate change present the potential to acidify ground water used for drinking water and other purposes if migration of the carbon dioxide to overlying aquifers occurs. Additionally, brackish and saline ground water may now be used after treatment to supply water deficient areas and may compete as locations for carbon sequestration. Other examples of ground-water impacts include agricultural pesticide and nutrient impacts, infiltration of stormwater as a result of best management practices (BMPs), commercial and industrial activities such as cooling water extraction and reinjection causing redistribution of contaminants, and the effects of artificial recharge and aquifer storage-recovery (AR/ASR) systems that may be using treated potable water, reclaimed water, or raw surface water or stormwater. All of these activities threaten both actively used aquifers and the baseflow of the streams they support. Not only may the baseflow rate be threatened, but ground water that has become contaminated often discharges to surface-water bodies, demonstrating how monitoring of ground-water quality is a critical component for understanding, restoring, and managing surface-water quality.

Interstate aquifer management is severely challenged by monitoring networks that end at State borders and have different objectives, designs, methods, and reporting requirements. The levels and quality of ground water are monitored by many well networks, but these networks do not have common objectives or reporting requirements. This situation precludes fundamental regional and national scale evaluations of the resource with assessments often based on local use of portions of aquifers underlying many jurisdictions. Coordinated monitoring needs to provide the basis for regional and national resource perspectives as a foundation for informed decision making at all levels. Because many aquifers support multiple jurisdictions, a focus on monitoring at the aquifer scale rather than at the political subdivision scale is a critical need to foster sustainable ground-water use.

To successfully manage present ground-water resources and ensure effective planning for future ground-water needs, an understanding of the processes and properties of the ground-water systems containing the water is required. Detailed information on ground-water levels is needed because ground-water level measurements are the sole direct measure available to evaluate aquifer conditions. Increases in ground-water levels demonstrate increased quantities of water stored within an aquifer. Decreases in water levels demonstrate decreased quantities of water in storage. Uses of ground-water level monitoring data are critical to evaluate

- short-term and long-term changes in ground-water recharge and storage,
- short-term and long-term impacts from climate variability (especially droughts),
- regional interstate and regional intrastate effects of ground-water development,
- the water-level surface (potentiometric surface) of the water table or confined aquifers,
- changes in ground-water flow directions,
- interactions between ground water and surface water, and (or)
- ground-water flow and contaminant transport through computer modeling.

Not only must ground water be present in sufficient quantity, but the water also needs to be of suitable quality for the intended use. Suitability of the ground water may depend on factors, such as taste and odor; presence of naturally occurring constituents, such as radionuclides or arsenic; microbial content; or presence of nitrates, pesticides, and other anthropogenic constituents. Saltwater or brackish water may contaminate water supplies in coastal areas as a result of the excessive withdrawal of ground water. Extended road salting along major corridors and in urban areas can contaminate aquifers. Aquifer contamination sources may be site specific (point) or diffuse (non-point). Commonly, contaminants are detected by monitoring wells, and contaminant transport is modeled by computer using ground-water level data to determine flow direction. The monitoring of spatial and temporal changes in ground-water quality must go hand-in-hand with ground-water level monitoring if the Nation is to evaluate the usability of its ground-water resources.

Despite the fact that ground-water levels are monitored in many places and at many scales, a comprehensive repository of ground-water level monitoring data does not exist. In fact, the availability of ground-water levels and rates of change is "not adequate for national reporting" according to the report, "The State of the Nation's Ecosystems" (H. John Heinz III Center for Science, Economics and the Environment, 2002). A followup report from the Heinz Center (H. John Heinz III Center for Science, Economics and the Environment, 2008) identified ground-water levels as "one of the 10 highest priority data gaps that must be filled to improve the Nation's ability to report on ecosystem conditions and use, and to make sound policy and operational decisions." The President's National Science and Technology Council (NSTC) Committee on Environment and Natural Resources (CENR) Subcommittee on Water Availability and Quality (SWAQ) cited three broad categories of scientific and technical challenges that the Nation must meet in order to ensure an adequate water supply. One of the categories challenges the United States to "…accurately assess the quantity and quality of its water resources..." (National Science and Technology Council, 2007). These references are but two examples illustrating that a National Framework for ground-water monitoring worthy of ground-water's importance to the Nation is needed. The Framework should recognize ongoing monitoring at many scales, provide mechanisms through which suitable data can be collated at the national scale, and also provide for collection of these data from critical areas where there are no existing networks.

1.1 Organization of the Report

This report consists of a Foreword, an Executive Summary, and seven chapters and eight appendixes. Chapter 1 provides background, purpose, and limitations relating to the National Ground Water Monitoring Network (NGWMN), and an introduction to the proposed network design. Chapter 2 is an overview of State, multicounty, and national monitoring programs in 2007. Chapters 3, 4, 5, and 6 present the national network goals and management issues, expanded presentation of network design and specifications, common field practices and comparability, and data standards and data exchange goals. Chapter 7 highlights major recommendations and suggests options for management of the proposed NGWMN. Appendixes 1 through 8 provide a list of members of the Subcommittee on Ground Water, a list of report contributors, a glossary of terms, and information that amplifies on the recommendations and concepts presented in Chapters 2 through 7.

In this report, the term "monitoring" may refer to ground-water level monitoring, ground-water quality monitoring, or both.

1.2 Background

The Advisory Committee on Water Information (ACWI) is a Federal advisory committee that has a membership representing Federal and non-Federal interests with a wide range of expertise in and responsibilities for water resources. ACWI oversees the activities of a number of subcommittees, including one for water-quality issues, which is called the National Water Quality Monitoring Council (NWQMC). The NWQMC has designed an excellent network that provides information about how near-shore inland activities affect the health of our oceans and coastal ecosystems. Because the scope of that effort is essentially limited to coastal ecosystems and because ground water is a minor part of that effort, ACWI formed the Subcommittee on Ground Water (SOGW) in 2007 to address U.S. ground-water level and ground-water quality monitoring needs at a national scale. More than 70 individuals representing the private sector and 54 different organizations, including nongovernmental organizations, State and local agencies, Federal agencies, and academia (figure 1.2.1), worked together through the SOGW to discuss ground-water monitoring needs at the national scale and develop the national framework for ground-water monitoring that is described in this document. Appendix 1 lists the individuals and organizations instrumental in the discussion and drafting process of this report.

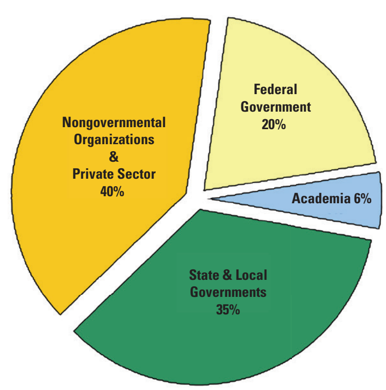

Figure 1.2.1 Organizational distribution of Subcommittee on Ground Water membership and work group participants.

1.3 Purpose and Scope

The overall goal of the Subcommittee on Ground Water (SOGW) is to develop and encourage implementation of a nationwide, long-term ground-water quantity and quality monitoring framework. The purpose of this document is to provide a framework for the National Ground-Water Monitoring Network. The goal of the network is to provide information essential for national-scale decisions to be made about current ground-water management, and future ground-water development while recognizing that the resource must continue to meet ecosystem requirements.

In undertaking its work, the SOGW considered policies, programs, and funding for the collection, analysis, assessment, distribution, reporting, management, and use of ground-water data at all levels of government and in the private sector. The SOGW obtained information about Federal and State monitoring programs, and reviewed products and activities of the ACWI or ACWI subgroups and their predecessors relevant to ground-water monitoring, data acquisition, or storage and retrieval. All of this information contributed to the recommendations provided in this document.

1.4 Network Design Features

The National Ground-Water Monitoring Network (NGWMN) is conceptualized as selected wells and springs from Federal, multistate, State, and local ground-water monitoring networks brought together under the defining principles presented in this document. The SOGW recognizes that many wells and springs used for monitoring within the various networks already in existence within the country can help generate the data required to address important questions about the availability and quality of the Nation's ground water.

The principal design features for the National Ground-Water Monitoring Network will be:

1. Identification of the aquifers to be monitored. Aquifer-system boundaries, not political boundaries, are the natural spatial units around which the conceptual models and network design are organized. Ground water and surface water are part of the same hydrologic system; therefore, NGWMN aquifer definition also must consider spatial relations between the selected aquifers and surface-water monitoring network(s).

2. Definition of a core set of data elements, including geographic data, well construction requirements, and measured parameters.

3. Definition of comparable field methods.

4. Defined protocols for selection of monitored locations in three dimensions within aquifers.

5. Specified monitoring timeframes and frequencies based on site characteristics and purpose. Specific network design issues, such as the spatial density and frequency of data collection, are tailored to conditions within each aquifer, such as aquifer heterogeneity, recharge and discharge areas, withdrawals, contamination extents, and other hydrogeologic factors.

6. Definition of water-quality analytes.

7. Definition of agreements with data providers through which data are made available to the national network.

8. A data-management system that allows national access to the data.

The NGWMN is envisioned as a voluntary, cooperative, integrated system of data collection, management, and reporting with a limited set of standards that provides the data needed to help address present and future ground-water management questions raised by Congress, Federal, State, and Tribal government agencies, the public, or others. Such questions include, but are not limited to:

- Where is ground-water use greater than what can be sustained on a long-term basis?
- What areas are most promising for future ground-water supply development?
- Where is ground-water use creating unacceptable impacts on surface water or on ecosystems?
- What are the effects of climate variability on ground-water levels across the country?
- What are the trends in ground-water levels and quality for major aquifer systems?

The NGWMN may be thought of as an aggregation of select wells and springs across the Nation. The network takes advantage of and also seeks to enhance existing Federal, multistate, State, Tribal, and local monitoring efforts. The NGWMN is not intended to replace existing monitoring systems nor is it intended to address local issues, such as contaminated industrial sites or regulated facilities. Rather, the network is focused on assessing the baseline conditions and long-term trends in water levels and water quality in important aquifers. The NGWMN is expected to provide an improved foundation and context within which to interpret information from various data-collection efforts. The network design is based on the following organizing principles:

- The NGWMN should be established within the context of aquifer conceptual models. Resulting data would, in turn, support improvement in these conceptual models, allowing improvement of the original monitoring system design.

- Aquifer-system boundaries, not political boundaries, are the natural spatial units around which the conceptual models and network design should be organized. Where needed, and if not already in existence, cooperative programs should be developed to address aquifers that cross political boundaries.

- Ground water and surface water are part of the same hydrologic system; therefore, the ground-water monitoring network must be integrated with surface-water monitoring network(s).

- Specific network design issues, such as the vertical and horizontal spatial density and frequency of data collection, are tailored to the needs of each aquifer depending on the thickness and areal extent of the aquifer, the use of ground water in the aquifer, and other hydrogeologic factors.

The overall network elements include:

- Conceptual modeling
- Monitoring design
- Field data collection
- Laboratory analysis
- Data transfer, storage, and dissemination
- Interpretation and reporting

The network is intended to produce data of sufficient quality and spatial/temporal distribution to support periodic evaluation of:

- Spatial and temporal patterns of ground-water levels and quality
- The extent to which ground-water levels and quality changes are related to human activity
- Responses to climatic variation
- The extent to which ground-water availability and quality changes affect human activities or ecosystems

1.4.1 Guidance

Numerous reports provided useful guidance for the design of the NGWMN. The National Research Council (NRC) report "Investigating Groundwater Systems on Regional and National Scales" (National Research Council, 2000), a U.S. Geological Survey (USGS) report "Concepts for National Assessment of Water Availability and Use" (U.S. Geological Survey, 2002), and a report by the Intergovernmental Task Force on Monitoring Water Quality (1997), "Conceptual Frameworks for Groundwater Quality Monitoring" provide valuable guidance for defining the questions to be addressed. None of the reports, however, directly address network design. In the last decade, the European Union (EU) recognized the need for and established a ground-water monitoring network for Europe. A series of European Commission (EC) reports on the common implementation strategy for EC Directive 2000/60/EC established a framework for community action in the field of water policy, commonly known as the EU Water Framework Directive (WFD), including EC Guidance Document No. 7, Monitoring Under the WFD; Ground-Water Monitoring: Technical Report on ground-water monitoring as discussed at the workshop of June 25, 2004; and EC Guidance Document No. 15, Guidance on Ground-Water Monitoring Directive 2006/118/EC on the protection of ground water against pollution and deterioration. Although there are numerous differences in design details, the European network with its *member-nation to Europe-as-a-whole* relation provides an excellent model for the NGWMN's *states-to-nation* relation.

EC Guidance Document No. 15 outlines a flexible monitoring approach designed to answer a set of core questions similar to the approach of the NGWMN. On a EU-wide scale, this flexible approach can be thought of as a *network-of-networks*, in which individual national networks are required to address a set of EU-wide questions/issues, but may also address specific needs of the member nation. Each member nation is required to prepare reports based on data from their own monitoring networks (Article 15), and the EC is required to prepare comprehensive summary reports initially within 12 years of the WFD effective date and every 6 years thereafter (Article 18).

Although ground-water monitoring in the United States does not have the legal framework that exists within the EU, the network-of-networks approach used by them is relevant in the United States and serves as a conceptual basis for the approach presented herein.

1.4.2 Network-of-Networks

The term "network-of-networks" sometimes is used to describe efforts to "roll up" existing networks operated over smaller areas into an inclusive network operated over a larger area. In the case of the proposed NGWMN, this usage is informal and refers to the logical linking through access to data of comparable quality from monitoring efforts already ongoing at national, regional interstate, State, Tribal, and local levels. This usage can cause confusion, however, because it can imply that all of the wells monitored in all of the combined networks are included in the larger-scale network. That is not the situation intended for the NGWMN. The proposed NGWMN will combine select wells from networks operated over smaller areas into a national-scale network. To avoid potential confusion, the "network-of-networks" terminology is not used in this report.

1.4.3 Well Classification Subnetworks

Monitoring points designated for the NGWMN will be selected using the criteria listed above, which include evaluation of conceptual ground-water flow models within aquifer systems. A ground-water monitoring point refers to a well or spring; occasionally throughout the report the phrase "well or spring" will be referred to as simply a "well" for brevity. Wells/springs included in the NGWMN will be flagged to designate that they belong in one of three subnetworks: (1) Background Subnetwork, for monitoring points located with little or no documented anthropogenic effect, (2) Suspected/Anticipated Changes Subnetwork (referred to hereafter as the Suspected Changes Subnetwork), for monitoring points located in areas with suspected or anticipated anthropogenic effects, and (3) Documented/Known Changes Subnetwork (referred to hereafter as the Documented Changes Subnetwork), for monitoring points with known anthropogenic effects. Monitoring points must have attributes that meet the subnetwork design criteria appropriate for their corresponding subnetwork designation. Figure 1.4.3.1 is a flowchart that describes the process of determining the appropriate subnetwork.

The subnetwork designation is selected for both water-level and water-quality networks because aquifers can be affected by either withdrawals or contamination. For example, a well in an undeveloped portion of an aquifer may be considered in the Background Subnetwork for water quality, but it could be in the Documented Changes Subnetwork for water levels because of effects from regional pumping. The appropriate subnetwork designations are determined by the data provider in consultation with NGWMN management. The subnetwork designations also can change if local conditions change as determined by the data provider.

1.4.3.1 Process for Establishing Baseline Conditions

The baseline process is required for all wells and springs in the NGWMN to provide an initial monitoring record that is used in conjunction with other hydrogeologic or climatologic information to place a well in one of the subnetworks (Background, Suspected Changes, or Documented Changes). These data also can be used as a baseline to examine changes and trends in water levels and (or) water quality over time. It is recommended that for the baseline process, 5 years of data collection be used to establish background conditions and to place the well (or spring) in the proper subnetwork.

The Subcommittee on Ground Water recognizes that 5 years of data collection may be adequate to establish background conditions in some environments and not in others. Sparse records over a longer period of time may also be sufficient to document the baseline process and place the well (or spring) in the proper subnetwork. The main objective of the baseline process is to place the wells in the NGWMN in the proper subnetwork; thus, there is some flexibility in the requirements of the baseline process period. Over time, individual sites are continually evaluated to assure that the site is in the proper subnetwork.

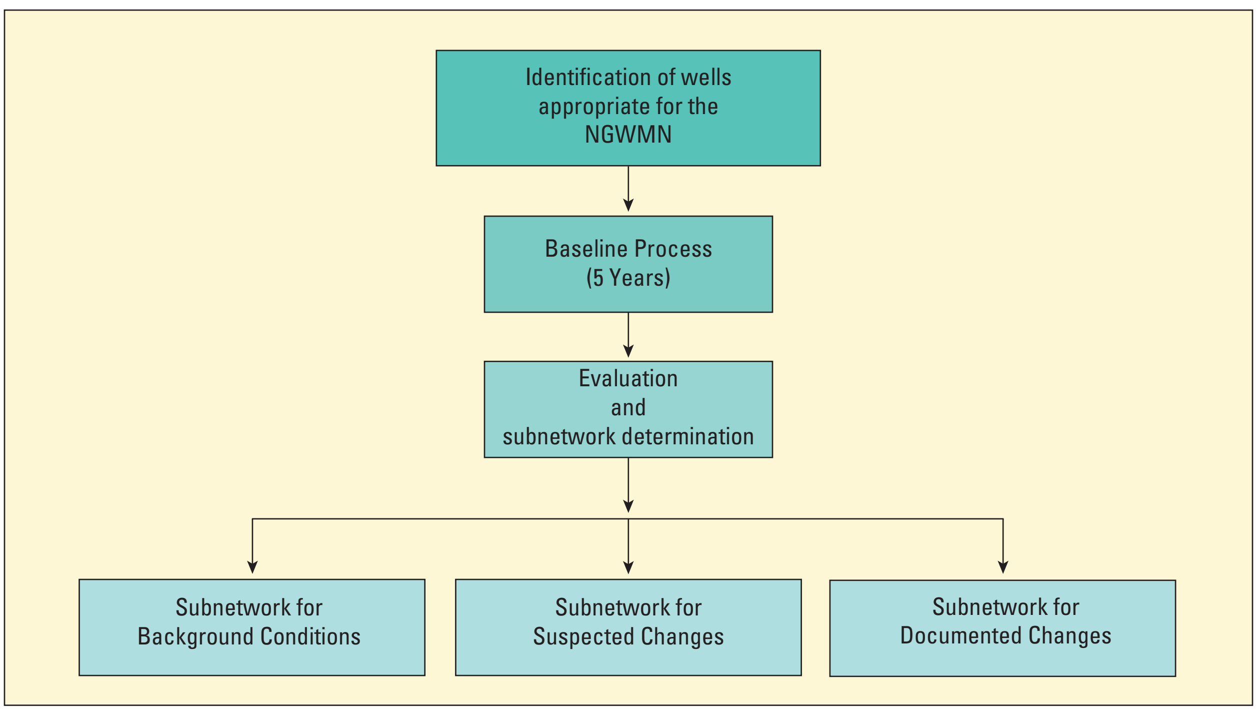

Figure 1.4.3.1 Flowchart for the determination of wells in each subnetwork of the National Ground-Water Monitoring Network.

Existing wells that are added to the NGWMN for which data have been collected for 5 years or more have already satisfied the baseline process requirement. These wells can be placed into the appropriate subnetwork.

If historic baseline data do not already exist, an initial baseline period of up to 5 years will be conducted on new monitoring points to define water-level and (or) water-quality conditions and to account for natural variability. Once baseline data are available (either from historic data or after 5 years of NGWMN data collection), data providers will evaluate the data and assign the monitoring point to the appropriate well classification subnetwork (Background, Suspected Changes, or Documented Changes). If 5 years of data are not adequate to make these determinations, the baseline phase may be extended. If the appropriate subnetwork can be determined prior to 5 years of data (for example, a clear pumping signal exists) or external factors predetermine the appropriate subnetwork (for example, a regulatory ruling), then the 5-year baseline period may not be necessary.

1.4.3.2 Background Subnetwork

The Background Subnetwork includes monitoring points that provide data from aquifers or parts of aquifers with no (or minimal) anthropogenic effects. Ideally, this network ensures that a consistent group of wells or springs is regularly monitored to generate water-level or water-quality data from areas where no documented effects to the natural ground-water flow system or natural water-rock chemistry is documented or suspected. However, it is likely that total network-wide isolation from land use and developmental pressures is not possible in some areas, or artifacts of historic land use may remain, such as where historic farmland has been placed into a conservation easement. Thus, in practice, background areas are those that have been minimally affected by human activities and are expected to remain as such.

1.4.3.3 Suspected Changes Subnetwork

The Suspected Changes Subnetwork includes monitoring points that provide data from aquifers that may have suspected or anticipated anthropogenic effects. These may be in areas where withdrawals are occurring, but regional water-level changes have not yet occurred or where land use has changed so that water-quality effects may be occurring. Also, wells in this subnetwork may be in areas where changes (such as areas targeted for growth or development) are anticipated.

1.4.3.4 Documented Changes Subnetwork

The Documented Changes Subnetwork includes monitoring points that provide data from aquifers that have documented anthropogenic effects. The aquifers may (1) be known to be heavily pumped, (2) have experienced substantial recharge-altering land-use changes, (3) be located in areas with managed ground-water resources (e.g., artificial recharge or enhanced storage and recovery), or (4) be known to have degraded water quality from human activities. The data provider will determine the criteria used to place wells into this subnetwork for either the water-level or water-quality network.

1.4.4 Monitoring Categories

Monitoring points within each subnetwork (Background, Suspected Changes, or Documented Changes) will be assigned to at least one monitoring category (surveillance, trend, or special studies) by the data provider on the basis of the categories described herein. Each monitoring category is discussed in detail in the following sections and presented in figure 1.4.4.1. The suggested monitoring frequencies are discussed in Chapter 4.

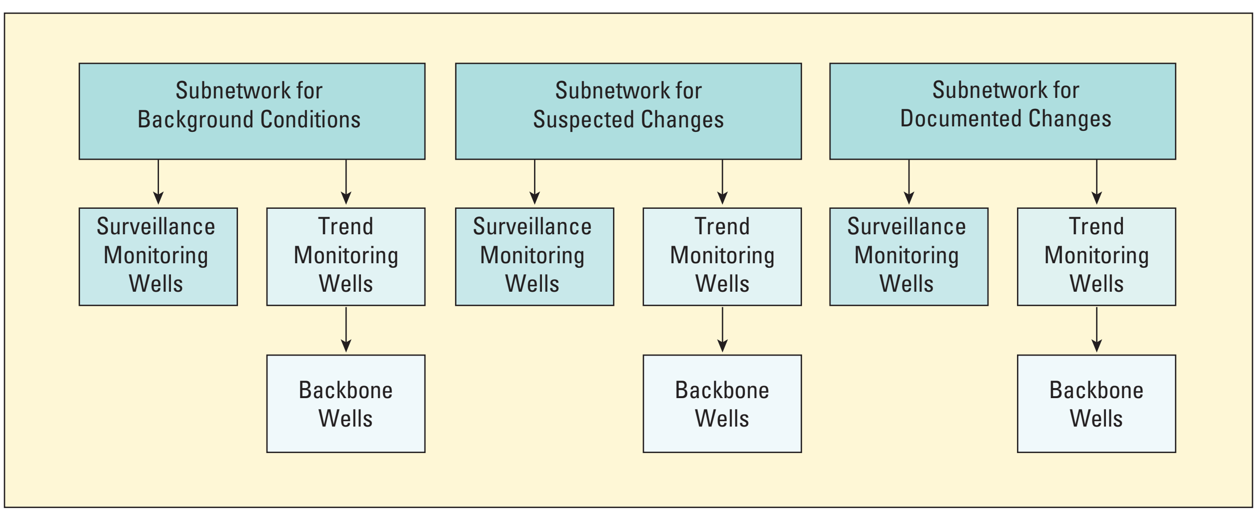

Figure 1.4.4.1 Classification of the wells in each subnetwork as surveillance or trend monitoring wells, and the identification of the subset of trend wells to be classified as "backbone wells."

1.4.4.1 Surveillance Monitoring

Surveillance monitoring provides data to assess long-term natural trends or the effect of slowly changing anthropogenic activities. Ground-water level surveillance monitoring is sometimes described as periodic aquifer “mass measurements,” or “synoptic measurements.” Surveillance monitoring could be used in conjunction with trend monitoring to periodically report on the overall water-level and water-quality conditions, or status, of the ground-water resources in the United States over time. NGWMN surveillance monitoring can be thought of as a periodic “census” of ground-water level and quality. It may not be possible to regularly monitor all surveillance wells because of cost limitations, but an aquifer census could be taken on a rotating basis. An overall snapshot of ground-water conditions in an aquifer can be obtained with surveillance monitoring. The frequency of surveillance monitoring generally is much less than trend monitoring.

1.4.4.2 Trend Monitoring

Trend monitoring provides detailed data to assess both long-term trends and seasonal variations. For trend monitoring, data collection is more frequent, but typically includes a reduced number of monitoring points than surveillance monitoring. Because long-term data from these monitoring points are extremely valuable, a subset of the trend monitoring wells would be designated as the “backbone” wells of the NGWMN. Over time, trend monitoring can be thought of as a series of “tie points” that are used in conjunction with the surveillance wells to monitor the ground-water resources in the United States. Every consideration possible would be given to continuing the long-term record from these wells.

1.4.4.3 Special Studies Monitoring

Special studies monitoring is a secondary aspect of the NGWMN. This monitoring is not required and is only provided as an option. Special studies monitoring would be most often associated with the Suspected or Documented Changes Subnetworks and would be used to evaluate the status of ground-water resources at risk, or potential risk, from depletion or impairment. The monitoring frequency would vary, depending on the study. Categorizing wells as special studies acts as a flag to indicate that additional information might be available because wells are measured or sampled for a special purpose regionally or nationally (for example, wells measured to observe the effects of hydraulic fracturing).

1.4.4.4 Subnetwork and Monitoring Category Summary

In summary, wells are described as surveillance or trend wells based on the frequency of measurement or frequency of sampling. Surveillance and trend monitoring are anticipated to be ongoing efforts and would represent the core of the NGWMN. Surveillance monitoring would be conducted at as many NGWMN wells in as many aquifer systems as practical, while trend monitoring would be conducted at a selected subset of these wells. In addition, a subset of the trend wells would be considered to be the “backbone” of the NGWMN. The baseline process is a startup activity that creates an initial dataset used to evaluate where a monitoring well fits in the various subnetworks. The spatial density for Background, Suspected Changes, or Documented Changes Subnetworks and the monitoring frequency for surveillance and trend monitoring are, in part, determined by regional and local aquifer characteristics.

1.4.5 Ground-Water Management and Decision Making

The NGWMN contains a strong analytical component designed to link national ground-water data with complementary datasets so that sufficient information can be provided to policy makers to support informed decision making. Figure 1.4.5.1 illustrates the role of the NGWMN data and other data in addressing ground-water assessment and management issues.

1.5 Network Limitations

Without ancillary information, data collected by the NGWMN cannot help answer important ground-water management questions. For example, questions pertaining to human health, agricultural impacts, effects of climate change, emerging ground-water availability and quality problems, the economic value of ground water, the adequacy of current and future ground-water supplies, and the development or protection of ground water could all be addressed by the NGWMN, but in order to do so, supplemental datasets may be required. Therefore, the NGWMN must work cooperatively with many other programs in order to be able to appropriately address these important issues. Before linking with other programs that offer ancillary data or databases, it is important to first organize and unify the available ground-water monitoring data across the Nation.

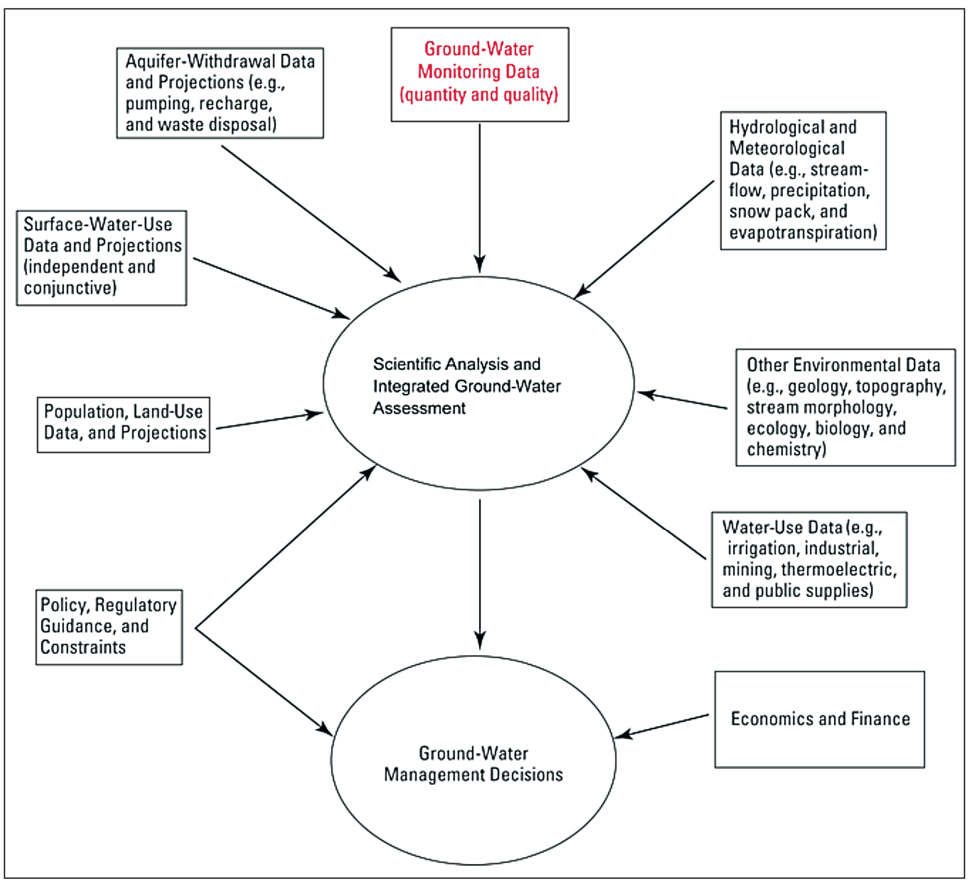

Figure 1.4.5.1 The role of the National Ground-Water Monitoring Network data and other data in addressing ground-water assessment and management issues.

Chapter 2 – A Summary of Statewide, Regional, and National Ground-Water Monitoring Programs in the United States, 2007

The development of a national framework for ground-water monitoring will require appropriate collaboration among Federal, State, local, and Tribal ground-water monitoring programs. To develop, manage, and operate a ground-water monitoring program at the national level, it will be necessary to incorporate appropriate monitoring locations and sampling schedules of existing Federal, State, local, and Tribal programs and develop agreements, funding arrangements, and a working relationship among these programs. This section of the report describes the statewide and regional ground-water programs that were operating in 2007.

Ground-water monitoring programs have been in place for a number of years in most States, and ground-water level monitoring has been conducted for many decades in some States. Data from ground-water level monitoring networks are useful in helping to identify and develop ground-water supplies. Ground-water quality monitoring programs have been developed more recently in response to the focus on water quality that resulted from passage of State and Federal environmental legislation, such as the Safe Drinking Water Act; the Clean Water Act; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA).

Data and information about State ground-water monitoring and sampling programs are summarized in a report entitled “State/Regional Ground Water Monitoring Networks” (Association of American State Geologists, the Ground Water Protection Council, the Interstate Council on Water Policy, and the National Ground Water Association, 2007). This report was instrumental to the SOGW analysis of the current status of ground-water monitoring across the Nation. The data and information were obtained from two questionnaires sent to all 50 States in September 2007 by the Association of American State Geologists (AASG), the Ground Water Protection Council (GWPC), the Interstate Council on Water Policy (ICWP), and the National Ground Water Association (NGWA). Questionnaires were sent to 174 program managers and staff in State agencies that have roles and responsibilities in ground-water management. Two separate questionnaires were sent to each agency: the first requesting information on water-level monitoring networks and the second requesting information on water-quality sampling programs. Forty-five responses were received from 41 States for the ground-water level monitoring questionnaire, and 61 responses from 50 States were received for the ground-water quality questionnaire. The U.S. Geological Survey also provided information about networks in States where the USGS has Cooperative Water Programs. The questionnaire results are available from the NGWA at *http://www.ngwa.org/Documents/Awareness/Form5.pdf*, and a copy of the report is reproduced at the end of appendix 2 (Section 2-2.5).

On the basis of the available information and original research, the SOGW developed an assessment of State ground-water level and quality monitoring networks. The highlights of that assessment are included in Sections 2.1–2.3. Details of the assessment are available in appendix 2.

2.1 Ground-Water Level Monitoring Programs

Ground-water level monitoring programs vary significantly among States. Some States, such as Texas and Montana, have comprehensive, well-organized water-level networks operated solely by the State. Some States, such as Maryland and New Jersey, have strong water-level monitoring programs operated cooperatively with the USGS. Many States have water-level monitoring programs that are less comprehensive. Some States do little or no statewide ground-water level monitoring.

In total, 37 States have some type of statewide monitoring program. Based on the information gathered for this report, the current status of ground-water level monitoring can be summarized as follows (figure 2.1.1):

- Twenty-two States have one or more statewide ground-water level monitoring network.
- Fifteen States have one or more statewide and intrastate regional ground-water level monitoring networks.
- Five States have only intrastate regional ground-water level monitoring networks.
- Eight States have no statewide or intrastate regional ground-water level monitoring network.

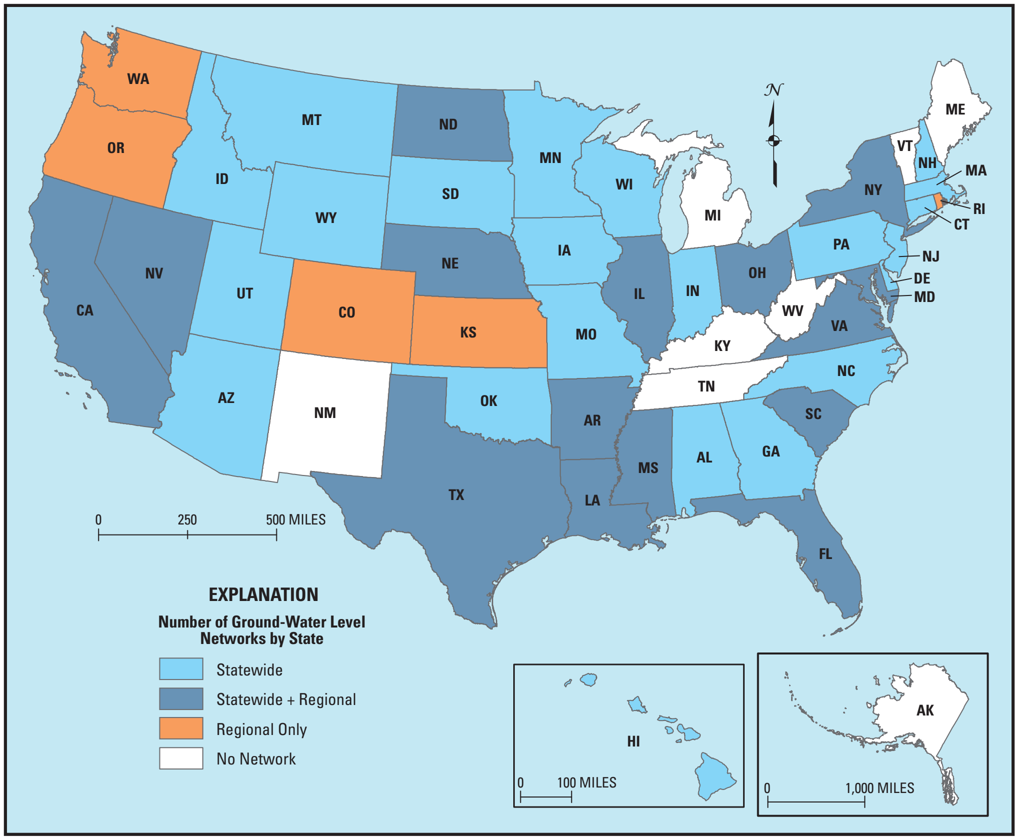

Figure 2.1.1 Ground-water level networks by State, from questionnaire of State monitoring programs led by the Association of American State Geologists, the Ground Water Protection Council, the Interstate Council on Water Policy, and the National Ground Water Association.

A complete summary of State and intrastate regional networks is available in appendix 2 and includes information on the following topics:

- Water-level network objectives
- The agency operating the water-level monitoring network
- The agency funding the water-level monitoring network
- The design criteria for the water-level monitoring network
- The measurement frequency for the wells in the water-level monitoring network
- The personnel who collect the water-level data
- The standard operating procedures used for water-level data collection
- The database used for the water-level information
- Whether the water-level data are available to the public by way of the Internet

2.1.1 Ground-Water Level Data Gaps

During the compilation and evaluation of the data gathered from the questionnaires, six significant data gaps were identified:

1. Thirteen States were identified as lacking State-managed/operated statewide networks (figure 2.1.1). Eight had no networks, and five had only intrastate regional networks. Although the USGS operates statewide networks in five of the 13 States, this still leaves a significant gap.
2. The lack of written standard operating procedures for field data collection in eight States is a significant limitation in State efforts, as is a similar lack in data management and storage capabilities in 12 States. There is also an almost complete lack of current activity in development of standard operating procedures in any of the States.
3. There is a distinct lack of information about the number and purpose of intrastate regional networks. In great part, this is due to the questionnaire specifically seeking information about statewide networks. A followup questionnaire would be required to help fill this information gap. For example, in an area that has a climate/

drought network in its unconfined aquifers, the State may lack a network to monitor underlying confined aquifers. Similar gaps may also exist in statewide networks.

4. The frequencies of well measurements vary across a wide spectrum, from 5-year measurement intervals to real-time instrumentation. The contrasting frequencies are a consequence of the purpose of the individual networks and perhaps available funding. Because the NGWMN is expected to be multipurpose, some well measurement frequencies will be more suitable for the designated purpose than others. These potential gaps would need to be identified and evaluated.

5. There is a lack of direct information in the questionnaire about the partnerships between the USGS and State, regional, intrastate, and local agencies. Some of these cooperative arrangements were reported in the results and some were not. This is an information gap that should be explored more fully.

Because information about individual wells and springs was not collected in this effort, additional work with network collaborators is needed to establish the location of wells in three dimensions with respect to principal and major aquifers and ground-water use.

2.2 Ground-Water Quality Monitoring Programs

Because a primary purpose of the National Ground-Water Monitoring Network would be to assist in assessments of the quantity of U.S. ground-water reserves as constrained by ground-water quality, it will be important to understand the quality of ground water in the aquifers being monitored for water levels. Sixty-one responses were received from 50 States to the questionnaire inquiring about ground-water quality sampling programs. A single response was received from 42 States and multiple responses were received from 8 States that have multiple monitoring programs: Delaware (2), Florida (2), Idaho (4), Illinois (3), Louisiana (2), Minnesota (2), Montana (2), and Tennessee (2). Responses were received from a variety of State agencies, including State environmental agencies, water-resources agencies, agricultural agencies, geological surveys, and public-health agencies.

The data from the questionnaires indicate that 33 States currently have at least one active ground-water quality monitoring program, either a statewide network or at least one regional intrastate network (figure 2.2.1). Seventeen States reported having a statewide ground-water quality monitoring

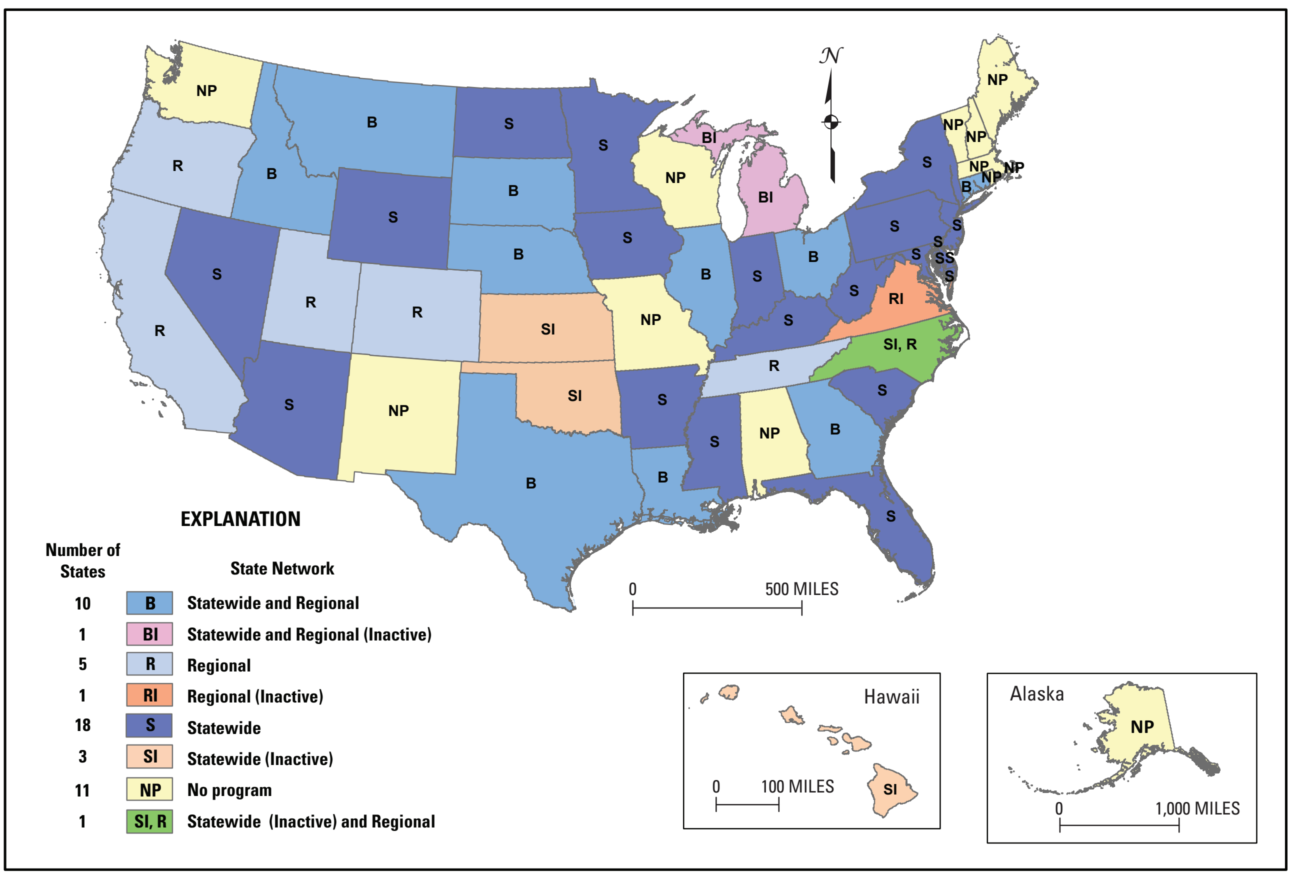

Figure 2.2.1 Ground-water quality networks by State, from questionnaire of State monitoring programs led by the Association of American State Geologists, the Ground Water Protection Council, the Interstate Council on Water Policy, and the National Ground Water Association.

program, 6 States reported having one or more regional intrastate ground-water quality monitoring program, and 10 States reported active statewide and regional intrastate ground-water quality monitoring programs. Eleven States indicated that they currently have no ground-water quality sampling program, and 5 States (Kansas, Michigan, Oklahoma, Virginia, and Wyoming) reported that a ground-water quality monitoring network exists but is currently inactive.

A comprehensive summary of State and regional intrastate water-quality networks is included in appendix 2, including information on the following topics:

- Water-quality network objectives
- The agency operating the water-quality network
- The agency funding the water-quality network
- The design criteria for the water-quality network
- The measurement frequency for the wells in the water-quality network
- The personnel who collect the water-quality samples
- The standard operating procedures used for sampling
- The database used for the water-quality data
- Whether the water-quality data are available to the public by way of the Internet

2.2.1 Ground-Water Quality Data Gaps

1. The questionnaire results show that ground-water sampling frequencies vary widely in the 33 States that have ground-water quality monitoring programs. However, the questionnaire responses do not provide the detail necessary to fully assess the frequency and specific analytes sampled for the State ground-water quality monitoring programs. This is a significant data gap.
2. Because information about individual wells and springs was not collected in this effort, additional work is needed with network collaborators to establish the location of wells in three dimensions with respect to principal and major aquifers and ground-water use. Detailed data on the location of ground-water monitoring locations for State programs will be necessary for helping determine which/how many wells should be included in the NGWMN.
3. Standard operating procedures and specific analytical methods were not defined in the questionnaire responses. These data will be required to help determine which wells/springs in a State program should be included in the NGWMN.

2.3 Federal Ground-Water Monitoring Programs

The SOGW also acquired information from Federal agencies about Federal monitoring programs that met the criteria of the State questionnaire. Representatives from the Army Corps of Engineers, Bureau of Land Management, Bureau of Reclamation, Department of Energy, Environmental Protection Agency, Forest Service, Geological Survey, Park Service, and Natural Resource and Conservation Service were contacted for information about long-term, non-regulatory ground-water networks. The following information was reported.

National Park Service: The National Park Service (NPS) collects ground-water level and ground-water quality data to meet a number of objectives, including long-term monitoring and some water-rights issues. The primary repository for NPS ground-water level data is the park unit where the data were collected, though some ground-water level data are processed through and stored in the NPS Water Resources Division Office in Fort Collins, Colorado. Ground-water quality data collected as part of the Vital Signs monitoring program are generally stored in the NPSTORET database in Fort Collins. Ground-water quality data collected for other purposes are stored in the individual park units (Glenn Patterson, National Park Service, written communication, 2008).

U.S. Forest Service: Though there may be a few exceptions, ground-water monitoring within the U.S. Forest Service (USFS) typically addresses site-specific or project-specific issues, such as mine cleanups, CERCLA activities, snow making, water rights, drinking-water system operation, or particular Forest Service research projects. With the exception of drinking-water data, which are stored in a national database, there is no systematic method for storing and accessing the resulting information. Most data reside at the unit where the data were collected. Some ground-water information is collected at Long Term Ecological Research and Experimental Watershed sites located on Forest Service lands, but these data generally are obtained for research purposes and are not readily available (Christopher P. Carlson, U.S. Forest Service, written communication, 2008).

U.S. Geological Survey: The U.S. Geological Survey (USGS) monitors ground-water levels, spring discharge, and ground-water quality primarily through agreements with State and local cooperators under the USGS Cooperative Water Program. Water levels from about 800,000 wells and water-quality data from more than 300,000 wells are stored in the USGS database. Federally directed water-quality monitoring is provided through the USGS National Water-Quality Assessment Program (NAWQA), and water-level monitoring is provided in a small number of wells through the USGS Ground Water Resources Program. Appendix 2 provides a State-by-State summary of the total number of wells for which ground-water level measurements are made (more than 20,000 wells in 2007) and ground-water quality measurements (more than 3,000 in 2006) are collected by the USGS or cooperators, stored in the USGS database, and made available on the Internet.

U.S. Environmental Protection Agency: The U.S. Environmental Protection Agency (USEPA) maintains two data-management systems containing water-quality information: the STORET (short for STOrage and RETrieval) Legacy Data Center (LDC) and Water Quality Data Exchange (WQX). The LDC is a static, archived database, and WQX is an operational system actively being populated with water-quality data from a variety of organizations across the country. LDC and WQX primarily are surface-water quality systems, but ground-water quality data from approximately 75,000 wells are available (*http://www.epa.gov/storet/*).

2.4 Key Concepts

Because a primary purpose of the National Ground-Water Monitoring Network is to assist in assessments of the quantity of U.S. ground-water reserves as constrained by ground-water quality, it will be important to understand the quality of ground water in the aquifers being monitored for water levels.

Information included in the 2007 questionnaire received from State monitoring programs provided an excellent summary of the monitoring programs across the Nation, including identifying the program operator, the program purpose, funding sources, number of monitoring points, the frequency of measurements, and standard operating procedures. This information allowed the SOGW to evaluate the feasibility of a NGWMN.

The questionnaire provided information on some excellent ground-water monitoring programs. Some State programs are operated cooperatively with the USGS, and some are operated solely by individual States. It is likely that a number of individual monitoring points in networks from many States could contribute directly to a NGWMN through careful selection from the wide variety of State network wells. Results from the Pilot Studies indicate that few changes to the standard operating procedures at the State level would be necessary.

Some States have regional intrastate networks, but no statewide network. Some States have neither. When considered together, existing Federal, State, Tribal, and other ground-water level and ground-water quality networks create an extensive “patchwork quilt” of ground-water monitoring programs. Individual patches in the quilt differ in spatial coverage, measurement frequency, quality-assurance documentation, and data availability. There is a great need for a coordinating infrastructure through which data can be aggregated at the national level and new monitoring sites identified to supply these data in areas with a low density or absence of monitoring wells.

The questionnaire did not attempt to gather details about individual wells, well locations, or aquifers monitored. The NGWMN will need to work with network collaborators to establish the three-dimensional relation of the wells and their networks to principal and major aquifers, and to relate the wells and networks to water use to help determine the appropriate subnetwork for each well.

Chapter 3 – Network Goals, Objectives, and Management Issues

The NGWMN is a logical framework of monitoring sites from which consistent, representative, long-term water-level and quality records describing ground-water resources are generated, made available, and evaluated. (A glossary of terms related to the NGWMN, which are used throughout this report, is provided in appendix 3.)

3.1 Network Goals and Objectives

The NGWMN would provide water-quantity and quality data useful to answer questions at a variety of scales, though the primary focus would be on national or regional interstate scales. Because the existing individual State monitoring programs may have differing objectives and produce data not sufficiently compatible for aggregation into a national dataset, establishment of a consistent national design for ground-water monitoring will allow selected wells in many of these State monitoring programs to be included in a national program that does have consistent goals, procedures, and data-quality standards. The national design recommends monitoring parameters, well-selection criteria, measurement and sampling standards, and measurement frequencies that will minimize data incompatibility issues within a national dataset.

The major goals of the NGWMN are to:

- Compile selected water-resources data that can be used to define the status and trends of ground-water availability at the national scale;
- Identify areas where additional monitoring is needed;
- Provide data to support regional, interstate, and national management actions; and
- Provide a data-management framework to receive, manage, and distribute data.

3.1.1 Status and Trends of Ground-Water Availability Nationwide

The NGWMN will generate the time series ground-water level and water-quality data necessary to evaluate the status and trends of the Nation's ground-water resources. Ground-water resource questions that can be addressed by a national network include:

- What is the current water quality of the Nation's major aquifers? (status)
- What are current water levels or pressures in the Nation's major aquifers? (status)
- What are the concentrations and spatial distribution of selected analytes in the Nation's major aquifers? (status)
- How are ground-water levels and quality changing in the Nation's major aquifers? (trend)

3.1.2 Potential Problem Areas where Additional Monitoring is Needed

A nationwide ground-water monitoring network can be used to identify areas where ground-water levels or quality may be at risk, or where there are insufficient data to evaluate ground-water availability. These areas may then be identified for additional ground-water monitoring activities.

If the need for additional monitoring activities is determined, data providers may identify existing monitoring points that meet network criteria, and these sites would be incorporated into the network. In the absence of existing monitoring points, the installation and monitoring of new dedicated monitoring wells would be supported so that new sites can be added to the network. Where more frequently collected data are necessary, the frequency of monitoring would be increased.

3.1.3 Data to Support Multiple-Scale Management Actions

Although data collected by the national network may be useful at regional interstate and local scales, States and local management entities may find it necessary to collect additional data to provide the level of detail necessary to address their own issues. Management issues that national network data, used in conjunction with ancillary datasets, may address are summarized in Section 3.1.5 (Level II questions).

3.1.4 Data-Management Framework to Store, Retrieve, and Distribute Data

An essential part of the NGWMN will be a data-management portal system to retrieve network data. The Web-based portal will allow the diverse network stakeholders to search for and retrieve data needed to address many of the Nation's ground-water resource questions.

Data are intended to be retrievable over user-defined time scales and geographic areas to allow data analysts to conduct evaluations at the national, multistate, State, and major aquifer scales. Because of the national focus of the network, it is likely that the information collected from the network will be most useful at the national and regional interstate scales. Spatial retrievals of nationwide data collected at known times provide snapshots of ground-water quantity or quality, and the ability to roll up ground-water information to the national level provides an overall status of the Nation's ground-water availability.

3.1.5 Network Design as Related to Network Objectives

The objectives of the network can be thought of in terms of the questions that the network is designed to answer. Some ground-water questions need to be addressed at the national scale, while others are better addressed at the multistate, State, or local scales. Some potential questions will require high-frequency monitoring, while others can be addressed with less frequent monitoring. Finally, some questions can be addressed from data generated directly by the network, while others require NGWMN data plus data from other sources. Not all ground-water resource questions can be answered using the same set of monitoring sites. Presentation of the network objectives as types of questions will help clarify how the objectives are to be addressed. For this reason and to assist the reader in better understanding the design of the NGWMN, key goals from Section 3.1 are reformatted and presented as Level I (A and B) or Level II questions in table 3.1.5.1.

Level I questions can be answered using NGWMN data. Level I questions are subdivided into groups A and B based on whether or not supplemental data are needed. Level IA questions are answered using data directly obtained from the NGWMN and address absolute change over time in both ground-water levels and quality. Level IB questions require supplemental data. Climate, land use, and water use are the major types of supplemental data. Because it is important to

Table 3.1.5.1 Major questions addressed by the National Ground-Water Monitoring Network.

Level IA – Example of Questions Addressed Using NGWMN-Generated Data (National, Regional Interstate, and Statewide Scales)
What are baseline ground-water level conditions against which future changes can be measured?
What are baseline quality conditions against which future changes can be measured?
How are ground-water levels changing over time?
How is ground-water quality changing over time?
In what areas is ground water unsuitable for human consumption?
What is the uncertainty in the information from the network?
Level IB – Example of Questions Addressed Using NGWMN-Generated Plus Supplemental Data (National, Regional Interstate, and Statewide Scales)
What are the effects of climate variability on ground-water resources?
What are the status and trends of the levels and quality of the Nation's ground water in relation to land-use or water-use categories?
What are the major causes of problems related to ground-water resources?
What are emerging problems related to ground-water levels and ground-water quality?
What is the national inventory of potable ground water?
Level II – Example of Questions That Can be Addressed but Require Additional Resources and Supplemental Data (National, Regional Interstate, and Statewide Scales)
Does each State (and the United States) have enough ground water available to meet human and ecosystem needs today and into the future?
Can the Nation meet its projected ground-water needs into the future?
What is the economic value of ground water today and into the future?
How does the Nation respond to ground-water level and quality issues?
What are the high-priority ground-water resources?
What are the impacts to ground water and surface water due to pumping of aquifers?
How do we optimize our ground-water resources?
Overall, how effective are ground-water programs in protecting ground water?
How might we apportion water from aquifers that cross political boundaries?

understand why ground-water changes are occurring, Level IB questions provide some specific items that potentially can be addressed. For example, aquifer storage near a group of wells may increase or decrease over an observed timeframe. In order to determine the reason for the change, network-generated data must be compared to other datasets. If changes in pumping are suspected as the cause of long-term water-level change, the water-level record may need to be compared to pumping data. As another example, if climate variability is suspected of causing water-level changes, then the water-level records must be compared to precipitation and recharge data if available. For these reasons, data users need access to as much ancillary data as possible in order to appropriately answer the “whys” associated with the questions that the network is helping to address.

Level II questions can be answered using NGWMN data, but supplemental data not obtained directly from the NGWMN may be required. Level II questions require additional resources above and beyond those necessary for the day-to-day operation of the network. Nevertheless, they are important and should be answered through comparison of NGWMN data with other datasets. The ability to answer Level II questions will depend on their applicability to particular data providers.

The NGWMN would provide the fundamental data with which to help answer these questions. Ground-water availability questions cannot be adequately addressed without the data described in the NGWMN. But ground-water availability is a complex concept, and supplemental information is needed to address all of the relevant questions associated with ground-water availability.

3.1.6 Goals and Assessment

The overall goal of the NGWMN is to provide information essential for national and regional scale decisions to be made about current ground-water management and future ground-water development. Figure 3.1.6.1 shows how water-level and water-quality data generated by NGWMN could be used to address resource issues. For ground-water availability evaluations, the network’s fundamental products are ground-water levels and statistical interpretations of ground-water level data. Supporting information, such as well construction and data pertaining to aquifer properties such as porosity or hydraulic conductivity, is to be included in the national network, depending on availability, and is important to fully analyze the primary water-level and water-quality datasets.

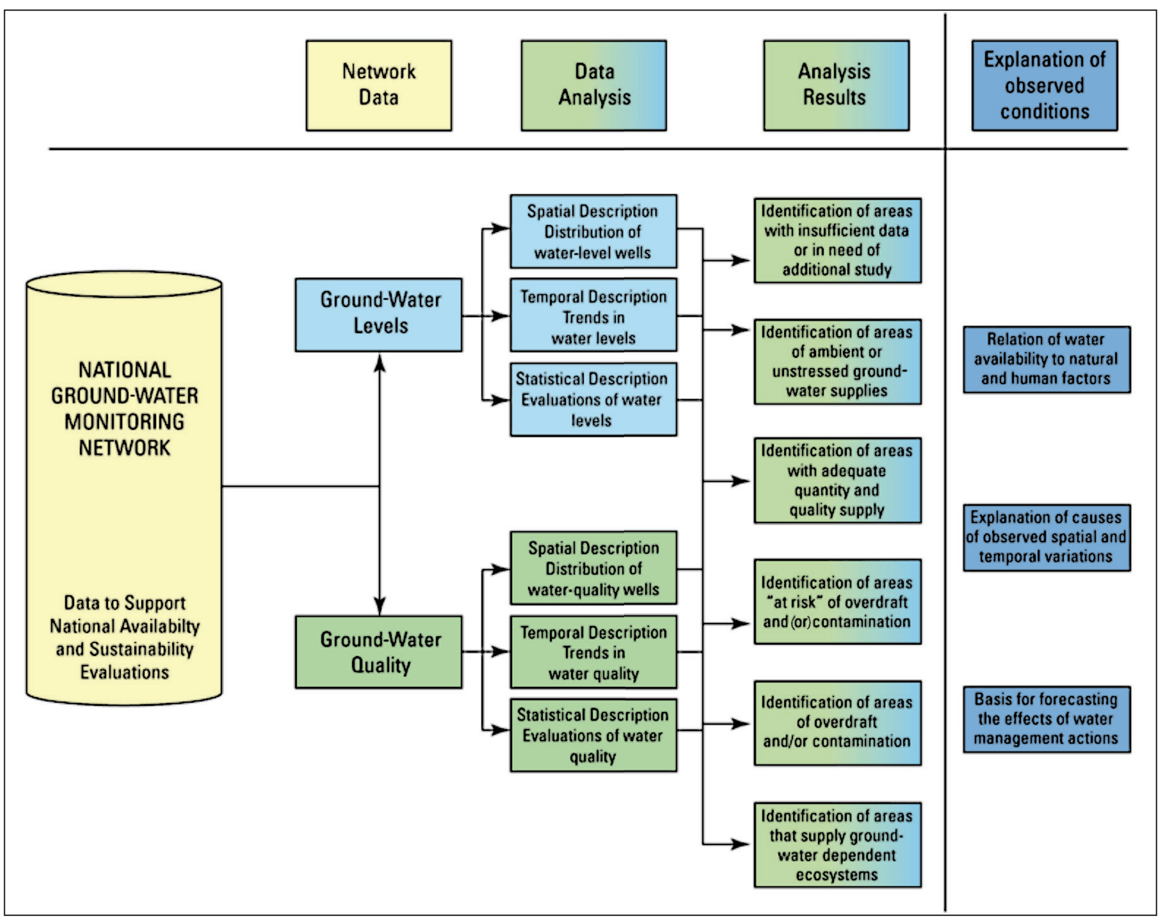

Figure 3.1.6.1 National Ground-Water Monitoring Network data and how these data may be used to support national ground-water availability and sustainability evaluations.

Water-level data and subsequent interpretations provide spatial, temporal, and trend descriptions of changes in ground-water storage or head that can be evaluated to identify areas that have (1) adequate ground-water supplies under various usage scenarios, (2) declining ground-water supplies under various usage scenarios, and (3) insufficient data from which to evaluate the status of ground-water availability.

For water-quality evaluations, the network's primary products will be chemical, physical, and occasionally biological data. Over time, the products allow for the spatial descriptions of water-quality variability, temporal descriptions of water quality, including trends, and statistical analyses that allow comparison of ground-water quality from area to area. When used as part of ground-water level evaluations, water-quality data may often place constraints on how much water is actually available for various uses. For example, if an aquifer supports drinking-water supplies, areas of high dissolved solids concentrations may limit the amount of water available for public-water supplies. Increases in dissolved solids concentrations with time may indicate saltwater intrusion limiting the amount of water calculated to be in storage for drinking-water supply purposes and ultimately limiting the amount of high-quality water that can be withdrawn.

The analysis of water-level data in conjunction with water-quality data provides the fundamental information necessary to understand water availability relative to natural and human factors, the identification of causes of observed spatial and temporal variation, and the basis for predicting the effects of water management actions. The NGWMN will bolster the visibility of monitoring nationally and assist States and the Nation to make sound long-term natural-resource management and environmental protection decisions with regard to ground-water resources.

3.2 Key Concepts

The NGWMN will provide water-quantity and quality data that can be used to answer questions at a variety of scales. The major goals of the NGWMN are to compile the water-resources data that can be used to define the status and trends of ground-water quantity and quality at the national scale; identify areas where additional monitoring is needed; provide data to support local, regional interstate, and national management actions; and provide a data-management framework to receive, manage, and distribute data.

An essential part of the network is the data-management portal system, which will retrieve network data directly from data providers. The Web-based portal will allow the diverse network stakeholders to search and retrieve data needed to address the many questions related to monitoring the Nation's ground-water resources.

The network is designed to address the baseline ground-water level and quality conditions against which future changes can be measured and how ground-water levels and ground-water quality are changing with time. Another key aspect of the network is that it will document the uncertainty in the information within it.

The NGWMN will bolster ground-water monitoring, data availability, and data access nationally and assist States and the Nation to make sound long-term natural-resource management and environmental protection decisions with regard to ground-water resources.

Chapter 4 – Network Design Features and Specifications

4.1 Aquifers Monitored

The NGWMN is designed to focus on monitoring ground water from the Nation's most productive aquifers and aquifer systems, including (1) the Nation's Principal aquifers (U.S. Geological Survey, 2003; figure 4.1.1), (2) major aquifers listed in the Ground Water Atlas, produced by the USGS (table 4.1.1), and (3) other important aquifers as defined by States or Tribes. General descriptions of each of the Principal aquifers of the Nation are available at (*http://capp.water.usgs.gov/aquiferBasics/alphabetical.html*).

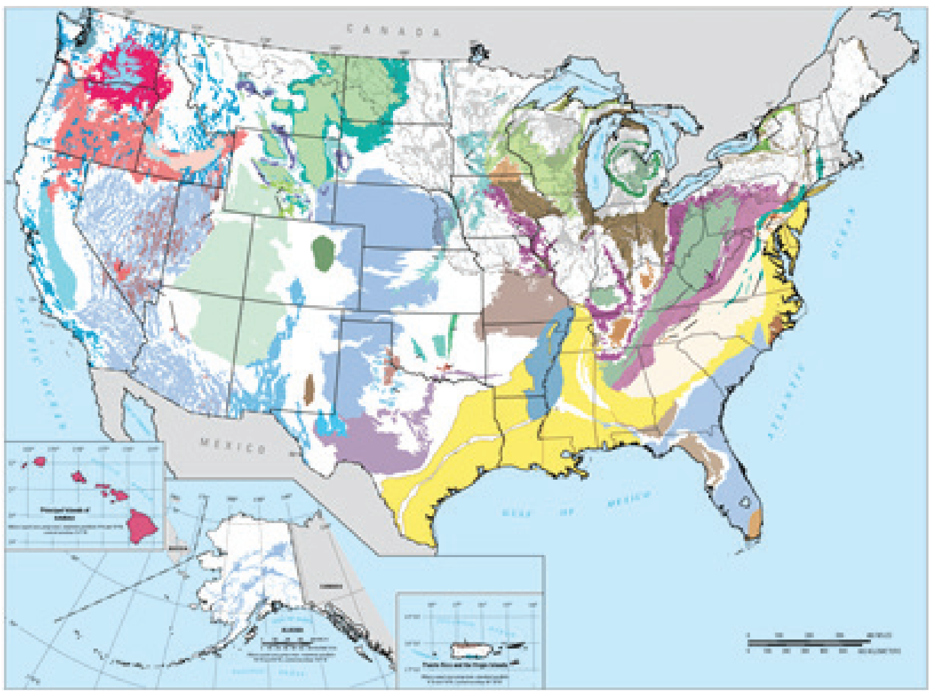

Figure 4.1.1 Principal aquifers of the United States *(http://www.nationalatlas.gov/wallmaps.html#aquifers).*

Table 4.1.1 Ground Water Atlas report segments (*http://pubs.usgs.gov/ha/ha730/gwa.html*).

	Introduction and National Summary	Published 1999
HA 730-B	California, Nevada	Published 1995
HA 730-C	Arizona, Colorado, New Mexico, Utah	Published 1995
HA 730-D	Kansas, Missouri, Nebraska	Published 1997
HA 730-E	Oklahoma, Texas	Published 1996
HA 730-F	Arkansas, Louisiana, Mississippi	Published 1998
HA 730-G	Alabama, Florida, Georgia, South Carolina	Published 1990
HA 730-H	Idaho, Oregon, Washington	Published 1994
HA 730-I	Montana, North Dakota, South Dakota, Wyoming	Published 1996
HA 730-J	Iowa, Michigan, Minnesota, Wisconsin	Published 1992
HA 730-K	Illinois, Indiana, Kentucky, Ohio, Tennessee	Published 1995
HA 730-L	Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia	Published 1997
HA 730-M	Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont	Published 1995
HA 730-N	Alaska, Hawaii, Puerto Rico and the U.S. Virgin Islands	Published 1999

Note that the Principal aquifers depicted in figure 4.1.1 could be, but are not necessarily, the same aquifers described in the Ground Water Atlas (table 4.1.1). Figure 4.1.1 shows the outcrop or subcrop extent of the shallowest Principal aquifer in two dimensions, and thus deeper aquifers or the extent of aquifers that are under other shallow Principal aquifers are not shown. Descriptions of the aquifers in the atlas are found at the following Web site (*http://pubs.usgs.gov/ha/ha730/*). The Web sites describe both the rock type and the general hydrogeologic properties of the aquifers and aquifer systems. Table 4.1.1 lists the States covered by each report segment of the atlas.

States also may designate other important aquifers to be included by the NGWMN, but to meet the purposes of the NGWMN those aquifers would be required to meet one of the following conditions:

- the aquifer must support withdrawals of regionally significant quantities of water, or support critical ecosystems;
- the aquifer crosses State or national boundaries; or
- the aquifer contributes flow to, or receives flow from, surface-water bodies of regional or national importance.

The significant withdrawals/critical ecosystem dependence criterion is vital so that monitoring data from NGWMN wells/springs support resource evaluations at the multistate and national levels. However, it should be reiterated that important aquifers, not shown in figure 4.1.1 but deemed important by individual data providers, can be included in the NGWMN. If future evaluations identify additional aquifers that provide critical data for national-scale interpretation, monitoring sites for those aquifers can be added to the NGWMN. Thus, it is expected that over time data providers will add additional aquifers into the NGWMN.

4.2 Principal Aquifers

The USGS (2003) defines a Principal aquifer as a multistate aquifer or aquifer system that has the potential to be used as a source of potable water. The aquifers and aquifer systems shown in figure 4.1.1 are the uppermost aquifer for a given region. Locally, a Principal aquifer may have a variety of names. Sixty-seven aquifers and aquifer systems have been identified by the USGS as Principal aquifers. Many Principal aquifers are aquifer systems composed of two or more aquifers that, although possibly separated by confining units, have regional interstate hydraulic continuity. Other Principal aquifers consist of aquifers that are not connected but share common geologic and hydrologic characteristics and would best be studied and described together.

An example from the Northern Atlantic Coastal Plain (NACP) Principal aquifer illustrates this concept. The NACP covers parts of six States from North Carolina to New York (figure 4.2.1).

Five aquifers make up the NACP Principal aquifer system, including the surficial, the Chesapeake, the Castle Hayne–Aquia, the Severn–Magothy, and the Potomac aquifers. The aquifers generally overlie each other (figure 4.2.2), but their areal extents differ. A correlation chart displays the relation between the five aquifers of the Principal aquifer (an aquifer system) and the corresponding stratigraphic units (figure 4.2.3).

The layered aquifers that compose the NACP also provide an example of the importance of three-dimensional monitoring. At one map location, there can be different aquifers with substantially different water levels. The well description information in the NGWMN must clearly identify the location of each well in full three-dimensional space. An example that shows the importance of this three-dimensional

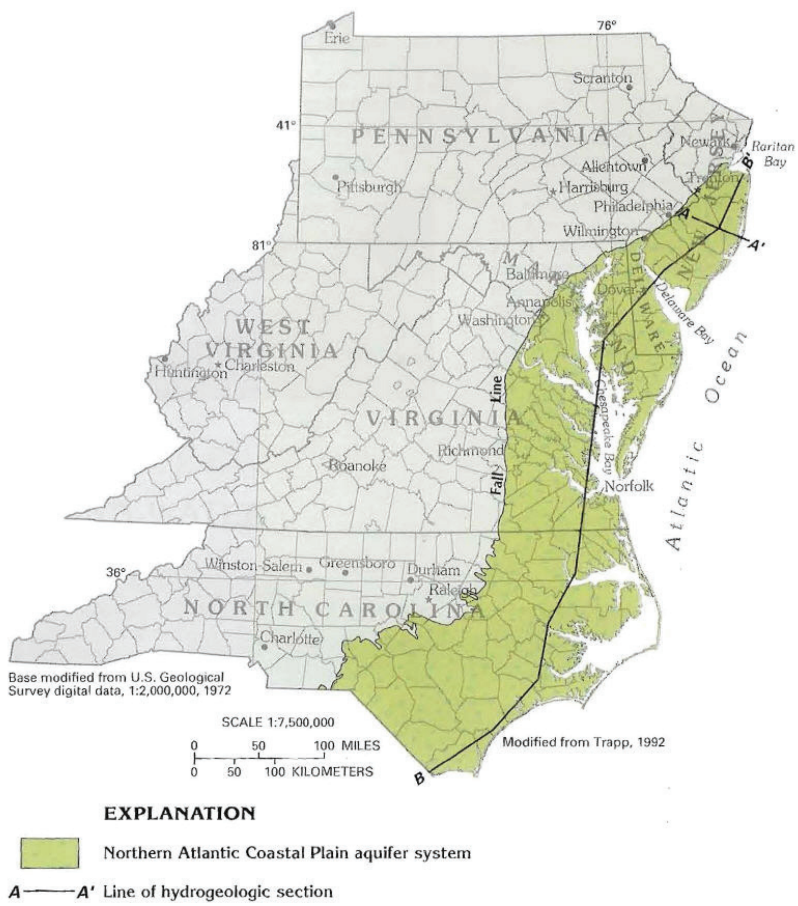

Figure 4.2.1 The Northern Atlantic Coastal Plain aquifer system (Trapp, 1992).

distribution in order to have adequate coverage of all aquifers is the New Jersey Pilot Study of the NGWMN (Domber and others, 2011).

A key opportunity within the NGWMN is the ability to create links between local aquifers, as defined by States and others, and corresponding Principal aquifers. Figure 4.2.3 shows the correlation between aquifers and confining units in the NACP. Through these correlations, data collected from wells completed in local aquifers have significance to the NGWMN at all scales (figure 4.2.3).

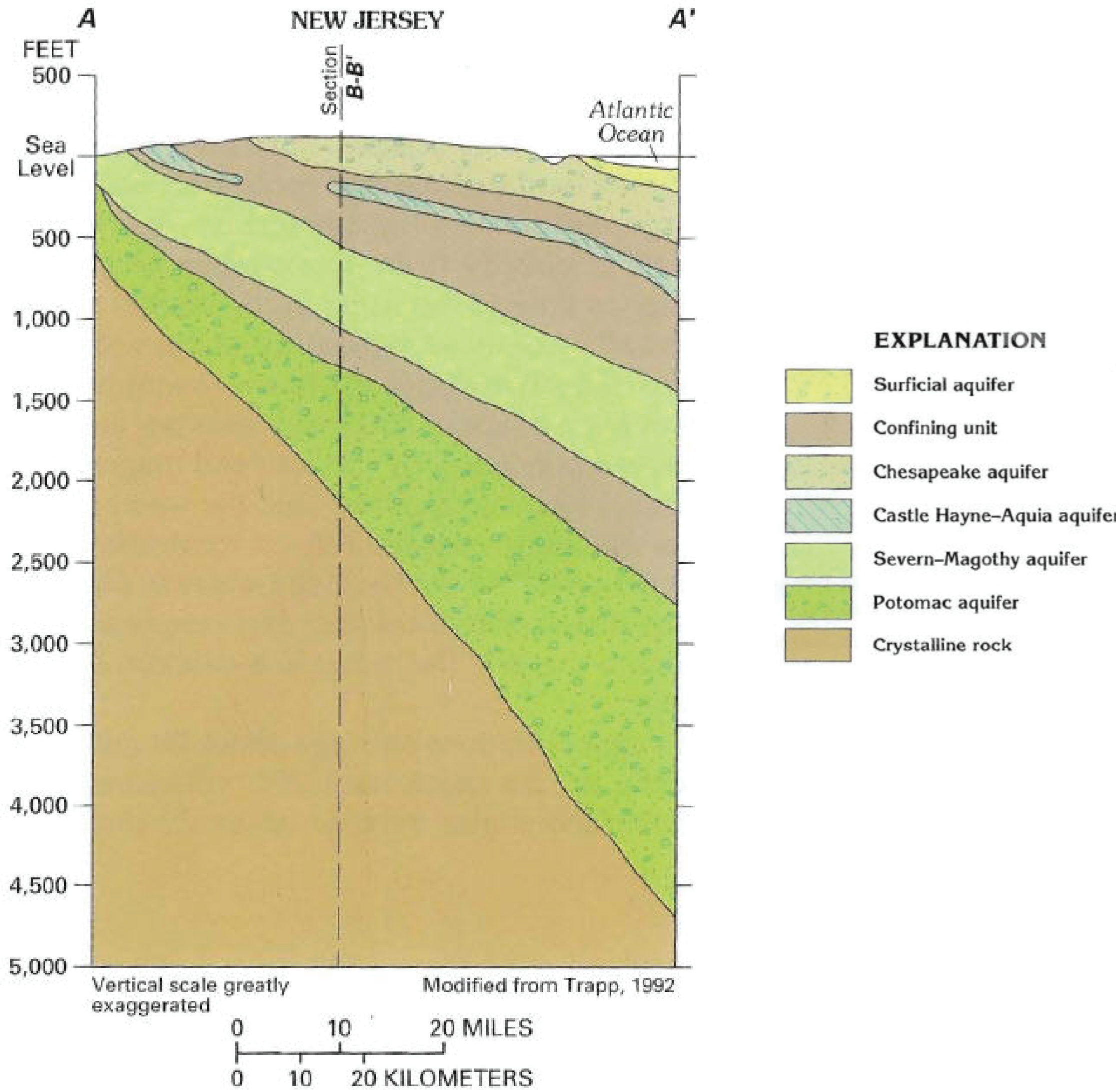

Figure 4.2.2 The thickening wedge of aquifers and confining units that compose the Northern Atlantic Coastal Plain aquifer system (Trapp, 1992).

System	Series	North Carolina	Virginia	Maryland and Delaware: Western Shore	Maryland and Delaware: Eastern Shore	New Jersey	Northern Atlantic Coastal Plain aquifer system (Trapp, 1992)	Principal lithology	Hydrogeologic nomenclature used in this chapter (Northern Atlantic Coastal Plain aquifer system)
Quaternary	Holocene / Pleistocene	Surficial aquifer	Columbia aquifer	Surficial aquifer	Surficial aquifer	Holly Beach aquifer / Cape May confining unit	Surficial aquifer	Sand and gravel	Surficial aquifer
Tertiary	Pliocene	Confining unit	Yorktown confining unit		Upper Chesapeake confining unit		Confining unit	Clay and silty clay	Confining unit
Tertiary	Miocene	Yorktown aquifer	Yorktown–Eastover aquifer		Upper Chesapeake aquifer	Kirkwood–Cohansey aquifer system (upper part)	Upper Chesapeake aquifer	Sand	Chesapeake aquifer
Tertiary	Miocene	Confining unit	St. Marys confining unit	Lower Chesapeake confining unit	St. Marys confining unit		Confining unit	Silt and clay	Chesapeake aquifer
Tertiary	Miocene	Pungo River aquifer	St. Marys–Choptank aquifer		Lower Chesapeake aquifer	Kirkwood–Cohansey aquifer system (lower part)	Lower Chesapeake aquifer	Sand, locally phosphatic	Chesapeake aquifer
Tertiary	Miocene	Confining unit	Calvert confining unit	Lower Chesapeake confining unit	Lower Chesapeake confining unit	Basal Kirkwood confining unit	Confining unit	Clay and sandy clay	Confining unit
Tertiary	Oligocene	Castle Hayne aquifer	Chickahominy–Piney Point aquifer	Piney Point–Nanjemoy aquifer	Piney Point–Nanjemoy aquifer	Piney Point aquifer	Castle Hayne–Piney Point aquifer	Limestone and fine to coarse, glauconitic sand	Castle Hayne–Aquia aquifer
Tertiary	Eocene	Confining unit	Nanjemoy–Marlboro confining unit	Nanjemoy–Marlboro confining unit	Nanjemoy–Marlboro confining unit	Vincentown–Manasquan confining unit	Confining unit	Silt and clay	Castle Hayne–Aquia aquifer
Tertiary	Paleocene	Beaufort aquifer	Aquia aquifer	Aquia–Rancocas aquifer	Aquia–Rancocas aquifer	Vincentown aquifer	Beaufort–Aquia aquifer	Fine to coarse, glauconitic or shelly sand	Castle Hayne–Aquia aquifer
Tertiary	Paleocene	Confining unit		Brightseat confining unit	Brightseat confining unit	Navesink–Hornerstown confining unit	Confining unit	Silt and clay	Confining unit
Cretaceous		Peedee aquifer		Severn aquifer	Severn aquifer	Wenonah–Mt. Laurel aquifer	Peedee–Severn aquifer	Fine to medium, glauconitic sand	Peedee–upper Cape Fear aquifer[1] / Severn–Magothy aquifer[2]
Cretaceous		Confining unit		Severn confining unit	Severn confining unit	Marshalltown–Wenonah confining unit	Confining unit	Clay and silt	Peedee–upper Cape Fear aquifer[1] / Severn–Magothy aquifer[2]
Cretaceous		Black Creek aquifer			Matawan aquifer	Englishtown aquifer	Black Creek–Matawan aquifer	Fine to medium, clayey sand	Peedee–upper Cape Fear aquifer[1] / Severn–Magothy aquifer[2]
Cretaceous		Confining unit	Upper Potomac confining unit	Matawan confining unit	Matawan confining unit	Merchantville–Woodbury confining unit	Confining unit	Clay and silty clay	Peedee–upper Cape Fear aquifer[1] / Severn–Magothy aquifer[2]
Cretaceous		Upper Cape Fear aquifer	Upper Potomac aquifer	Magothy aquifer	Magothy aquifer	Potomac–Raritan–Magothy aquifer system: Upper Potomac–Raritan–Magothy aquifer	Potomac aquifer[1] / Magothy aquifer[2]	Fine to medium sand	Peedee–upper Cape Fear aquifer[1] / Severn–Magothy aquifer[2]
Cretaceous		Confining unit	Middle Potomac confining unit	Patapsco confining unit	Patapsco confining unit	Potomac–Raritan–Magothy aquifer system: Confining unit	Confining unit	Clay and sandy clay	Confining unit
Cretaceous		Lower Cape Fear aquifer	Middle Potomac aquifer	Patapsco aquifer	Patapsco aquifer	Potomac–Raritan–Magothy aquifer system: Middle Potomac–Raritan–Magothy aquifer	Middle Potomac aquifer	Fine to medium sand	Potomac aquifer
Cretaceous		Confining unit	Lower Potomac confining unit	Potomac confining unit	Potomac confining unit	Potomac–Raritan–Magothy aquifer system: Confining unit	Confining unit	Clay and sandy clay	Potomac aquifer
Cretaceous		Lower Cretaceous aquifer	Lower Potomac aquifer	Patuxent aquifer	Patuxent aquifer	Potomac–Raritan–Magothy aquifer system: Lower Potomac Raritan–Magothy aquifer	Lower Potomac aquifer	Fine to coarse sand	Potomac aquifer
Cretaceous		Confining unit	Confining unit	Confining unit	Confining unit		Sediments underlying the lower Potomac aquifer	Clay and silt	Confining unit

[1]Southern Virginia and southward
[2]Delmarva Peninsula and northward

Modified from Trapp, 1992

Figure 4.2.3 Correlation chart for the aquifers and confining units included in the Northern Atlantic Coastal Plain aquifer system (Trapp, 1992).

4.3 Network Scales

The NGWMN is proposed as an aquifer-based network designed at the scale of principal and major aquifers. Because most monitoring networks are State-based, the NGWMN will be able to provide data at three scales: (1) national, (2) regional interstate (multistate), and (3) statewide. The network is designed to address national-scale questions. However, intrastate, including local-scale, questions also may be addressed using NGWMN data. In addition, international transboundary questions between the United States and Canada and the United States and Mexico could be addressed using data from the NGWMN.

4.4 Distribution and Number of Monitoring Sites

At a minimum, the number of monitoring sites in the subnetworks needs to be sufficient to address the Level I questions of the NGWMN. The actual number of wells needed to address each question is expected to be highly variable based in part on the hydrogeologic setting, water-use distribution, and climate conditions. The NGWMN's management and operations group in conjunction with the national board (Chapter 7) will work with States and other data providers in determining the number of monitoring sites needed to address national questions pertaining to each Principal aquifer. The number of wells required to address local-scale questions would be determined by each State, and the data and information would be maintained in State and local databases.

Final designs for the water-level and water-quality networks for each aquifer may differ depending on a number of factors. These factors likely include the relatively lower cost of obtaining water-level measurements compared to water-quality measurements, the differences in spatial variability of ground-water levels compared to that of water quality (i.e., possible need for different spatial sampling densities, horizontally and vertically), and the suitability of an existing well for inclusion in the water-level network compared to that for inclusion in the water-quality network (for example, selection criteria might qualify a well for inclusion for water levels but not for water quality).

Final network designs also might differ among aquifers. Factors likely to result in design differences among aquifers include aquifer transmissivity, degree of aquifer confinement, degree of aquifer development (i.e., pumping), and variability in aquifer water quality, climate, and other hydrologic factors.

The spatial distribution of monitoring likely will be sparse relative to the spatial variability of ground-water levels and ground-water quality in an aquifer. Consequently, a general goal of the national network will be to provide water-level measurements and water-quality sample results in as many locations within an aquifer as feasible. Given likely funding constraints, consideration of the trade-offs between a design that includes a greater number of monitoring sites but fewer measurements versus that of a fewer number of monitoring sites but more measurements at those sites will be necessary.

4.4.1 Distribution of Monitoring Points

Various probability designs for spatial monitoring include: (1) simple random sampling, (2) stratified random sampling, (3) systematic grid sampling, and (4) random sampling within blocks (Gilbert, 1987; Alley, 1993). The four design approaches are shown in figure 4.4.1.1. Alley (1993) provides a detailed discussion of these and other probability designs.

Generally, stratified random sampling (figure 4.4.1.1b) generates more precise estimates of population statistics than simple random sampling (Stuart, 1976; Alley, 1993). Grid-based approaches (figure 4.4.1.1c and d) help ensure that measurement-site locations are areally distributed across the unit of interest. This helps avoid possible biases in sampling design because of an unequal areal distribution of existing, clustered measurement sites. Thus, random sampling within blocks (figure 4.1.1.1d) helps produce a more uniform distribution of sites across the area of interest and tends to reduce spatial correlation among wells (Alley, 1993). Within this probability design, it is important to note the

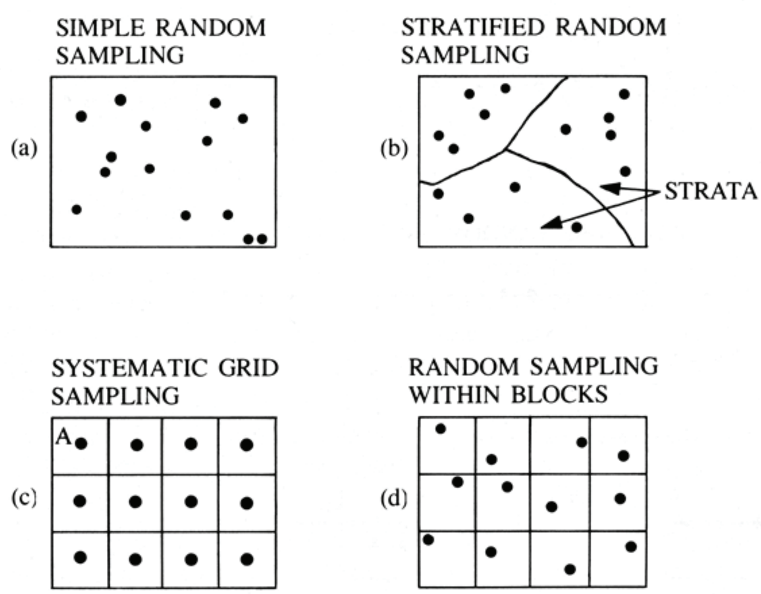

Figure 4.4.1.1 Examples of two-dimensional probability sampling designs over space (modified from Gilbert, 1987).

three-dimensional nature of aquifers, particularly at the scale of a Principal aquifer. Distribution of monitoring points in the NGWMN must account for this in some aquifers and also must consider some of the known hydrologic features, such as aquifer recharge and discharge areas.

The suggested general design for distributing monitoring sites for the NGWMN is stratified random sampling within blocks. The stratification would be by aquifer, part of an aquifer, or other defined unit. This design combines the statistical strength of stratified random sampling and the distribution strength of grid-based approaches. Monitoring programs that apply this general design include, for example, a statewide survey of agricultural chemicals in rural, private water wells in Illinois (McKenna and others, 1990) and the USGS National Water-Quality Assessment Program (Gilliom and others, 1995). Exceptions to this general design can likely be expected to occur when building the network. For example, a well that has a long-term historic record of water levels and (or) water quality and that is planned for continued long-term measurement might be important enough to include in the network regardless of how it fits within the overall design approach. A discussion with examples of the use of statistics in addressing NGWMN questions is provided in appendix 8.

4.4.2 Number of Monitoring Points

It is difficult to determine the number of wells that are needed in a national-scale network, and it is likely that, by necessity, much if not all of the network will be populated through the voluntary efforts of data providers at the Federal, State, and local level. This section describes the goals of the NGWMN for the number of monitoring sites (wells/springs) necessary to evaluate water levels and water quality. The number of sites necessary for adequate monitoring of water levels and water quality would differ.

4.4.2.1 Considerations for Water Levels

The number of observation wells or springs necessary for a ground-water level network typically is not determined before the system has been examined at some level. Heath (1976) provided a broad, general design for ground-water level monitoring based on specific network objectives similar to those of the NGWMN. Heath (1976) suggested a density of wells of 2 to 100 wells per 1,000 square miles (mi^2) in a network designed to evaluate the status of ground-water storage, depending on the complexity of the aquifer. Commonly, existing networks are analyzed statistically, hydrographs are compared, and the network is optimized on the basis of this statistical analysis (e.g., Sophocleous, 1983).

Ideally, ground-water modeling and monitoring are evaluated together to determine the adequacy of monitoring activities. In ground-water modeling, current conditions are defined by monitoring data in the context of the relatively slow changes that may be taking place in the hydrologic system. Many aquifer systems have undergone several decades of development and may be far from equilibrium. Data on current conditions may not indicate, for example, how future stream-flow depletion will evolve from pumping that has already occurred, but this can be estimated by the use of models. Monitoring and computer modeling are complementary activities, but too often are treated separately, ignoring important links and feedbacks. An idealized framework for integration of monitoring and modeling in the context of ground-water assessment is illustrated in figure 4.4.2.1.1. Monitoring data serve as the primary information used for calibration of computer models. Conversely, the process of model calibration and use provides insights into the adequacy of and gaps in monitoring data. This is shown in figure 4.4.2.1.1 by the arrows representing long-term monitoring as input to modeling and a feedback loop to evaluate long-term monitoring networks on the basis of modeling (Reilly and others, 2008).

Regional interstate ground-water flow models are available for several of the Nation's Principal aquifers, but coverage is not comprehensive. Until these tools are available, ground-water level monitoring will be distributed based on the purpose of the network and conceptual model of the aquifer system, including the position of the wells in the flow system (recharge areas, discharge areas), the degree of confinement of the aquifer (confined, unconfined, or leaky), topographic and climate characteristics, and the hydraulic characteristics. At the national and regional interstate scales, broad well and spring coverage over these various settings should be adequate.

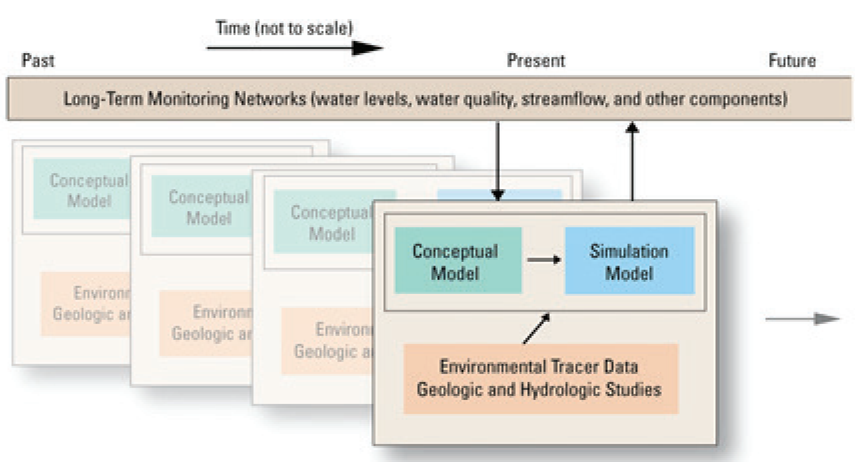

Figure 4.4.2.1.1 A framework for integration of monitoring and modeling (Reilly and others, 2008).

4.4.2.2 Considerations for Water Quality

Two possible approaches for determining the number of monitoring sites needed for the national network are: (1) an approach that specifies a minimum number of monitoring sites, by aquifer or other unit, and (2) an approach that determines the number of monitoring sites required in an aquifer or other unit given a prescribed sampling density. It should be noted that neither of these approaches attempts to describe spatial density in the vertical dimension. The relative importance of spatial density in the vertical dimension varies among aquifers, thus spatial density should be addressed individually among aquifers in the NGWMN.

For many populations, "a sample size of about 30 is considered large enough for the sampling distribution of the sample mean to be approximated by the normal distribution" (Alley, 1993, p. 65). Alley (1993, p. 71) also notes that "it is not uncommon to hear sampling surveys criticized because they only sampled a very small percentage of the population [but] … the size of the sample, not the proportion of the population it contains, generally determines the precision of the estimate [of the standard error of the sample mean]." The first approach of specifying a minimum number of measurement sites in a defined unit regardless of the area of the unit is an approach used by some monitoring programs (Gilliom and others, 1995). The State of Florida ground-water monitoring program is described as an example in appendix 4. The approach of specifying a minimum number of measurement sites for ground-water quality sampling also is a requirement of the USGS NAWQA Program for those studies that have the general objective of providing a broad overview of ground-water quality. A minimum of 20–30 wells is required to be sampled by NAWQA in each aquifer "subunit," with 30 wells prescribed for subunits where the "greatest variability in ground-water quality is expected" (Alley and others, U.S. Geological Survey, written communication, June 15, 1992; Gilliom and others, 1995).

The second approach of specifying a prescribed sampling density also is used by some monitoring programs (Gilliom and others, 1995). For example, the USGS NAWQA Program also has a general goal of using a spatial density of one well per 100 square kilometer (km^2) of aquifer when the sampling objective is to provide a broad overview of ground-water quality (Gilliom and others, 1995).

Examples of applying the two design approaches described above for determining the number of wells are shown in appendix 4 for 67 principal or other aquifers in the United States and for those 67 aquifers combined. The example shows both the resulting monitoring well spatial densities given a prescribed minimum number of monitoring wells (30 wells per aquifer) and the resulting number of monitoring wells required given a prescribed sampling density (one well/100 km^2). Results of the two approaches can be compared in terms of numbers of monitoring wells and (or) sampling densities by aquifer and for all 67 aquifers combined.

Nationally, at the Principal-aquifer scale, a total of 2,010 monitoring wells would be required in the national network to achieve a minimum of 30 monitoring wells required for each of the 67 Principal or other aquifers (appendix 4). Spatial densities of monitoring wells would range from one well/3 km^2 in the Kingshill aquifer (Virgin Islands) to one well/82,288 km^2 in the Glacial aquifer system. An average spatial density for all 67 aquifers of one well/5,755 km^2 would result.

Approximately 115,670 monitoring wells would be required in the national network if a spatial density of one well/100 km^2 for each of the 67 principal or other aquifers was the design approach (appendix 4). The number of wells in each aquifer would range from one well in the Kingshill aquifer (Virgin Islands) to 24,687 wells in the Glacial aquifer system (note, one well in the Kingshill aquifer would not provide sufficient measurements for statistical analysis of the Kingshill aquifer itself).

The numbers of wells discussed above do not take into consideration the need for measurements at various depths, in addition to an areally distributed set of measurements. If a spatial density of one well/100 km^2 was the design target, but at three general depths (near the top, middle, and bottom of each aquifer), about 347,000 monitoring wells would be required in the national network (appendix 4).

The final network design for each aquifer or aquifer system likely will be some combination of the two design approaches discussed above. An early version of the network would establish a target minimum number of monitoring sites in an aquifer or other unit. Over time, and as funding permits, additional wells would be added to meet target spatial and vertical sampling densities in each aquifer or other unit. Ideally, the network design for each aquifer or other unit will need to be developed individually to account for and accommodate the unique features of each aquifer.

4.4.3 Perspective on the Distribution and Number of Monitoring Points Gained from the Pilot Studies

The previous information indicates that there is not one ideal well density for either ground-water levels or ground-water quality. The NGWMN is designed to be flexible and allow for a monitoring network design that is iterative in nature. The five pilot studies (Subcommittee on Ground Water, 2011) all had different well densities based on the areal extent of the aquifer, the three-dimensional layering of the National aquifer and local aquifers, the availability of wells, the stresses on the system, the wells available, and costs associated with the network to name some of the more important constraints. Appropriate densities will be assessed in the future as more organizations participate in the NGWMN and the data are used. The experiences of the five pilot studies are discussed below.

The Illinois-Indiana Pilot Study (Wehrmann and others, 2011) evaluated a network for two sand and gravel aquifers that cover 4,654 square miles (mi^2) in the central part of Illinois and Indiana, the Mahomet-Teays aquifer and the Glasford and Mason aquifers. The ground-water level network consisted of 28 wells, and the ground-water quality network consisted of 14 wells.

The Minnesota Pilot Study (MacDonald and Kroening, 2011) focused on the Cambrian-Ordovician aquifer system within southeastern Minnesota. This system consists of four local aquifers and covers an area of approximately 15,000 mi^2, including the seven-county Minneapolis–St. Paul metropolitan area (TCMA). The ground-water level network consisted of 52 wells, and the ground-water quality network consisted of 37 wells.

The Montana Pilot Study (Patton and Buckley, 2011) evaluated a network for seven Principal aquifers in Montana: alluvial aquifers, glacial aquifers, Northern Rocky Mountains Intermontane Basin aquifer system, Lower Tertiary aquifers, Upper Cretaceous aquifers, Lower Cretaceous aquifers, and Paleozoic aquifers. The area of the entire state is 147,042 mi^2. The ground-water level network consisted of 271 wells, and the ground-water quality network consisted of 261 wells; many of the water-level wells are the same wells used for the water-quality network.

The New Jersey Pilot Study (Domber and others, 2011) evaluated a network for eight Principal or major aquifer/aquifer systems as defined by the USGS in the Ground Water Atlas of the United States (HA-730 by Miller, 1999, and HA-730-L by Trapp and Horn, 1997). The network includes the sand and gravel aquifers, the Early Mesozoic basin aquifers, the Piedmont and Blue Ridge crystalline-rock aquifers, the Piedmont and Blue Ridge carbonate-rock aquifers, the New York and New England carbonate-rock aquifers, the Valley and Ridge aquifers, the Valley and Ridge carbonate-rock aquifers, and the Northern Atlantic Coastal Plain aquifer system. New Jersey divides the Northern Atlantic Coastal Plain aquifer system into several different aquifers that are regionally important and hydrologically distinct from each other. This delineation is at a finer scale than either the Principal or major aquifer definitions of the USGS, resulting in a pilot with 13 local aquifer names. The area of the State is 8,721 mi^2. The ground-water level network consisted of 982 wells, and the ground-water quality network consisted of 145 wells; many of the water-level wells are the same wells used for the water-quality network.

The Texas Pilot Study (Hopkins and others, 2011) evaluated a network for six Principal aquifers, including eight local aquifers. The pilot chose to omit the Ogallala aquifer to focus more attention on aquifers that have not been as thoroughly studied. The area of the State excluding the area of the Ogallala aquifer is 235,180 mi^2 (268,580 mi^2 of total State area minus 33,400 mi^2 of the Ogallala aquifer). The six Principal aquifers evaluated are the Coastal lowlands aquifer system (Gulf Coast Aquifer), Texas Coastal uplands aquifer system (Carrizo-Wilcox Aquifer), Seymour aquifer, Pecos River Basin alluvial aquifer, Rio Grande aquifer system (including the Hueco-Mesilla Bolsons), and Edwards-Trinity aquifer system (Trinity, Edwards, and the Edwards-Trinity Plateau aquifers). The ground-water level network consisted of 425 wells, and the ground-water quality network consisted of 851 wells; many of the water-level wells are the same wells used for the water-quality network.

4.5 Frequency of Monitoring

Because the primary focus of the NGWMN is to monitor ground-water conditions in Principal and major aquifers, the frequency of measurement is designed to adequately detect short-term, seasonal, and long-term ground-water level and water-quality fluctuations of interest and to discriminate between the effects of short- and long-term hydrologic stresses. As with the number of necessary monitoring points, NGWMN's management and operations group and board (Chapter 7) would assist States in determining the measurement frequency necessary to address national questions within each Principal aquifer. The frequency of monitoring required to address local-scale questions would be determined by each State or other data provider.

4.5.1 Water Level

Trend monitoring is designed to look at long-term and seasonal water levels at a limited number of wells; thus, a minimum monitoring frequency of at least quarterly is suggested for trend water-level monitoring. Surveillance monitoring is designed to periodically "tie together" the trend wells to give spatial details to the water levels. The frequency of surveillance monitoring could range from quarterly for small networks to every 3 years for regional, multi-aquifer networks. A minimum monitoring frequency of once per 3 years is suggested for surveillance water-level monitoring.

A single monitoring frequency, as suggested above, for each monitoring well category may not provide adequate monitoring under certain conditions. Factors that can affect the water-level monitoring frequency include aquifer type, ground-water flow and recharge rates, ground-water withdrawals, and climatic conditions. A schematic diagram is shown in figure 4.5.1.1 to illustrate factors that should be considered in determining water-level measurement frequency.

The environmental factors shown in figure 4.5.1.1 can be used by NGWMN partners to determine the appropriateness of the frequency of making ground-water level measurements. An example of how the factors above could be used to determine monitoring frequencies applied to the NGWMN design is described in table 4.5.1.1. In this example more frequent monitoring is used for wells in high recharge, unconfined aquifers and high hydraulic conductivity confined aquifers. Trend monitoring wells are measured at least once per quarter and surveillance monitoring wells are measured on a multi-year interval. The monitoring frequency for both trend and surveillance networks increases as withdrawals increase.

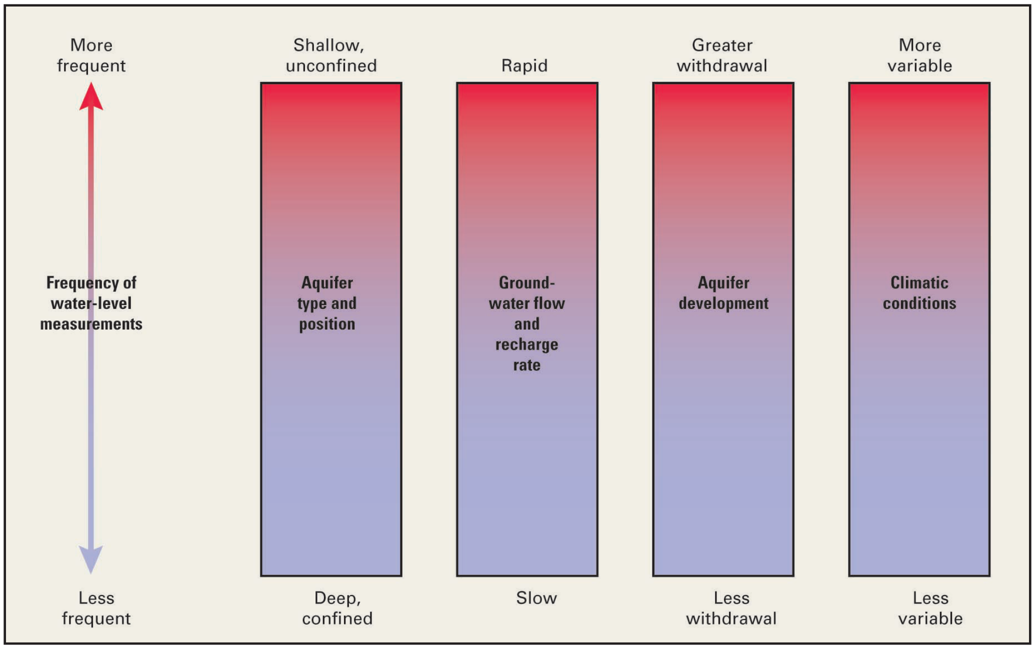

Figure 4.5.1.1 Factors that determine the frequency of monitoring ground-water levels (Taylor and Alley, 2001).

Table 4.5.1.1 Example of water-level measurement frequency guidelines based on environmental factors.

[in/yr, inches per year; ft/d, feet per day]

Monitoring Category	Aquifer Type	Nearby Long-Term Aquifer Withdrawals		
		Small Withdrawals	Moderate Withdrawals	Large Withdrawals
Trend Monitoring Category	**Unconfined**			
	"low" recharge (<5 in/yr)	Once per quarter	Once per quarter	Once per month
	"high" recharge (>5 in/yr)	Once per quarter	Once per month	Once per day
	Confined			
	"low" hydraulic conductivity (<200 ft/d)	Once per quarter	Once per quarter	Once per month
	"high" hydraulic conductivity (>200 ft/d)	Once per quarter	Once per month	Once per day
Surveillance Monitoring Category	**Unconfined**			
	"low" recharge (<5 in/yr)	Every three years	Once per year	Twice per year
	"high" recharge (>5 in/yr)	Every three years	Twice per year	Once per quarter
	Confined			
	"low" hydraulic conductivity (<200 ft/d)	Every three years	Every two years	Once per year
	"high" hydraulic conductivity (>200 ft/d)	Every three years	Every two years	Once per year

The frequency of sampling for the baseline process is not included in table 4.5.1.1. Because the baseline process is designed to assess conditions at a well that has no or little data, an initial high-frequency sampling cycle similar to the trend category is suggested. The sampling frequency can be reduced after the baseline period is completed or the use of a well is redefined. The main objective of the baseline process is to place the wells in the NGWMN in the proper subnetwork; thus, there is some flexibility in the requirements of the baseline process period. Once baseline data are available (either from historic data or after 5 years of NGWMN data collection), data providers evaluate the data and assign the monitoring point to the appropriate well classification subnetwork (Background, Suspected Changes, or Documented Changes). If the appropriate subnetwork can be determined prior to 5 years of data (for example, a clear pumping signal exists) or external factors predetermine the appropriate subnetwork (for example, a regulatory ruling), the 5-year baseline period may not be necessary.

For purposes of the NGWMN it is important to obtain static water-level data. Therefore, wells that are actively pumped are not recommended to be included in the network of wells used to obtain water-level data. If an actively pumped well is used to obtain water levels, it is important to make sure the data are identified as coming from an actively pumped well. It is also important to note that, if public water-supply wells are included in the NGWMN, the location of these wells must be available as required of all wells in the NGWMN. Because the location of public-supply wells typically is not available due to security reasons, they are usually not appropriate for the NGWMN.

4.5.2 Water Quality

Water-quality sampling presents one of the most significant challenges to monitoring network operators. The collection of high-quality and valid samples requires trained staff, well-maintained field equipment, and provisions for sample transportation, storage, preservation, and custody chains that record these protocols so the chemical results are robust, accurate, precise, and defensible. Water-quality sampling is both time consuming and a demand on resources. Thus, the NGWMN recommendations for water-quality sampling analyte suites and frequencies for sampling take these factors into account.

Trend monitoring is designed to look at long-term patterns in water quality at a limited number of wells; thus, a minimum sampling frequency of annually is suggested. Surveillance monitoring is designed to periodically present a synoptic picture of the range and distribution of chemical characteristics that incorporate the trend monitoring spatial and temporal variation. The frequency of surveillance monitoring could range from quarterly for small networks to every 5 years for regional, multi-aquifer networks.

A single minimum monitoring frequency for a particular network type, however, may not provide adequate monitoring under prevailing or changing climatic, land-use, or hydrologic conditions. Factors that can affect the water-quality monitoring frequency include aquifer type, ground-water flow and recharge rates, ground-water withdrawals, land-use changes, and climatic conditions.

Table 4.5.2.1 displays guidelines for water-quality sampling frequencies for surveillance and trend monitoring wells. The frequencies represent a starting point or recommended action and should not be considered mandatory. Over time, as NGWMN operators begin to better understand the intricacies of monitoring the Nation's ground-water resources and as funding is better defined, sampling frequencies will be modified as needed.

Table 4.5.2.1 Suggested water-quality monitoring frequencies for surveillance and trend monitoring categories.[1]

[in/yr, inches per year; ft/d, feet per day]

Monitoring Category	Aquifer Type	Flow Characteristics			
		Porous Medium	**Porous Medium**	**Fractured Rock**	**Karst**
		Deep Well	**Shallow Well**	**All Wells**	**All Wells**
Trend Monitoring Category	**All aquifer types** throughout range of hydraulic conductivity	Recommended: Annual	Recommended: Annual	Recommended: Annual	Recommended: Annual
Surveillance Monitoring Category	**Unconfined**				
	"low" recharge (<5 in/yr)	Recommended: Annual, or per study design	Recommended: Annual, or per study design	Recommended: Annual, or per study design	Recommended: Annual, or per study design
	"high" recharge (>5 in/yr)	Recommended: Annual, or per study design	Recommended: Annual, or per study design	Recommended: Annual, or per study design	Twice per year
	Confined				
	"low" hydraulic conductivity (<200 ft/d)	Every 5 years	Every 5 years	Every 5 years	Every 5 years
	"high" hydraulic conductivity (>200 ft/d)	Every 2 years	Every 2 years	Every 2 years	Every 2 years

[1] The table is applicable for water-quality sampling where an understanding of the aquifers is adequate. The suggested sampling frequencies should be used as a guide where the conceptual understanding is limited and existing data are not available. Alternate monitoring frequencies will be adopted as necessary as a better understanding of ground-water quality, plus the behavior of the hydrogeologic system, may be obtained.

The frequency of sampling for the baseline process is not shown in table 4.5.2.1. However, because the baseline process is designed to assess conditions at a well that has no or little data, an initial high-frequency sampling cycle similar to the trend category is suggested. The sampling frequency can be reduced after the baseline period is completed or the use of a well is redefined. The main objective of the baseline process is to place the wells in the NGWMN in the proper subnetwork, so there is some flexibility in the requirements of the baseline process period. Once baseline data are available (either from historic data or after 5 years of NGWMN data collection), data providers evaluate the data and assign the monitoring point to the appropriate well classification subnetwork (Background, Suspected Changes, or Documented Changes). If the appropriate subnetwork can be determined prior to 5 years of data (for example, a clear pumping signal exists) or external factors predetermine the appropriate subnetwork (for example, a regulatory ruling), the 5-year baseline period may not be necessary.

4.6 Analytes and Other Determinants

Many wells in the NGWMN will be sampled primarily for water quality. The analytes to be sampled are grouped on the basis of (1) the purpose of the monitoring event, (2) the frequency of monitoring (table 4.6.1), and (3) costs and efficient use of resources. The *standard list* includes analytes recommended to be monitored during every sampling event and consists of common field measurements taken from wells to obtain an overview of water-quality conditions. The *extended list* includes a greater number of analytes that better define aquifer geochemistry. Because of the increased laboratory costs, logistics, and time considerations associated with collecting a more complex suite of analytes, a relatively lower frequency for sampling is recommended to balance the demand on resources. An *optional* supplemental list includes other analytes of national interest that may be included on the basis of issues of local or State concern, depending on circumstances and available funding. The sampling frequency

Table 4.6.1 National Ground-Water Monitoring Network analyte list.

Sampling Goal	Monitoring well type	Lists	Determinants
Quality	Trend *Note the sets of wells used to obtain water-quality samples for water *quality* monitoring may not be the same sets as those used for *quantity* monitoring.	Standard list[1]	Ground-water level Temperature pH Specific or electrical conductance
	Surveillance	Extended plus standard list (total or dissolved, depending on needs or questions being addressed)	Sodium Calcium Magnesium Potassium Chloride Sulfate Alkalinity Nitrate + nitrite as nitrogen Ammonia Orthophosphate Dissolved oxygen Total dissolved solids Oxygen reduction potential Iron Manganese Other analytes with Federal Drinking-Water Standards
	Trend or surveillance	Supplemental (Optional)	Trace metals Synthetic organics Emerging Contaminants Selected Isotopes Others
	Special studies	Unique to monitoring project (e.g., special studies)	Variable; depending on specific questions to be addressed

[1]If desired, trend wells can also be sampled for extended list.

for the supplemental lists is expected to be very low due to complex treatment, handling, processing, and high cost of analysis.

It should be recognized that the NGWMN water-quality subnetworks are primarily identified by sampling frequencies and location or setting of the wells, which reflect the recognized expense and resource allocation involved in water-quality sampling. Thus, the particular analyte suites identified by the NGWMN (e.g., standard, extended) are not prescriptive to the specific type of subnetwork to which a well is assigned. For example, a synoptic study of a regional aquifer using wells identified as part of surveillance monitoring may involve the collection of both the standard and extended list of analytes in order to obtain a comprehensive characterization of the inorganic water chemistry of the aquifer. Contrarily, the same wells may be sampled for only the standard suite of analytes if the goal of the network was to only look at changes in water quality resulting from widespread road salting, where electrical conductivity was being used as a proxy for identifying changes in salinity. Another example is where a trend monitoring well may have a continuous data logger that collects continuous standard list components and may have a data string that has been continuous for 20 years. While the suite of analytes may not be robust, the continuous string of standard components (temperature, pH, electrical conductivity) would be very valuable for determining long-term changes, if any, in general water quality.

Trace elements and metals are a unique suite of analytes that require more involved field and laboratory procedures. Samples collected for trace metals can be filtered or unfiltered. Unfiltered samples collected from trend and surveillance wells are most useful for the objectives of the NGWMN, and results from unfiltered samples are required for determination of compliance with Safe Drinking Water Act standards; however, it is important to recognize that trace metal samples are often filtered, and it may be useful to analyze both filtered and unfiltered samples. As a result, it will be necessary to assign a code to the data to know if the sample was filtered or unfiltered.

The analyte lists are designed to address Level I questions (Section 3.1.5). Data providers can add analytes as needed, especially for special studies monitoring activities.

4.7 Monitoring Site Attributes and Selection Criteria

Detailed information about a monitoring site and the contributing aquifer will be a critical component for management and subsequent analysis of data collected for the NGWMN. By including attributes for each monitoring site, users of NGWMN data will have the maximum flexibility in terms of addressing many ground-water resource questions. Many attributes will be assigned to each monitoring site as it is included in the NGWMN. Over time, the number of attributes is expected to increase.

Ideally, NGWMN wells should be dedicated monitoring sites constructed specifically for monitoring ground-water levels, ground-water quality, or both. In practice, cost control requires that network wells come from many sources—some are drilled specifically for monitoring programs, but others are former domestic wells, irrigation wells, or public-supply wells. The network design must balance the construction design and history of use of a well with the need for adequate well coverage. Whether a NGWMN site is dedicated to the collection of ground-water data or also provides other services, such as self-supplied water for domestic purposes, is a factor that may be important when evaluating water-level or water-quality data. Therefore, NGWMN sites are identified as to whether they are dedicated monitoring points, and data users can filter data using this information. A detailed discussion of NGWMN requirements for well-attribute information is presented in Chapter 6.

The selection process for NGWMN monitoring sites also will consider the needs of the National Water Quality Monitoring Network for Coastal Waters and their Tributaries. The NGWMN framework focuses on Principal and major aquifers with conceptual flow model guiding placement of wells. Within this monitoring scheme, there may be opportunities for wells to be selected that would serve the monitoring objectives of both the NGWMN and the National Water Quality Monitoring Network for Coastal Waters and their Tributaries.

4.8 Examples of State and Regional Monitoring Designs

The NGWMN will need to coordinate with many existing ground-water and spring monitoring networks established at national, regional interstate, regional intrastate, State, Tribal, and local scales. Monitoring efforts also exist to track international issues on the Canadian and Mexican borders. While significant disparity exists among State ground-water monitoring networks, several States, as well as regional networks, stand out in regard to the overall caliber of their comprehensive efforts. The examples highlighted in appendix 4 include networks operating in Montana, Florida, South Dakota, and a consortium of States and the USGS that make up the regional High Plains Aquifer Water-Level Monitoring Program. While the geology, geography, diversity and distribution of land uses, and climate vary considerably among these State examples, several common threads relate their respective network design and operation. These include:

1. **Statutory establishment of the network and funding:** Each of the States promulgated legislation that formally established the network, assigned management and

operational duties, and provided appropriation for operation and execution of the monitoring plan.

2. **A high number and (or) density of monitoring sites:** The networks highlighted include from 145 (South Dakota) to 20,000 (Florida) monitoring sites. The monitoring sites in South Dakota are dedicated for ground-water monitoring.

3. **Aquifer-based monitoring:** The network designs focus monitoring on the aquifers that are important to the State or region. For Florida, the monitoring plan has evolved to include surface-water monitoring, because of strong interactions with ground water in that environment.

4. **Monitoring ground water in three dimensions:** The network designs incorporate wells that monitor the aquifer at varying depths in order to capture variations in water levels and water quality at different depths within the aquifer.

5. **Monitoring stressed and unstressed conditions:** The network designs incorporate monitoring sites that represent unstressed, background conditions as well as environments where the ground-water flow regime is disturbed by pumping, land use, or other conditions that affect ground water.

6. **A high measurement and sampling frequency:** Water-level measurement frequency is based on the local and regional conditions and data needs, and includes real-time, non-real-time continuous, and manual measurements. Nearly all wells sampled for quality include the standard field parameters, major ions, and nutrients. Enhanced sampling events include natural and manmade organics, pesticides, and radionuclides.

The proposed NGWMN incorporates the commonalities that make these networks effective and will build on this foundation for the national framework design, while incorporating innovations, new technologies, and improved methods for making the data produced by individual networks accessible and comparable.

4.9 Key Concepts

The NGWMN design is based on Principal aquifers, major aquifers, and other aquifers deemed important by the data providers.

The NGWMN is proposed as a national-scale network. Monitoring points may include wells, springs, and other important surface waters receiving direct ground-water discharge. Monitoring points that meet the criteria for the NGWMN can be included in the associated data portal even if the monitoring points are not in a NGWMN subnetwork.

The sites in the NGWMN and the frequency of measurement will be different for water-level and water-quality monitoring. Ideally, the NGWMN will use dedicated wells, though that may not always be possible. The selection of wells/springs requires close collaboration between data providers and the NGWMN.

The distribution of ground-water level monitoring points will be based on the purpose of the site, the position of the wells in the flow system, the degree of confinement of the aquifer, topographic and climate characteristics, and the hydraulic characteristics of the aquifer.

The number of measurement points and the measurement frequency for the NGWMN are only broadly known and will depend on the purpose of the monitoring, the confinement of the aquifer, the depth of the well, and the flow characteristics of the aquifer. It is clear that tens of thousands of wells and springs will need to be monitored to produce an effective network.

Selected key site attributes must be known in order for the site to be included in the NGWMN.

Chapter 5 – Common Field Practices to Ensure Comparability of Ground-Water Data

The purpose of this chapter is to establish a recommended framework for measurements of ground-water levels and analytical results of water-quality data to ensure an accurate representation of the water levels and water quality in an aquifer. This chapter and appendix 5 identify a selected set of practices and elements that should be present to ensure that water-level and water-quality data can be incorporated into the NGWMN. Common data-collection techniques are necessary in order to ensure comparability of data that will be provided by a wide variety of Federal, Tribal, State, and local organizations.

The NGWMN does not propose to place strict requirements on equipment use, techniques and methods, and the other aspects of individual data-collection programs used by NGWMN data providers, which will include a wide variety of Federal, Tribal, State, and local organizations. However, two overriding philosophies guide the NGWMN: (1) common data-collection methods are necessary to ensure comparability of data that will be provided, and (2) documentation of the techniques, methods, and other aspects of individual data-collection programs should be available from data providers so that users of the data can make appropriate judgments about the suitability of individual datasets for their needs. Under these philosophies, most existing ground-water data-collection programs should meet NGWMN standards.

Field practices are likely to be similar, though not identical, across different data provider programs. A variety of instrumentation and quality-assurance procedures are used, and these varied procedures are likely acceptable. However, documentation is essential so the users of NGWMN data can track not only the original source of the data, but the techniques used to collect the data and the quality-assurance procedures that were used by the specific data provider.

5.1 Ground-Water Level Monitoring Field Practices

The SOGW reviewed water-level field-practices documents from National, regional, and State data-collection programs, including the American Society for Testing and Materials (ASTM), USGS, USEPA, National Aeronautics and Space Administration (NASA), World Meteorological Organization (WMO), regional water authorities, and State agencies. Field practices include, but are not limited to, periodic, continuous, and real-time water-level monitoring and remote sensing of ground-water levels.

Appendix 5 details the recommended minimum field and data-collection standards, training, field preparation, measurement techniques and standards, and data handling guidelines for NGWMN ground-water level data collection.

5.2 Ground-Water Quality Monitoring Field Practices

The SOGW reviewed water-quality field-practices documents from International, National, regional, and State data-collection programs, including, but not limited to, the Environmental Protection Authority (Victoria, Australia), ASTM, USGS, USEPA, WMO, regional water authorities, and State agencies.

The field collection of ground-water samples is a multi-staged process that includes a number of elements:

- Pre-collection site review and preparation
- Onsite preparation
- Sample collection
- Sample processing, preservation, handling, and transport
- Data recording
- Quality assurance/quality control (QA/QC)

Field-sampling procedures must adequately address these elements to ensure that

- Samples are being collected at the correct location, source, and time;
- Equipment and supplies are appropriate for the sampling being conducted;
- Sample sites are prepared properly prior to sampling;
- Samples are handled in a manner that preserves the validity of their analysis and data value;
- Data and information recorded during sampling contain all of the information needed to normalize and compare analytical results; and
- Measures are taken to ensure the accuracy of analytical results.

The elements of a sampling program should be documented in a written set of procedures for field sampling. The procedures should be approved by the appropriate authority and reviewed periodically for adequacy, appropriateness, and compliance with current scientific principles. Appendix 5 outlines the onsite preparation, sample collection, documentation, and data-recording requirements for NGWMN ground-water quality data.

5.3 Quality Assurance

The value of the data derived from an analysis is directly related to the measures taken to ensure that the quality of the data is appropriate and not compromised by the use of improper measurement and sampling techniques, materials, or methods. Additionally, quality assurance includes conducting controlled checks of the data. A quality-assurance plan is a formal document that describes the management policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of the organizational unit or group that is responsible for ensuring quality in its products. Implementation of a quality-assurance plan helps to ensure

- Consistency (across projects),
- Accountability (to data users),
- Comparability (yields results of known quality),
- Traceability (written record of how, who, and when work was performed, training, equipment, etc.), and
- Repeatability (documentation of technique that leads to the similar results time after time with the same accuracy).

Such a plan provides a minimum set of guidelines and practices that can be used by data producers to assure quality in ground-water measurement and sampling activities. The plan should cover quality-assurance policies pertaining to the collection, processing, analysis, storage, review, and publication of all types of ground-water data.

This Framework Document does not recommend the use of any specific existing quality-assurance plan, but recommends that a plan be in place for any data-collection activities that are part of the NGWMN. The plan should be available electronically so that a data consumer will have access to the plan if necessary.

5.4 New Technologies

Various new technologies have been developed and continue to be developed for monitoring of water levels or water-level changes. Non-contact methods of water-level measurement using radar and sound waves have been tested and used for determining liquid levels in wells. Accuracy of these devices typically is not as good as current standard methods to measure water levels (<0.1 foot (ft)) but they have some advantages over standard measurement methods in terms of speed of measurement when the water level is very deep or in situations when access to the well is limited.

Other indirect methods have been or are being developed to estimate water levels on a regional intrastate or regional interstate basis where wells may be sparse. Examples are microgravity (Howle and others, 2003), interferometric synthetic aperture radar (InSAR; Galloway and others, 1999), and the Gravity Recovery and Climate Experiment (GRACE), which measures the gravity field of the Earth from a satellite platform and could be used to derive large-scale changes in ground-water storage (Han and others, 2005).

The use of field water-quality equipment, such as meters for measuring total dissolved solids, pH, temperature, and dissolved oxygen, has become commonplace and, provided the equipment is properly calibrated, typically is accepted for non-enforcement purposes. Continuous water-quality measurements using data sondes are becoming more widely accepted as standard procedures for collecting high-frequency ground-water quality data. In addition to using probes for measuring pH, specific conductance, temperature, and dissolved oxygen, ion-specific probes, such as those used for measuring nitrate, chlorine, phosphate, and ammonia, are now more commonly being used in the field for continuous measurement of ground-water quality. Borehole hydrophysical methods are also being developed that help in the understanding of the vertical heterogeneity of water quality within the borehole, including production wells (Izbicki, 2004).

The NGWMN embraces the concept that new technologies will continue to be developed and perfected. The scale of these new technologies may range from individual water-level and water-quality sensors to satellite-based sensors. These new technologies may result in significant cost savings for ground-water monitoring programs. New technologies will be incorporated into the NGWMN as appropriate.

5.5 Key Concepts

The NGWMN does not propose to place strict requirements on specific aspects of individual data-collection programs used by NGWMN data providers. However, common data-collection techniques and adequate documentation of the programs are necessary in order to ensure comparability of data and to assure quality in ground-water measurement and sampling activities.

Chapter 6 – Data Standards and Management

Detailed information about a monitoring site and its associated aquifer is a critical component of any subsequent analysis of NGWMN data. Data with common attributes enable comparisons and facilitate exchange of information. This chapter addresses key aspects of data standards and management that contribute to assembling and accessing a national dataset that can be used to answer significant national, interstate and regional ground-water questions.

Ground-water scientists and engineers are keenly aware that having adequate metadata (context and description of the data) for water-level and water-quality data are critical for the long-term usefulness of that data. Unfortunately, tens of thousands of measurements and samples, representing millions of dollars, are collected every year and the results are stored without adequate metadata (Intergovernmental Task Force on Monitoring Water Quality, 1996). Collection and submission of these data may satisfy a regulatory requirement or policy; however, because of inadequate metadata, this vast store of information cannot be used for other purposes, such as evaluating the conditions of ground-water resources in a particular State or region. Two case studies highlight this issue of consistency in data and metadata collection and reporting.

In the first case study, a USGS NAWQA Program investigation (Lapham and others, 2000) was conducted to evaluate chemistry data from 47 individual programs being conducted by Federal and State agencies for use in a national study of the occurrence, status, and distribution of volatile organic compounds (VOCs). In this study, Lapham and others (2000) evaluated the presence or absence of 10 required metadata elements related to sampling and analysis and 20 metadata elements related to the sampled well and hydrogeologic setting of the well. A substantial portion of data from the individual programs could not be used because of two widespread metadata problems: (1) the VOC analyte list and reporting limits for many of the analyses were not recorded, and (2) adequate records of the characteristics of sampled wells (location, construction, aquifer characteristics) were not maintained.

In the second case study, the Delaware Geological Survey (DGS) evaluated chemistry data from six programs being conducted by three Delaware State agencies and the USGS for assessing the potential for human exposure to toxic and carcinogenic compounds through shallow domestic water-supply wells (Pellerito and others, 2008). This study used a similar approach to metadata evaluation as the Lapham and others (2000) study with the goal of relating Delaware observations of water quality in shallow (<100 ft depth) domestic wells to national trends.

In the DGS case study, two of the three State agencies maintained digital databases of results of water-quality analyses. All of the State agencies stored metadata related to laboratory protocols (e.g., detection and reporting limits, analytic methods, and sample handling) in hard-copy records requiring a labor-intensive effort to access and use the results. Local well identifiers were reported by all agencies, however, only one of the State programs reported metadata regarding the wells being sampled. Despite staff expertise with Delaware's well permitting database and access to complete consultant reports, data from several thousand samples collected from hundreds of wells were rejected for lack of basic information on well depth or owner. As a result of these findings, the agencies now have a signed memorandum of agreement to use the State-issued well permit number as the primary site identifier for all ground-water data collected by and submitted to State agencies.

These two case studies, which report only a subset of data evaluations, highlight common problems with many ongoing monitoring efforts and indicate the large potential pool of additional data that could be used if additional efforts were made to collect and report sufficient metadata. To the State and local agencies, the benefit of using a nationally consistent metadata profile would be a technically sound mechanism for efficient and systematic comparison of findings to regional interstate and national trends and an important potential means for augmentation of collaborating organizations' data for decision making at very low or minimal cost (National Water Quality Monitoring Council, 2006).

6.1 State of Ground-Water Data Systems

Ground-water data systems in the United States exist at all organizational levels (local, State, national, academic, and in the private sector), and because of historical differences in purpose, the data cannot easily be shared and compared. To overcome this problem, consortia of private sector, academic, and governmental organizations have begun developing data standards and common vocabularies to facilitate sharing of monitoring data. As new databases are developed and old systems are updated, the standards gradually are being incorporated into these systems. Because the investment in existing databases and data-exchange mechanisms has been substantial, the process of using the standards developed by these organizations is being accepted. New technological approaches, taken together with these common data standards, are increasingly promoting integration of similar data-field names (also referred to as “data elements”) from different databases to establish shared datasets and promote data sharing. Because these larger “shared” datasets potentially provide more complete records of ground-water levels and quality, spatial and temporal analyses may be more complete and therefore more relevant when applied to water-resource management, regardless of the initial purpose of the monitoring data.

Among the several Federal agencies that collect and store ground-water data, some serve data to the public in varying degrees. These agencies include the USGS, USEPA, U.S. Department of Agriculture (USDA), U.S. Department of Energy (USDOE), U.S. Army Corps of Engineers (USACE) and other branches of the military, the U.S. Forest Service (USFS), and the National Park Service (NPS). There also are a number of different agencies within each State that perform monitoring and data-management functions. For example, a summary of State programs that collect and provide ground-water levels lists almost 60 different efforts in the United States (*http://acwi.gov/sogw/nmi-wkg/State_Ground-Water_Level_Data.htm*). On another level, local, county, township, municipal, watershed groups, water purveyors, consultants, and academia may collect, store, and serve data in their own manner. Multiple databases that store essentially the same types of data, though not necessarily redundant, create barriers to data sharing. Some of these datasets exist only in hard copy, resulting in resources that are difficult or impossible to access and work with. When an attempt to share and use these data occurs, significant amounts of time and money often are required to obtain the data and convert it into a usable format.

Additionally, several National Science Foundation efforts are working to address exchange of ground-water level data, surface water-quality data, and in some cases ground-water quality data. The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI; *http://www.cuahsi.org/*), Hydrologic Information System, the WATERS network (*http://www.watersnet.org/index.html)*, and the Collaborative Large-scale Engineering Analysis Network for Environmental Research (CLEANER, *http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13337*) are examples, and coordination with efforts such as these could prove to be beneficial.

6.1.1 Standards for Federal-State Data Exchange

Fundamental to implementation of a data exchange for any sets of data are agreements on data elements and conditions for exchange and format, as well as willing and capable data exchangers. At the Federal and State levels, agreements on data elements and conditions are in place, such as through the Environmental Data Standards Council (EDSC). The challenge for wider use of data, including ground-water level and quality data, is the knowledge of the existence of these agreements on standards and conditions of exchange and the applicability to a particular interest or need for data.

The EDSC established that “Data standards are documented agreements on representations, formats, and definitions of common data. Data standards improve the quality and shareability of environmental data by: (1) increasing data compatibility, (2) improving the consistency and efficiency of data collection, and (3) reducing data redundancy.” Furthermore, “Data standards establish a common language across organizations and can facilitate easier and more accurate information exchange among environmental agencies. Data standards are documented agreements on formats and definitions of common data. Key elements of a data standard consist of data element names, definitions, data type, and formatting prescriptions. A data standard may also include some guidance for usage to facilitate and promote its widespread use” (Environmental Data Standards Council, 2006a). Lack of data standards introduces substantial risk of inaccuracy and (or) loss of information in the exchange of data.

In the United States, the Federal and State governments have participated in several efforts to establish agreements to facilitate data exchange nationally. These efforts include:

- The USGS National Water Information System (NWIS) Web data dictionary (*http://waterdata.usgs.gov/nwis/help/?codes_help*)
- The USEPA Water-Quality Data Exchange (WQX) (*http://www.exchangenetwork.net/schema/WQX/2/WQX_DET_v2.1.xls*)
- The USEPA WQX XML Schema (*http://www.exchangenetwork.net/schema/WQX/2/WQX_Schema_v2.1.zip*)
- EDSC data standards (*http://www.exchangenetwork.net/*)
- The Federal Geographic Data Committee (FGDC) National Spatial Data Infrastructure (NSDI) (*http://www.fgdc.gov/nsdi/nsdi.html*)

Additionally, the Federal government has collaborated with the ASTM to develop standards specific to monitoring that include standards for data elements. These standards are available to ASTM member organizations and individuals of ASTM or can be purchased from ASTM. These standards are widely used in the water industry and government organizations and have been incorporated into some databases, such as NWIS.

The International Organization for Standardization (ISO), an international standard-setting body composed of representatives from 157 national standards organizations, has also established industrial and commercial standards that are recognized around the world. The standards are not law but are incorporated into national standards and often are referred to in laws, regulations, and treaties. ISO has established standards for geographic data useful for data sharing as well as for metadata records.

The Open Geospatial Consortium (OGC) is another international standards organization that works closely with the geographic-data standards within the ISO (ISO/TC211). OGC is composed of more than 400 companies, government agencies, and universities internationally that collaborate to develop open standards for discovery, integration, and dissemination of geospatially related datasets. OGC spans 10 different domains, one of which is "Geosciences and the Environment." Within this group, the Hydrology Domain Working Group was formed in 2009 to test and evolve OGC standards with a special emphasis on hydrologic data. A Ground Water Interoperability Experiment (Brodaric and Booth, 2010) was initiated among international participants from government, academia, and the private sector to focus on ground-water data exchange across the U.S./Canadian border. Ground Water Markup Language (GWML), a ground-water specific data-model extension to the OGC Geographic Markup Language (GML; Boisvert and Brodaric, 2011b), was investigated as a model to describe well characteristics, and WaterML 2.0 as a model for encoding water-level measurements. These models were used by OGC Sensor Observation Services (SOS) and Web Feature Service (WFS) for the exchange of data.

Many data systems were evaluated for this Framework Document. Data standards developed by ASTM, EDSC, USEPA, and USGS were used to develop the consensus list of data elements for ground-water levels and quality incorporated in this monitoring framework. Data elements for ground-water monitoring are listed in table 6.1.1.1. The list includes data elements for (1) point of contact, (2) site identification, (3) geologic/hydrogeologic description, (4) well location, (5) well characteristics, (6) measurement/sampling event, and (7) water-quality results. The SOGW agreed that these seven categories of metadata are essential for exchanging data of known and comparable quality. The data elements were presented to public forums for input before the SOGW determined the final scope and detail.

Table 6.1.1.1 Data elements for ground-water monitoring of levels and quality.

Data Element	Definition
1.0 POINT OF CONTACT (Metadata collected and reported one time for a well or monitoring site)	
1.1 Source of data	Identifies the primary source or provider of data, including name, address, telephone number, email address.
1.1.1 Organization Name	Legal formal name of organization that is the primary source of data.
1.1.2 Mailing Address	Exact address where mail is intended to be delivered, including street, rural route and (or) PO Box.
1.1.2.1 City, Town, Village Name	Municipality where organization that collected information resides.
1.1.2.2 State Name	State
1.1.2.3 Mailing Address ZIP Code/Postal Code	5-digit Zone Improvement Plan (ZIP) code and 4-digit extension code (if available).
1.1.3 Telephone number	Telephone number (including area code) of the person who is the point of contact for the organization.
1.1.4 Electronic Mail Address	Electronic Mail Address (email) of the contact person at the organization.
2.0 SITE IDENTIFICATION/DESCRIPTION (Metadata collected and reported one time for a well or monitoring site)	
2.1 Site Identifier	Unique site identifier consisting of latitude (DDMMSS), longitude (DDDMMSS), and sequence number (NN) (DDMMSSDDDMMSSNN) or other unique identifier.
3.0 GEOLOGIC/HYDROLOGIC DESCRIPTION (Metadata collected and reported one time for a well or monitoring site)	
3.1 Geologic unit(s) containing aquifer (Aquifer lithology; the lithology of the primary contributing unit(s))	Name of geologic unit given by national, Federal, or interstate agency for the Principal aquifer for which measurement is taken.
3.2 Aquifer tapped (Principal aquifer or other significantly used aquifer; primary unit(s) contributing water to the well)	USGS Atlas designation of aquifer (blank otherwise).
3.3 Local aquifer or geologic formation name (if applicable)	Local or State name of an aquifer or geologic formation.
3.4 Aquifer conditions	Hydrogeologic characteristics of the aquifer identified as: (1) confined (2) unconfined or leaky confined
4.0 WELL LOCATION (Metadata collected and reported one time for a well or monitoring site)	
4.1 Horizontal Location	
4.1.1 Latitude	Measure of angular distance on a meridian north or south of the equator in decimal degrees.
4.1.2 Longitude	Measure of angular distance on a meridian east or west of the prime meridian in decimal degrees.
4.1.3 Horizontal Reference Datum	The reference datum to determine latitude and longitude coordinates.
4.1.4 Location Horizontal Accuracy	The measure of accuracy (in feet) of the latitude and longitude coordinates.
4.1.5 Location Collection Method	Method used to determine latitude and longitude coordinates for well.
4.2 Vertical Location	
4.2.1 Altitude of top of well casing	Altitude of the casing at the wellhead for the well at which a measurement is being taken.
4.2.2 Altitude measurement method	Method used to determine altitude.
4.2.3 Altitude of the land surface next to the well casing (at the wellhead)	The measure of elevation of the ground level at the wellhead .
4.2.4 Altitude accuracy	The accuracy of altitude measurement.
4.2.5 Vertical Reference Datum	Datum of altitude
5.0 WELL CHARACTERISTICS (Metadata collected and reported one time for a well or monitoring site)	
5.1 Local/State Identifier	State unique identifier/State permit number.
5.2 Depth of well	Well depth to bottom of open hole or casing.

Table 6.1.1.1 Data elements for ground-water monitoring of levels and quality.—Continued

Data Element	Definition
5.2.1 Depth of Well unit of measure	Measurement of well depth in (a) Feet (b) Meters
5.3 Source of Data	The contributing source of the well-depth data.
5.4 Casing depth of well	Depth to casing string bottom.
5.4.1 Casing depth of well unit of measure	Measurement of well casing depth in (a) Feet (b) Meters
5.5 Top of uppermost screened interval or open hole (Depth to top of each open interval)	Depth to top of uppermost open interval.
5.5.1 Top of uppermost screened interval or open hole unit of measure	Measurement unit to top of uppermost screened interval or open hole in (a) Feet (b) Meters
5.6 Bottom of lowermost screened interval or open hole (Depth to bottom of each open interval)	Depth to lowermost open-interval bottom.
5.6.1 Top of lowermost screened interval or open hole unit of measure	Measurement unit to top of lowermost screened interval or open hole in (a) Feet (b) Meters
5.7 Casing material(s), if there is a casing	Casing material such as steel, polyvinyl chloride (PVC) fiberglass, etc.
5.8 Screen material type(s) at each open interval(s), if the well has well screen(s)	Screen material such as steel, polyvinyl chloride (PVC) fiberglass, etc.
5.9 Well Log or Completion Report Available	Indication of well log or Completion Report availability: Yes/No
5.10 Measurement Location (Metadata collected and reported one time for each well)	
5.10.1 Description of Measurement/Sampling/Reference Location	Location at which the measurement/sampling was done: (a) top of well above land surface (b) top of well at land surface (c) top of well below land surface
5.10.2 Measurement/Sampling reference location elevation (Measuring-point elevation relative to datum (rtd)	Height of measurement/sampling reference location from land-surface elevation (altitude).
5.10.2.1 Measurement/Sampling reference location elevation unit of measure	Measurement unit of reference location elevation at wellhead in (a) Feet (b) Meters
5.10.3 Measuring/Sampling Point Accuracy of Measurement	Indication of accuracy of the point of measurement or sampling in feet or meters.
6.0 MEASUREMENT/SAMPLING EVENT (Metadata collected and reported for each measurement and sampling event and data for water-level measurement)	
6.1 Purpose	
6.1.1 Monitoring Purpose	Specified monitoring purpose: (a) baseline (b) surveillance (c) trend (d) special studies
6.2 Date and Time (Metadata collected and reported for each measurement and sampling event)	
6.2.2 Measurement/Sampling date/time	
6.2.2.1 Level Measurement date and time (Data for water-level measurement collected and reported for each measurement event)	
6.2.2.2 Water-level measurement date	The calendar date when water level was measured, reported as 4-digit year, 2-digit month, and 2-digit day in YYYYMMDD format.
6.2.2.3 Water-level measurement time	The measure of clock time and time zone when water level was measured, reported as a 24-hour day with 2-digit hour, 2-digit minute, and 2-digit second.

Table 6.1.1.1 Data elements for ground-water monitoring of levels and quality.—Continued

Data Element	Definition
6.2.3 Quality Sampling date and time (Metadata for water-quality sampling collected and reported for each sampling event)	
6.2.3.1 Sample Collection Date	The calendar date when collection of the sample was started, reported as 4-digit year, 2-digit month, and 2-digit day in YYYYMMDD format.
6.2.3.2 Sample Collection Time Measure	The measure of clock time and time zone when collection of the sample was begun, reported as a 24-hour day with 2-digit hour, 2-digit minute, and 2-digit second.
6.3 Measurement/Sampling Site Use (Metadata collected and reported each time for water-level or water-quality sampling event)	
6.3.1 Site use at time of measurement/sampling event	Use of area immediately around well: Commercial, industrial, agricultural cropping, undeveloped pasture/range, forest, or residential at time of measurement or sampling event.
6.4 Level Elevation Measurement (Data collected and reported each time for a water-level measurement)	
6.4.1 Water Level	Water level reported to accuracy of measurement to the nearest ones, tenths, or hundredths of a unit.
6.4.1.1 Water Level Unit of Measure	Measurement unit of water elevation in well (a) Feet (b) Meters
6.4.2 Measurement method	Method of water-level measurement.
6.4.3 Water-level accuracy	Accuracy of water-level measurement in feet or meters.
6.4.4 Water-level status	Status of water-level: (a) static (b) pumping
6.5 Sample Collection (Metadata collected and reported for each water-quality sample)	
6.5.1 Sample Type	The type of sample being described. Permitted values include: (1) Sample (2) Duplicate sample (3) Other entries as applicable
6.5.2 Sample Identification	The unique name, number, or code assigned to identify the sample.
6.5.3 Sample Collection Method Code	An alphanumeric label to identify the sample-collection method.
7.0 WATER-QUALITY RESULTS (data from laboratory reported for each sample and analyte tested)	
7.1 Result Value	Reportable numerical measure of the result for the chemical or microbiological analyte, or other characteristic, being analyzed.
7.1.1 Result Value Unit of Measure	The name of the determinate quantity for a standard of measurement used for measuring dimension, capacity, or amount (e.g., mg/L, pCi/L, CFU/mL, etc.).
7.1.2 Analyte Name	The name assigned to a substance or feature that describes it in terms of its molecular composition, taxonomic nomenclature, or other characteristic.
7.1.3 Chemical Identifier/Number (Chemicals only)	Chemical Identifier/Number is the unique number assigned to all chemical substances in the Chemical Abstract Service's (CAS) Registry or, in the USEPA Chemical Registry System, to chemical groupings for which CAS Registry Numbers do not exist and cannot be assigned.
7.1.3.1 Chemical Classification System	The name of the classification system used to assign a systematic name to a chemical analyte.
7.1.4 Biological Identification Number	The unique identification number assigned by either the Integrated Taxonomic Information System, (ITIS) the International Committee on Taxonomy of Viruses, or the USEPA Biological Registry System.

Table 6.1.1.1 Data elements for ground-water monitoring of levels and quality.—Continued

Data Element	Definition
7.1.4.1 Biological Systematic Context Name	The name of the classification system used to assign a systematic name to a biological entity.
7.2 Analytical Method Number	The method number of the analytical method used, represented as a reference number.
7.2.1 Analytical Method Classification System	The name of the classification system used to assign a systematic number to an analytical method. (a) USEPA (b) ASTM (c) Standard Methods (d) Other methods as applicable

Sources:
U.S. Geological Survey (USGS) data elements listed in appendix 6.
Advisory Committee on Water Information (ACWI), 2006
U.S. Environmental Protection Agency (USEPA) Water-Quality Data Exchange (WQX) data elements listed in appendix 6.

6.2 Assessment of Data Standards and Exchange Needs for a National Ground-Water Monitoring Network

Data and metadata standards are developed to ensure the quality, efficiency, and accuracy of the processes of data and metadata entry, storage, transfer, and reporting. The process of analyzing data is related to and dependent on, but wholly separate from, these processes. Data analysis is the business of the end user, and the needs are specific to the issue at hand. In this regard, one size does not fit all. A policy maker and legislative aide have different needs than the scientists responsible for conducting regional interstate or national assessments of ground-water conditions.

It is clear that there are adequate metadata standards available and already in place at the USGS, USEPA, and with the CUAHSI initiative. The body of ASTM standards related to collection of ground-water data and conducting ground-water studies, which were developed with the assistance of the USGS, USEPA, and representatives of other governmental, academic, and private entities, provide detailed documentation that supports the aforementioned metadata standards. It is likely, though not absolutely certain, that many existing State and regional interstate monitoring networks follow these or similar standards and as a result generate significant quantities of high-quality information. Many State ground-water database models and data elements are based on those of the USGS.

6.2.1 Unique Site Identifiers

An absolute necessity for a national ground-water monitoring network is that each site has a unique identifier. Additionally, it is important that the unique identifier for a well be consistent across the multiple agencies or organizations that provide data for that well.

6.2.2 Aquifer Naming (Hydrostratigraphy)

Currently (2013), there is a lack of a peer reviewed and published procedure or code for naming, mapping, and classifying aquifers and confining units throughout the Nation. This creates some significant problems for the design of a national ground-water monitoring network and subsequent analysis of the collected ground-water monitoring data. The North American Commission on Stratigraphic Nomenclature (NACSN) and the International Subcommission on Stratigraphic Classification (ISSC), which are the scientific bodies that were created for dealing with issues related to classification and naming of bodies of rock and sediment, have long recognized the need for a classification system for hydrostratigraphic units. Attempts to address this issue were made in the 1990s; however, members of the NACSN did not complete the work needed to establish a code of hydrostratigraphic nomenclature and left practitioners with this guidance in Article 22 of the North American Stratigraphic Code:

> "(g) Economically exploited units. Aquifers, oil sands, coal beds, and quarry layers are, in general, informal units even though named. Some such units, however, may be recognized formally as beds, members, or formations because they are important in the elucidation of regional stratigraphy (North American Commission on Stratigraphic Nomenclature, 2005)."

In the absence of a formal system, the USGS has created a classification scheme and promulgated names for many aquifers, confining beds, and sample intervals described in Chapter 4. NWIS contains data elements for "Principal" or National aquifers and "local" aquifers. In practice, the Geologic Names Committee of the USGS is charged with maintaining lists of geologic unit names and metadata. Thus, the Geologic Names Committee, together with the 7th edition of the USGS Suggestions to Authors (Hansen, 1991), is the formal mechanism used to classify hydrologic units and establish names within the USGS. In practice, however, the lack of a formal national system has led to authors creating multiple names for the same physical entities (e.g., aquifers and confining beds). Although this is a problem, it does not warrant stopping the development of a national ground-water monitoring network until a formal naming system can be developed. Thus, this exemplifies the need for comprehensive metadata so wells can be associated with the proper aquifer once formal hydrostratigraphic assignments are complete.

In the absence of consensus national aquifer naming and mapping standards, some States have developed their own naming and mapping frameworks to assist with regulatory and resource evaluation programs. One key finding of these efforts that will be needed in a national ground-water information system is that three levels of aquifer classification are needed in the data structure rather than the two levels used by NWIS or the one level used in the USEPA STORET water-quality data system.

6.2.3 Approaches to Facilitate Data Exchange

It is clear that in the future multiple monitoring networks will continue to be operated across the country. The data will continue to be managed in distributed databases. Though it is a worthy goal not to promote the creation of an ever-increasing number of databases, there is no need for a single database or to overly penalize States or other data providers whose data needs are not met by one of the national standards. The challenge is to foster means to connect the distributed databases and exchange information among all of the entities generating data. Ground-water program managers should be strongly encouraged to follow these standards to promote effective data use. In this regard, there is a need for training and professional development to increase awareness and use of these standards.

It is clear that many different agencies and academia will continue to improve technology for the collection and interpretation of data and the software developed to store, retrieve, analyze, and display ground-water data and interpreted information. As a result, there may be no need to develop a single Web-based comprehensive database for the storage, retrieval, and analysis of data or to focus resources on one agency to develop applications for such a database. Rather, the focus should be on developing applications that facilitate the access, retrieval, and collation of data on an as-needed basis from multiple, dispersed data repositories, allowing the data to continue to be housed and managed by the data provider while being accessible to anyone with a need for it. A review of data portals, electronic Web-access sites receiving and serving water data, indicates that at a national level, USEPA, CUAHSI, and the USGS could potentially manage access to ground-water data in this way (Section 6.3).

One step that emerges from Chapters 4 (Design Framework) and 5 (Field Practices) in combination with this chapter on Data Standards and Management is an agreement, through consensus, on a common set of data elements to facilitate data exchange and comparison. Agreement on a set of data elements by all ground-water monitoring partners expands the amount of data each agency can use with minimal cost, allows comparison of data covering larger or adjacent areas, and provides more complete coverage where data are collected by multiple agencies for different purposes at different locations in the same area (Advisory Committee on Water Information, 2006). A list of data elements that emerged among the data models and standards reviewed previously is presented in appendix 6. Agencies that agree to use a common set of data elements may desire to collect and store additional data and metadata for their own purposes, but common elements facilitate exchange and allow other agencies to decide whether the metadata meet their needs. Additionally, a common data-element set enables assembly of a consistent dataset for national, regional, interstate, and statewide purposes that did not exist previously.

To maximize the benefit of existing datasets that use different, but substantially similar data elements, the technique of mapping of data elements of one database to those of another should facilitate exchange of data without having to restructure existing databases. Providing data to other agencies mapped to the common data elements saves resources and maximizes previously collected as well as future data to be used for other purposes.

6.3 National Ground-Water Monitoring Network Data Portal

A publically accessible data portal is proposed as a primary product of the National Ground-Water Monitoring Network. Data from the NGWMN will be available from the data portal, as well as contributions from other data providers that meet NGWMN criteria, but which may not be selected as a designated NGWMN site. The basic requirements for a data exchange and access system for ground-water data are envisioned as follows:

1. The ground-water levels, quality, and associated metadata should be of documented quality based on field practices and the core set of data elements necessary for basic comparison of results.

2. The processes employed in the NGWMN data system should allow for the most current data practical to be retrieved, including real-time or near-real-time data such as daily or weekly results for ground-water levels and quality.

3. The data-exchange network (composed of a Web portal, the underlying databases, and Web-service infrastructure)

is proposed to be an automated system. Although there will be an initial investment in establishing automated Web services to retrieve data offered by data providers, once the services are established, minimal effort should be required on the part of the data provider to participate in managing the data flow, provided their native data structure does not change. The primary goal of such a data system is for a measurement in the data provider's database to be transferred to the NGWMN data system without human intervention. Throughout the pilot process it was decided that the providers' data would be retrieved on-the-fly using standard Web services and then aggregated and interpreted by a centralized mediation framework.

4. The manager of the portal and data-exchange framework for the NGWMN will maintain a catalog of wells identified to be in the national network and other wells as appropriate along with the corresponding set of required metadata elements. Data providers will be responsible for maintaining the quality of the data in the NGWMN system as well as maintaining the Web services that serve their data and the mapping between their local data systems and the portal.

5. Mechanisms will be established to allow data providers and well managers to maintain the required metadata about their wells and add additional wells if necessary.

6. A map-based graphical user interface (GUI) will be used for locating wells and retrievals from the data system.

7. The GUI will provide some indication of the data available in the data system and the "conditions" reflected by the most recent measurements available in the data system.

8. The retrieval times from the NGWMN data system will be acceptable for its designed use(s) as determined by the SOGW.

9. The data system will be maintained indefinitely.

Figures 6.3.1 and 6.3.2 illustrate the steps taken and flow of information for a data request from the public for one approach to the proposed NGWMN data portal. A user selects a well or wells from the portal GUI and requests water-level data, water-quality data, or both. The portal evaluates the request and sends a data request to the appropriate database or databases. The results are returned to the portal, compiled, and provided to the public user.

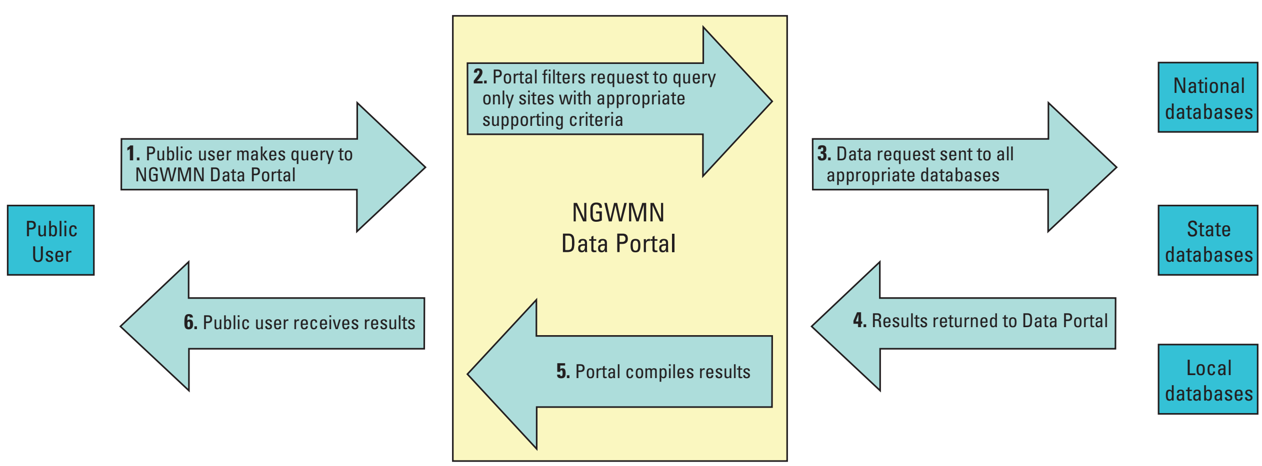

Figure 6.3.1 Steps taken and information flow from a public data request to the proposed National Ground-Water Monitoring Network data portal.

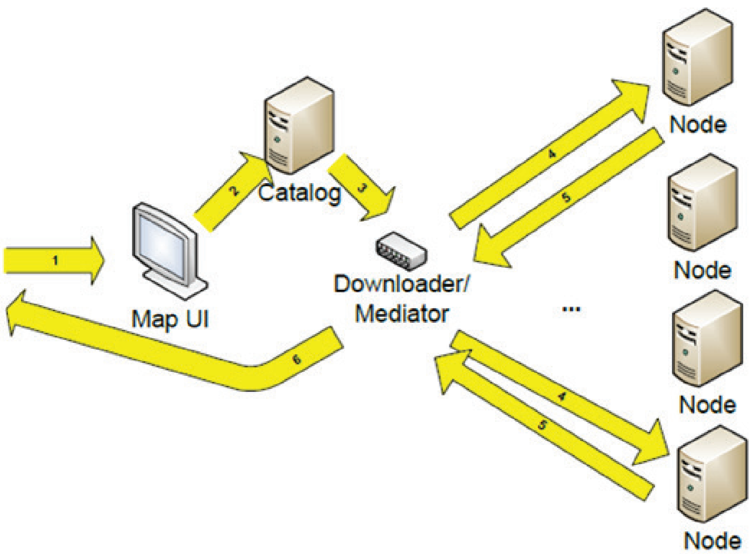

Figure 6.3.2 Data portal architecture schematic. (1) Locate ground-water wells, (2) Sites (wells) are identified, (3) Catalog passes site information to mediator, (4) Mediator requests relevant datasets from data providers, (5) Services return requested data, (6) Mediator transforms, aggregates, and returns requested data to user.

To support data exchange without modifying existing data structures, mediation tools that allow mapping or relating data elements from one database to data elements in another database, similar to the approach CUAHSI is developing in its Hydrologic Information System, are recommended. To encourage this exchange mechanism, efforts should be continued to map data elements between STORET and NWIS and other existing databases and support efforts on the State level to map their databases and incorporate XML tags in the metadata to the STORET and (or) NWIS models.

Agreement on a common set of data elements by all ground-water monitoring partners will expand the amount of data each agency can use with minimal cost, allowing comparison of data covering larger or adjacent areas and providing more complete coverage where data are collected by multiple agencies for different purposes at different locations in the same area.

6.4 Key Concepts and Recommendations

Data systems in the United States exist at all organizational levels (local, State, national, academia, and private sectors), but because of the historical differences in purpose, the data cannot easily be shared and compared. To overcome this problem, several national level private and governmental organizations have evolved data standards and a common vocabulary, in this case applying to monitoring data, to facilitate data sharing. As new databases are developed and existing systems are updated, the standards gradually are being incorporated into these systems.

It is clear that there are adequate metadata, domain-specific data models, and data-exchange standards available and already in place at the USGS, USEPA, and with the CUAHSI initiative. Many existing State and regional interstate monitoring networks follow these or similar standards and as a result generate significant quantities of high-quality information.

The focus of the NGWMN data system should be on developing applications that facilitate the access, retrieval, and collation of data on an as-needed basis from multiple, dispersed data repositories, allowing the data to continue to be housed and managed by the data provider while being accessible to anyone with a need for it. To maximize existing datasets that use different, but substantially similar data elements, the technique of mapping of data elements of one database to those of another should facilitate exchange of data without having to restructure existing databases.

It is not the intent of the SOGW to recommend any one existing data standard or data model (e.g., NWIS, STORET, and CUAHSI) over another or recommend development of a new data standard and model. Rather, it is recommended that an effort be made to standardize data-element names and definitions, allowed values, and XML data-tag values. This standardization of data-element names should be based on existing data models and standards reviewed previously. Agreement on a minimum set of common data elements for ground-water monitoring from these models and standards should facilitate data exchange. A key step to the exchange of data would be for the USGS to develop a unique site identification system (site identifier) that does not conflict with security requirements for public-water supplies.

Currently (2013), there is a lack of a peer reviewed and published procedure or code for naming, mapping, and classifying aquifers and confining units throughout the Nation. It is recommended that a minimum of three aquifer naming fields be included in all databases and data models meant to serve a national audience. In this regard, it is recommended that efforts to map and classify aquifers and develop a consistent national hydrostratigraphic nomenclature be encouraged.

A publicly accessible data portal (*http://cida.usgs.gov/ngwmn*) is a primary product of the National Ground-Water Monitoring Network. Data from the NGWMN water-level and water-quality networks and subnetworks will be available from the data portal, as well as contributions from data providers that meet NGWMN criteria, but may not be selected for the national network. The NGWMN data portal will be a mechanism for the public, as well as for data providers, to access NGWMN data. With this portal, data providers who do not already have information systems that provide ground-water data to the public by way of the Internet will gain a significant capability by participating in the NGWMN and may also benefit from the resulting data assimilation within their own State.

Chapter 7 – Network Implementation

This chapter provides a summary of important design concepts in the NGWMN, recommendations for management of the network, and a path forward for network implementation.

7.1 National Network Design

The NGWMN takes advantage of, but also seeks to enhance, existing Federal, multistate, State, and local monitoring efforts. The NGWMN is not intended to replace existing monitoring programs nor is it intended to address localized issues such as contaminated industrial sites. Rather, it is focused on assessing the overall status of major aquifers or aquifer systems and changes as they occur. The NGWMN is expected to provide an improved foundation and context at the national and regional multistate scale within which to interpret data from various data-collection efforts. The network design includes three well classification subnetworks: a Background Subnetwork, a Suspected Changes Subnetwork, and a Documented Changes Subnetwork.

The Background Subnetwork will include monitoring points that provide data from unstressed (or minimally stressed) aquifers. Ideally, this subnetwork ensures that a consistent group of wells is regularly monitored to generate water-level and water-quality data from nonpumped and uncontaminated areas. However, it is likely that total subnetwork-wide isolation from land-use and developmental pressures is not possible, so in practicality, background areas are those that either have no stress or have been minimally affected by human activities. The Suspected Change Subnetwork includes monitoring points where it is not yet clear that documented changes have occurred, but changes are suspected. The Documented Change Subnetwork will include monitoring points that provide data from aquifers that (1) are known to be heavily pumped, (2) have experienced recharge-altering land-use changes, and (3) are located in areas with managed ground-water resources (e.g., artificial recharge or enhanced storage and recovery). The Documented Change Subnetwork also will include monitoring points that are known to have degraded water quality from human activity. A subset of the trend monitoring wells within these subnetworks would be designated as the backbone wells/springs of the NGWMN. These backbone monitoring points are carefully selected core sites that would warrant full support by Federal funds. In instances where backbone sites are operated by NGWMN cooperators, Federal funding assures that data collection and delivery follow NGWMN requirements. Every consideration possible would be given to continuing the long-term record from these wells.

7.2 Incorporating Selected Wells from Existing Monitoring Programs

The NGWMN is planned as an aggregation of selected wells from multistate, State, and local ground-water monitoring networks brought together under the defining principles presented in this document. It is recognized that many wells within the various networks already in existence within the Nation can collectively produce most or all of the data required to address important questions about the availability and quality of the Nation's ground water.

7.3 Inventory of Current Monitoring

When considered together, existing Federal, State, Tribal, and other ground-water level and ground-water quality networks create a "patchwork quilt" of national ground-water monitoring. The design of these programs varies greatly among States. Some have strong ground-water level programs; some have strong ground-water quality monitoring programs. Few have both, and some have neither. Eight States have no statewide or regional intrastate ground-water level monitoring network, and 33 States have no active statewide ground-water quality network. There is a lack of written standard operating procedures for field data collection in at least 8 States with monitoring programs, and a lack of data management and storage capabilities in at least 12 States that have monitoring programs.

Water-level measurement frequencies vary significantly from a 5-year interval to real-time instrumentation. The different frequencies are a consequence, in great part, of the purpose of the individual networks. There is even less consistency in monitoring frequency among State water-quality monitoring programs. It will be a challenge to combine data from these disparate monitoring networks into a coherent national program. Some data gaps likely will result, but the amount of existing ground-water monitoring across the Nation is impressive, and with a clear sense of purpose such a network can be built.

7.4 Metrics

A large number of metrics could be developed to track the success of the NGWMN. These may include goals for participation by Federal, State, Tribal, and other organizations. The metrics could include the number of monitoring sites, length of data records at network wells, data storage, and the ability to provide the ground-water data necessary to help answer the key questions outlined in Chapter 1 of this document. The principal metrics can be summarized in three goals for the NGWMN:

1. Full participation by the principal ground-water data producers in the United States.
2. Full acceptance by these data producers of the NGWMN recommendations for data-collection techniques, data elements, and documentation of these techniques and data-storage methods.
3. Inclusion of an adequate distribution of wells and springs within the major aquifers and aquifer systems throughout the United States so meaningful interpretations can be made on the status and trends of ground-water levels and ground-water quality in these major aquifers.

A successful NGWMN is nearly assured if these three goals are met. This will enable the United States to meet the challenge for ground water cited by the Subcommittee on Water Availability and Quality to "…accurately assess the quantity and quality of its water resources..." (National Science and Technology Council, 2007). But even without fully meeting the goals, progress toward them will move the Nation closer to a fuller understanding of its ground-water resources. As the benefits of the network become apparent, additional participation is expected to be realized.

7.5 Network Products

The NGWMN is both a concept for a common monitoring approach and a mechanism for the compilation of ground-water level and ground-water quality data. The NGWMN is not designed to be an interpretive product, but rather an information tool from which coherent and systematic data can be obtained by all parties to generate myriad interpretive products at a variety of scales. Through a data portal on the Internet, the NGWMN would provide critical information necessary for the planning, management, and development of ground-water supplies to meet current and future water needs and ecosystem requirements. The information available through the NGWMN is expected to be used to assist in assessments of the quantity of U.S. ground-water resources, as constrained by ground-water quality. Interpretive products can be generated from the data provided by the NGWMN by anyone interested in ground-water resources.

The importance of the NGWMN data portal as a product should be emphasized. Many data providers do not serve their data to the public on the Internet. Some serve their data on the Internet, but the information systems and Web pages used to serve the data are not robust. The NGWMN will be constructed with a national focus, but for some data providers, the NGWMN data portal will provide a new tool for their customers to access State and local ground-water data.

7.6 Communication, Coordination, and Collaboration

The National Water Quality Monitoring Council placed great emphasis on the need for communication, coordination, and collaboration to successfully implement the National Water Quality Monitoring Network for Coastal Waters and their Tributaries work, stating that "There will need to be considerable communication, coordination, and collaboration among all members of the monitoring community to implement the Network design…" (National Water Quality Monitoring Council, 2006). Given the immense scope of the NGWMN, this concept is equally as critical.

The NGWMN should be based on a cooperative approach where Federal, regional interstate, State, Tribal, and local stakeholders can collaborate to implement ground-water monitoring programs. To be successful, all stakeholders (Federal, State, multistate, Tribal, regional cooperatives, local agencies, academic, and private sector partners) who operate monitoring networks and collect ground-water level and quality data have to be committed to the NGWMN and to their own monitoring programs by sharing data that will help serve both local needs and those of the Nation. The SOGW anticipates that a successful network will involve more than 100 data providers and stakeholders.

7.7 Recommendations for Network Management

The proposed structure of the NGWMN makes gaining and maintaining the cooperation of various entities overseeing these current networks key to successful implementation. The following are identified as necessary precursors for gaining and maintaining this cooperation and achieving an effective and efficiently operating NGWMN, as set out in this document:

- A voice in the process for stakeholders
- Incentives that recognize the contributions of data providers
- Flexibility to accommodate differences among data providers

- Clear direction, informed by stakeholder input, and authority for an entity to undertake day-to-day operations

7.7.1 Structure

A three-tiered structure (fig. 7.7.1.1) is recommended with the above precursors in mind.

1. The Subcommittee on Ground Water should continue with its current structure of public and private sector data providers and data users. The SOGW would undertake activities, such as
   - Interface with the Advisory Committee on Water Information, share information regarding NGWMN goals, achievements, and hurdles as well as identifying areas for potential cooperation and collaboration with other ACWI efforts;
   - Provide advice to the NGWMN on Federal issues and suggest directions and priorities for the NGWMN;
   - Assist in program evaluation and provide feedback to the NGWMN; and
   - Assist in program startup and outreach.
2. A Program Board or Boards should be established. The Program Board would be composed of NGWMN data providers. Because of the potential for a large number of stakeholders nationally, a two-tiered system of national and regional boards may be necessary to adequately solicit input at every level. The Program Board(s) would undertake activities, such as
   - Provide input regarding the program's scope, priorities, and overall direction;
   - Assist in the evaluation of funding proposals; and
   - Undertake outreach and communication with current and potential data providers on national issues.
3. An agency should be named to provide day-to-day management of the NGWMN as well as provide guidance to NGWMN data providers. The SOGW recommends, based on experience and mission, that the USGS be considered for this role and that within the USGS a distinct Management and Operations Group be created to
   - Implement the startup of the program, including developing a solicitation for participation and organizing stakeholders;
   - Coordinate and consult with the Program Board(s) and the SOGW;
   - Create and manage the data portal;
   - Evaluate and recommend new technologies;
   - Provide program guidance and technical advice to stakeholders;
   - Identify funding priorities, administer funding programs, and coordinate with other funding sources;
   - Disseminate data and interpretive reports as needed in an open and flexible system;
   - Assist in developing report findings, answering basic questions, promoting the program with relevant and timely technical results; and
   - Ensure that data at backbone sites are collected by allocating Federal funds if available or coordinating with other agencies to allocate Federal funds through a portfolio of funding options.

7.7.2 Funding Models

The SOGW recommends a portfolio of funding models in order to create the necessary incentives to achieve nationwide coverage in a cost-efficient manner that builds on existing efforts and leverages Federal and cooperator resources (table 7.7.2.1). The models are not exclusive of one another.

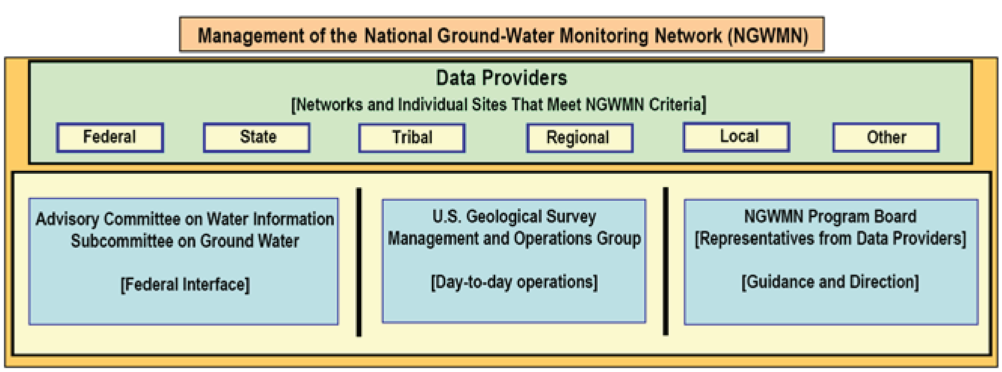

Figure 7.7.1.1 Management structure of the proposed National Ground-Water Monitoring Network.

Table 7.7.2.1 Critical cooperative agreement factors and National Ground-Water Monitoring Network funding/data gathering applicability.

Funding/data-gathering model	Data collection, storage, and transfer	Work assignment, funding flow, and cooperator support	Long-term, not issue-driven, monitoring	NGWMN applicability
Federal Programs	USGS personnel collect and manage NGWMN data. If other Federal agencies have data-collection and management capability, agreements address how these data are transferred to or accessed by USGS or NGWMN data systems.	USGS bears costs for monitoring backbone network wells. If USGS provides data-collection services to the other agency in conjunction with NGWMN monitoring, cost sharing offsets some of the cost. If another Federal agency collects data for NGWMN and their own use, that agency absorbs the monitoring cost.	Long-term monitoring could be an issue if a cooperator does not have a monitoring mission strongly aligned with the objectives of the NGWMN.	Backbone sites would be a key component of the network. Collaboration among agencies is most necessary where access to monitoring sites on Federal lands or at Federal facilities may be restricted such as military reservations or national parks.
USGS Cooperative Water Program (CWP)	Data are collected by USGS employees or cooperator staff but are managed within NWIS. If cooperators use CWP data for non-CWP purposes, the data must be retrieved from NWIS and integrated with non-CWP data.	Monitoring costs are shared between the cooperator and the USGS. Total project cost includes State share, Federal share, and Federal administrative charges. For projects where USGS personnel do the work, non-Federal funds are paid to the USGS. For projects where work is shared, the cooperator may provide in-kind services in lieu of funds.	CWP requires funds from the Federal and non-Federal partners. Project development is driven by the non-Federal agency and those interests may change, depending on local issues. Successful use of CWP for NGWMN requires non-Federal cooperators to dedicate funds to long-term ground-water monitoring.	CWP is most applicable for State agencies, Tribal governments, municipalities, and local governments that need long-term data, but do not choose to collect them. Federal CWP resource allocations depend on CWP funding and non-Federal interest and resources dedicated to long-term monitoring.
Modified STATEMAP	Data are collected by cooperators and are managed with provisions to either be transferred to the USGS management and operations group or be accessible to NGWMN. Data are available at the cooperator level without the need for retrieval from other data systems such as NWIS.	Data are collected by the cooperators. Funds for NGWMN data collection are from the USGS to the cooperator but require a 50-percent match by non-Federal funds. The cooperator share represents the value of the data to the cooperator.	Cooperators must have an aligned mission to collect ground-water data similar to that of NGWMN and the dedicated long-term funding to support the data collection.	Best application is with State agencies, Tribal governments, municipalities, and local governments that have the capability to collect and manage long-term data. Cooperators with long-term monitoring missions similar to that of the NGWMN are most desirable.
USEPA grants supporting monitoring	Data are collected by cooperators and are managed with provisions to either be transferred to the USEPA Water Quality Exchange, the USGS NWIS or otherwise be accessible to NGWMN. Data are available at the cooperator level without the need for retrieval from other data systems such as NWIS.	Data are collected by cooperators. Funds for data collection contributing to the NGWMN are from the USEPA to designated agency(s) or to cooperators through State-level direct grants. Matching funds are required at the cooperator level as defined by USEPA. State-level grants for this monitoring would create another forum where decisions about NGWMN are made.	Cooperators must have an aligned mission to collect ground-water data similar to that of NGWMN, reflecting a priority for ground-water monitoring recognized by the State cooperator agency.	USEPA-funded cooperator agency and USGS management and operations group cooperation at the agency level is essential to coordinate effort. Historically, these funds have been exclusive to water-quality monitoring.

The models provide the flexibility to tailor potential funding to the interests, capability, and long-term monitoring missions of potential NGWMN cooperators. The SOGW recognizes that all funding/data gathering models are affected by variability in Federal and non-Federal funding.

1. Various **Federal Programs** and **Federal-to-Federal collaboration** can provide for direct Federal monitoring of backbone network sites, such as those in the USGS Climate Response Network or NAWQA water-quality monitoring, or for monitoring sites at locations with restricted access, such as in national parks or military installations.

2. **USGS Cooperative Water Program** agreements are appropriate for cooperators that have funding for long-term monitoring but lack the technical expertise or personnel to collect the data.

3. A **modified STATEMAP/NGWMN** funding model is appropriate for cooperators who have no operating network or an existing long-term ground-water monitoring network but need to build or enhance their infrastructure, instrumentation, frequency of data collection, the technical expertise and personnel to successfully collect the data, and long-term ground-water monitoring funding, and who have a mission closely aligned with that of the NGWMN.

4. **USEPA funding** for NGWMN has great potential to add data-collection sites, enhance infrastructure, and provide for more frequent measurement and instrumentation. The USEPA and the USGS must coordinate closely at the agency level, however, so that duplication of effort is minimized.

7.8 Summary of Incremental Costs for State Participation in National Ground-Water Monitoring Network

In 2010 and 2011, six States participated in five pilot projects to test the NGWMN and provide guidance for full implementation. The results of these studies were documented in reports for each project: Illinois-Indiana (Wehrmann and others, 2011), Minnesota (MacDonald and Kroening, 2011), Montana (Patton and Buckley, 2011), New Jersey (Domber and others, 2011), and Texas (Hopkins and others, 2011), and the projects were documented in a summary report (Subcommittee on Ground Water, 2011). The pilot projects developed costs for the incremental activities in which they would need to engage to be part of the NGWMN based on the Framework Document of 2009 (Subcommittee on Ground Water, 2011). These costs occurred in the following monitoring categories: initial organization/participation, new additional wells, well-network installation and maintenance, field practices, data management, and monitoring program implementation. These costs also include one-time (program startup) expenses, capital costs, and operation and maintenance costs. Tables 7.8.4.1 and 7.8.4.2 provide details of costs, which are summarized in the sections below. Because the number of wells significantly affects the incremental costs, some costs vary widely from State to State, ranging from no additional wells to 245 new wells proposed.

Table 7.8.4.1 Summary of incremental State pilot project costs to participate in the National Ground-Water Monitoring Network.

Incremental Cost to Address Framework Gap

	One-Time and Capital Costs						
	IL/IN	TX	NJ	MT	MN	TOTAL	AVERAGE
State Initial Participation	$32,500	$36,275	$38,000	$35,059	$27,000	$168,834	$33,767
Monitoring Network	200,600	131,950	1,515,900	1,604,000	3,525,000	6,977,450	1,395,490
Field Practices	0	0	0	0	17,500	17,500	3,500
Data Management	13,100	21,800	121,000	5,000	17,500	178,400	35,680
Monitoring Program	0	0	0	0	15,000	15,000	3,000
Baseline Process	0	0	0	552,750	0	552,750	110,550
Total One-Time and Capital Costs	246,200	190,025	1,674,900	2,196,809	3,602,000	7,909,934	1,581,987
Operation and Maintenance Costs							
	IL/IN	TX	NJ	MT	MN	TOTAL	AVERAGE
Monitoring Network	$33,715	$0	$1,116,500	$160,230	$13,500	$1,323,945	$264,789
Field Practices	0	100	32,900	0	0	33,000	6,600
Data Management	34,000	21,800	121,000	0	0	176,800	35,360
Monitoring Program	0	83,625	3,648,700	147,300	123,100	4,002,725	800,545
Total Annual Operation and Maintenance Costs	67,715	105,525	4,919,100	307,530	136,600	5,536,470	1,107,294

Incremental Cost of Using Existing Wells Only Under Framework

	One-Time and Capital Costs						
	IL/IN	TX	NJ	MT	MN	TOTAL	AVERAGE
State Initial Participation	$32,500	$36,275	$38,000	$35,059	$27,000	$168,834	$33,767
Monitoring Network	66,000	131,950	--	--	--	197,950	39,590
Field Practices	--	--	--	--	17,500	17,500	3,500
Data Management	13,100	21,800	121,000	317,600	17,500	491,000	98,200
Monitoring Program	--	--	--	--	--	--	--
Total One-Time and Capital Costs	111,600	190,025	159,000	352,659	62,000	875,284	175,057
Operation and Maintenance Costs							
Monitoring Network	--	--	--	$160,170	$13,500	$173,670	$34,734
Field Practices	--	$100	$32,900	--	--	33,000	6,600
Data Management	--	--	--	--	--	0	0
Monitoring Program	--	83,625	1,313,400	147,300	123,100	1,667,425	333,485
Total Annual Operation and Maintenance Costs	$0	83,725	1,346,300	307,470	136,600	1,874,095	374,819

Capital and one-time costs: Primarily some limited well logging and instrumentation, modification of field practices and data standards, and data-collection automation.

Incremental annual operation and maintenance costs: Changes in field practices for levels and quality measurement, data transmission to a national portal, and increasing frequency of monitoring.

Note: Objective of coverage in spatially underrepresented aquifers would not be addressed from perspective of State pilot projects if using only existing wells.

Table 7.8.4.2 Incremental per-well costs of State pilot projects to participate in the National Ground-Water Monitoring Network and fill gaps identified.

Incremental and Per Well Costs to Address Framework Gap

	One-Time and Capital Costs							
	IL/IN	TX	NJ	MT	MN	TOTAL	AVERAGE	RANGE *MEDIAN*
New Well Capital Costs	$134,600	$0	$1,515,000	$1,604,000	$3,525,000	$6,779,500	$1,355,900	$0–$3,525,000 *$1,515,000*
Number of New Wells	13	0	168	245	136	496	NA	NA *NA*
Average Per New Well Cost	$10,354	$0	$9,018	$6,547	$25,919	NA	$13,668	$0–$25,919 *$9,018*
Other One-Time and Capital Costs	$111,600	$190,025	$159,000	$40,059*	$77,000	$1,130,434	$226,087	$40,059–$190,025 *$111,600*
Number of Total NGWMN Wells	51	1,246	1,142	516	225	3,180	NA	NA *NA*
Average Per-Well Cost	$2,188	$153	$139	$78	$342	NA	$314	$78–$2,188 *$153*
Operation and Maintenance Costs								
Total Annual Operation and Maintenance Costs	$67,715	$105,525	$4,919,100	$307,530	$136,600	$5,536,470	$1,107,294	$67,715–$4,919,100 *$136,600*
Annual Operation and Maintenance Costs Per Total Wells	$1,328	$85	$4,307	$596	$607	NA	$1,741	$85–$4,307 *$607*

Note: "NA" means not applicable.

*Excludes Baseline Process Costs of $552,750.

Table 7.8.4.2 Incremental per-well costs of State pilot projects to participate in the National Ground-Water Monitoring Network and fill gaps identified.—Continued

Incremental and Per Well Cost of Using Existing Wells Only Under Framework

	One-Time and Capital Costs							
	IL/IN	TX	NJ	MT	MN	TOTAL	AVERAGE	RANGE *MEDIAN*
Total One-Time and Capital Costs	$111,600(a)	$190,025(b)	$159,000(c)	$352,659(d)	$62,000(e)	$875,284	$175,057	$62,000–$352,659 *$159,000*
Number of Existing Wells	38	1,246	1,124	271	89	2,768	NA	NA *NA*
Average Cost Per Existing Well	$2,937	$153	$141	$1,301	$697	NA	$316	$153–$2,937 *$697*
	Operation and Maintenance Costs							
Total Annual Operation and Maintenance Costs	$0	$83,725	$1,346,300	$307,470	$136,600	$1,874,095	$374,819	$0–$1,346,300 *$136,000*
Annual Operation and Maintenance Costs Per Existing Well	$0	$67	$1,198	$1,135	$1,535	NA	$677	$0–$1,535 *$1,135*

Notes:

"NA" means not applicable.

(a) Mainly for telemetry and data logging equipment at existing wells.

(b) Mainly for videoing boreholes that lack completion data.

(c) Mainly for one-time logging and data entry for existing wells.

(d) Mainly for one-time baseline water-quality sampling/testing and logging equipment.

(e) Mainly to update field practices and data management.

Incremental and Per Well Cost of Data Management Using Existing Wells Only

	One-Time Costs by State						
	IL/IN	TX	NJ	MT	MN	TOTAL	AVERAGE
Data Management One-Time Costs	$6,200	$20,000	$0	$3,400	$17,500	$47,100	$9,420
Number of Existing Wells	38	1,246	1,124	271	89	2,768	NA
Average Cost Per Existing Well	$163	$16	$0	$13	$197	NA	$17
	Operation and Maintenance Costs by State						
Annual Operation and Maintenance Costs	$0	$0	$0	$0	$0	$0	$0
Annual Operation and Maintenance Costs Per Existing Well	$0	$0	$0	$0	$0	NA	$0

Note: "NA" means not applicable.

7.8.1 State Participation – One-Time Costs

State monitoring program costs to participate in the proposed NGWMN were fairly consistent from State to State. These costs are primarily for staff time to understand the NGWMN Framework, consult internally and with the Subcommittee on Ground Water, analyze their monitoring networks relative to the Framework, identify wells for the State's portion of a proposed NGWMN, evaluate field practices and data management to determine their consistency with the Framework, and write a report identifying their proposed portion of a national network, any monitoring program gaps, and the associated costs to be equivalent to the proposed Framework, as well as propose potential changes to the Framework. The costs ranged from $27,000 (Minnesota) to $38,000 (New Jersey) and averaged $33,767.

7.8.2 State Incremental Framework Costs

States evaluated their monitoring programs and networks to determine what the costs would be to meet the specifications of the NGWMN Framework in four principal areas: (1) well network, (2) field practices, (3) data management, and (4) monitoring program. Each area may have incremental Framework ("gap") costs that are one-time ("startup" or "front-end") expenses, capital expenditures, and annual operation and maintenance outlays.

Monitoring Network. The monitoring-well installation and instrumentation incremental costs across the five State pilot projects averaged $1,395,490, primarily to install monitoring wells in areas not adequately represented by the current State networks. Notably, three State pilot projects focused on the network for the entire State area, and two focused on an individual aquifer or a metropolitan area. For the three States that examined the networks for the entire geographic State area, the average well-installation and instrumentation incremental costs were $1,183,950.

The capital costs for the new wells by themselves averaged $1,355,900 per State, with an average per-well cost of $13,668.

The average incremental operation and maintenance cost for the wells in the monitoring network was $264,789 per State.

Field Practices. Examples of costs include: updating field manuals and additional field time. Relative to field practices operation and maintenance costs, Texas proposed $100/year for measuring tape cleaning, and New Jersey identified $32,900 for modified levels measurement and well sampling preparation. One-time costs for field practices averaged $3,500 per State. Operation and maintenance costs for carrying out the field practices averaged $6,600 per State.

Data Management. One-time data-management costs include modifying data standards, automating data collection, and establishing Web services to deliver data to the portal. The total cost was $178,400 for five State pilot projects, with an average cost of $35,680.

Monitoring Program. States will need to increase monitoring for levels and (or) quality at greater frequencies. Incremental operation and maintenance costs for more frequent monitoring averaged $800,545. The cost was elevated because New Jersey proposed a large number of additional wells for its portion of the network; without New Jersey the average cost for increasing monitoring frequency across the four other State pilots is $71,263.

Cross-State Program Costs. Combined, the one-time and capital costs for the five State pilot projects are $7,909,934 and $4,061,734 for the three States, which included the entire State areas or an average of $1,353,911 across the three States. The incremental operation and maintenance costs for the five State pilots are $5,536,470 and for the three States reporting on entire State networks is $5,332,155 or an average of $1,777,385 per State.

Per-Well Costs. Factoring out new well capital costs and only considering other one-time and capital items, the average per-well capital cost was $314 with a median per well capital cost of $153. Annual operation and maintenance costs per well were $1,741 with a range of $85 to $4,307 and a median of $607.

7.8.3 Cost of Using Existing Wells Only

If the NGWMN relied only on existing wells, the incremental costs of well installation and maintenance and associated monitoring, including the one-time baseline process, would not be considered. In this case, the incremental cost of the NGWMN would be significantly different. The capital and one-time costs would include some limited well logging, modification of data standards, and automation of data collection with an average cost of $175,057 for the five State pilot projects and a per-well cost of $316. Incremental annual operation and maintenance costs would include changes in field practices for levels and quality measurement, data transmission to a national portal, and an increase in the frequency of monitoring, averaging $374,819 for the five State pilot projects with a per-well cost of $677.

7.8.4 Cost of Data Management Only

If the cost of accepting data for existing wells for an initial NGWMN startup were considered, the average incremental one-time data management cost was $9,420 per State—primarily to adjust data systems to report to the national portal—with a per-well cost of $17. The incremental annual operation and maintenance cost per well was $0.

7.9 Recommendations and Next Steps

Water is needed for a growing U.S. population, and ground-water use is increasing. Ground-water level declines have been documented in nearly every area of the Nation. Ground-water quality deterioration is apparent in some regional interstate aquifers. Despite the fact that ground-water level monitoring is done in many places at many scales, a comprehensive repository of ground-water level monitoring data does not exist. The concept of a National Ground-Water Monitoring Network is not new. Past efforts have cited valid justification for such a network, and the reasons for such a network have not diminished over time but in fact have increased in importance. Increasing water demands, climate change, and energy development and their associated effects underscore the need for a network. Past efforts have been hamstrung by the difficulty in combining data from many networks into one data system. The need for a NGWMN has not diminished.

Increased use of computer data systems and development of Internet technologies have made it much easier to combine data from myriad sources. Major steps already have been achieved with recent links between water-quality data in the USGS and USEPA databases. Although there is a "patchwork quilt" of networks across the Nation, it is clear that computer systems have progressed to the point where most data producers are storing information in computer databases, and many serve those data to the public by way of the Internet. These data systems typically can be configured in such a way to document the source of the data and the methods used to collect those data. The feasibility of Internet portal systems for data distribution has been documented commercially by systems such as travel Web sites and environmentally by systems like the CUAHSI Hydrologic Information System. Portal systems may obviate the need for centralized data systems. Data can be maintained where it should be—by the data producer. With the cooperation of data producers, a portal system can be used to obtain the necessary data at the State, regional, interstate, and national scale.

The SOGW recommends that the ACWI pursue a National Ground-Water Monitoring Network through the use of a national data portal. Several steps are necessary to establish such a network:

1. The Subcommittee on Ground Water should continue with its current structure of public and private sector data providers and data users.

2. A National Program Board, possibly supported by Regional Program Boards, composed of NGWMN data providers should be established.

3. An agency should be named to provide day-to-day management of the NGWMN as well as provide guidance to NGWMN data providers. The SOGW recommends, based on experience and mission, that the USGS be considered for this role and that a distinct management and operations group be created within the USGS. The ACWI should provide this recommendation to the Department of Interior for their appropriate action.

4. The management and operations group should begin dialog with data producers to evaluate existing well networks, the coverage of major aquifers, and the addition of the appropriate wells into the NGWMN.

5. Protocols for site selection for the NGWMN should be developed, and gaps in the network should be identified.

6. The preliminary Internet portal system used for the Pilot Studies should be developed into a full production level data portal that can handle all the data for the Nation.

7. The NGWMN cannot be completed without Federal funds to support it. The ACWI should facilitate the Federal funding opportunities outlined in this chapter. Federal funding sources would assure participation by data providers, operation of backbone wells/springs, management and operation of the network, and development and operation of a data portal.

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Appendix 1. Report Contributors

More than 70 individuals representing the private sector and 54 different organizations, including nongovernmental organizations, State and local agencies, Federal agencies, and academia, worked together through the SOGW to discuss ground-water monitoring needs at the national scale and develop the national framework for ground-water monitoring that is described in this document. The following table lists the individuals and organizations instrumental in the discussion and drafting process of this report.

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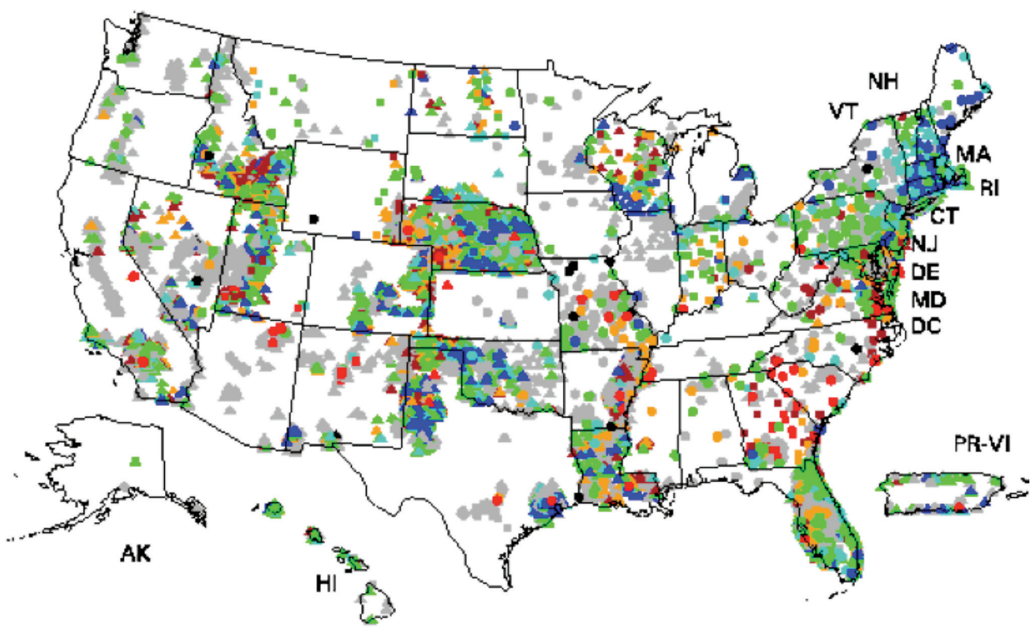
James R. Weise	State of Alaska, Department of Environmental Conservation
Jason R. House, C.G., P.G.	Woodard & Curran, Inc.
Jay Silvanima	Florida Department of Environmental Protection
Jeffrey Farrar	ASTM - c/o Bureau of Reclamation
Jennifer Steadman Ryan	Sarasota County Government
John Jansen, Ph.D.	National Ground Water Association
Jon Duncan	CUAHSI
Joseph Gurrier	USDA Forest Service
Joyce Harris	Illinois State University
Kathleen Stanley	Water Systems Council
Kelly Warner	U.S. Geological Survey
Kevin D. Frederick, P.G.	Wyoming Department of Environmental Quality
Lisa Corbitt	Mecklenburg County
Lori Huntoon	ASTM
Lorne G. Everett, PhD, D.Sc.	Haley & Aldrich
Luke J. Buckley	Montana Bureau of Mines and Geology
Mac McKee	Utah Water Research Laboratory
Mary Ambrose Musick	Musick Groundwater Consulting
Michael C. Alfieri, P.G., P.Hg., CGWP	SDII Global Corporation
Michael Houts	State of Oklahoma Dept. of Environmental Quality/ ASWIPCA - Ground Water Task Force chair (Retired)
Michael Napolitan	Taylor GeoServices
Michael P. Nickolaus	Ground Water Protection Council
Mike Paque CAE	Ground Water Protection Council
Mike Wireman	U.S. EPA
Molly Bayer	U.S. EPA
Patrick M. Reed	The Pennsylvania State University
Paul Gruber	Independent Consultant
Paul Jehn, Technical Director	The Ground Water Protection Council
Paul Summers	Bureau of Land Management
Ralph J. Haefner	U.S. Geological Survey, Ohio Water Science Center
Rhonda Artho	North Plains Groundwater Conservation District
Rick Copeland	Florida Geological Survey/Florida Department of Environmental Protection
Rick Johnson	CDM
Robert J. Sterrett	HCItasca Denver, Inc.
Robert Morgan	ASTM
Robert P. Schreiber, P.E., D.WRE, BCEE	CDM
Robert Schweinfurth	Water Environment Federation
Rodney A. Sheets	U.S. Geological Survey, Eastern Region Science Office
Stephen Fisher	Kentucky Geological Survey
Steve Wilson	Illinois State Water Survey
Susan Seacrest	Groundwater Foundation (Retired)
Thomas P. Van Biersel	Louisiana Geological Survey - Louisiana State University
Thomas W. Patton, Senior Research Hydrogeologist/ Program Leader	Montana Ground-Water Assessment
Timothy K. Parker, PG, CEG, CHG	Schlumberger Water Services
Tom Allen	Ohio EPA
Tom Tomastik, Geologist	The Ohio Department of Natural Resources, Division of Mineral Resources Management
Walter D. Wood, PG	Lake County BCC, Division of Water Quality Services, Tavares, Florida
Wayne Lapham	U.S. Geological Survey
William L. Cunningham	U.S. Geological Survey

Appendix 2. Summary of Statewide Ground-Water Level Monitoring and Sampling Programs in the United States

Additional details on the status of ground-water monitoring activities in the United States are provided in this appendix. Sections 2-2.1 and 2-2.2 present a State-by-State summary of the total number of wells for which ground-water level measurements were made and ground-water quality samples were collected by the U.S. Geological Survey (USGS) or cooperators, stored in the USGS database, and made available on the Internet. Sections 2-2.3 and 2-2.4 present a summary of the water-level and water-quality results from the State/Regional Ground-Water Monitoring Networks Report (Association of American State Geologists, the Ground Water Protection Council, the Interstate Council on Water Policy, and the National Ground Water Association, 2007). Section 2-2.5 provides a copy of the initial report from the Association of American State Geologists, the Ground Water Protection Council, the Interstate Council on Water Policy, and the National Ground Water Association, including the survey questions.

2-2.1 Water-Level Data Collected by the U.S. Geological Survey and Cooperators in 2008

The USGS monitors ground-water levels primarily through agreements with State and local cooperators as part of the USGS Cooperative Water Program, and secondarily through Federal programs like the Ground-Water Resources Program and the National Water-Quality Assessment Program. Water levels from about 800,000 wells are stored in the USGS database. Locations of wells with water levels measured in 2008 by the USGS and cooperators are shown in figure 2-2.1.1, and listed by State in table 2-2.1.1.



EXPLANATION

Percentile classes—Symbol color based on most recent measurement								
Low	<10 Much below normal	10 to 24 Below normal	25 to 75 Normal	76 to 90 Above normal	>90 Much above normal	High	Not ranked	○ Real time □ Continuous △ Periodic measurements

Figure 2-2.1.1 Locations of wells with water levels measured in 2008 by the U.S. Geological Survey and cooperators.

Table 2-2.1.1 Wells with water levels measured in 2008 by the U.S. Geological Survey and cooperators, entered into the National Water Information System database, and made available on the Internet.

State	Total wells	Total wells with at least 5 years of measurements	Wells measured once per year	Wells measured four times per year	Wells measured monthly	Wells measured daily	Real time wells
Alabama	27	4	17	0	0	10	10
Alaska	15	15	2	10	0	3	1
Arizona	279	141	102	35	0	49	15
Arkansas	751	343	673	36	4	20	19
California	2,151	1,344	1,270	354	54	182	90
Colorado	1,046	871	656	126	67	1	1
Connecticut	75	74	59	2	0	4	4
Delaware	39	31	34	4	0	1	1
District of Columbia	31	25	1	22	0	5	0
Florida	1,595	462	2	0	0	524	205
Georgia	665	231	450	19	0	190	29
Hawaii	60	13	0	1	0	15	4
Idaho	1,734	746	418	405	16	16	4
Illinois	89	21	74	7	0	3	1
Indiana	213	130	88	1	0	34	6
Iowa	15	6	7	1	2	5	5
Kansas	399	378	2	337	0	32	24
Kentucky	65	53	2	33	0	30	1
Louisiana	383	303	82	264	0	9	9
Maine	25	19	0	0	0	25	24
Maryland	613	525	345	51	81	10	9
Massachusetts	178	147	114	8	16	16	14
Michigan	184	122	80	30	0	40	2
Minnesota	102	11	69	0	0	32	23
Mississippi	53	36	22	9	9	5	4
Missouri	166	85	26	0	0	138	138
Montana	44	42	3	18	4	17	2
Nebraska	4,373	4,071	3,436	43	51	44	24
Nevada	651	541	329	185	6	11	11
New Hampshire	26	26	24	0	0	2	2
New Jersey	300	162	37	19	0	184	20
New Mexico	991	522	495	178	12	97	0
New York	711	75	13	8	1	123	74
North Carolina	201	175	55	45	30	68	64
North Dakota	53	52	6	40	0	3	3
Ohio	107	55	54	33	0	20	12
Oklahoma	489	123	482	0	0	7	7
Oregon	220	188	62	82	0	17	4
Pennsylvania	197	137	78	9	31	77	69
Puerto Rico	136	52	44	16	16	54	2
Rhode Island	38	36	19	0	11	6	5

Table 2-2.1.1 Wells with water levels measured in 2008 by the U.S. Geological Survey and cooperators, entered into the National Water Information System database, and made available on the Internet.—Continued

State	Total wells	Total wells with at least 5 years of measurements	Wells measured once per year	Wells measured four times per year	Wells measured monthly	Wells measured daily	Real time wells
South Carolina	85	16	33	1	0	21	21
South Dakota	139	134	120	3	1	12	12
Tennessee	89	69	43	7	0	35	22
Texas	2,868	2,194	2,647	8	17	36	24
Utah	849	680	752	27	0	39	1
Vermont	13	13	13	0	0	0	0
Virginia	450	341	41	287	0	99	81
Washington	426	304	96	147	98	1	1
West Virginia	30	7	18	0	0	12	12
Wisconsin	157	95	88	22	11	33	3
Wyoming	66	61	21	0	0	44	2
Total	**24,662**	**16,307**	**13,604**	**2,933**	**538**	**2,461**	**1,121**

2-2.2 Water-Quality Data Collected by the U.S. Geological Survey and Cooperators in 2006–2007

The USGS monitors ground-water quality primarily through agreements with State and local cooperators as part of the USGS Cooperative Water Program as well as the USGS National Water-Quality Assessment Program. Table 2-2.2.1 lists the number of wells and springs, by State, for which water-quality samples were analyzed in water year[1] 2006 by the USGS and cooperators.

[1]Water year is the period October 1 to September 30 and is designated by the year in which the period ends. For example, water year 2006 is October 1, 2005, to September 30, 2006.

Table 2-2.2.1 Wells and springs for which water-quality samples were analyzed in water year 2006 by the USGS and cooperators, entered into the National Water Information System database, and made available on the Internet.

	Ground water		Springs	
	Wells Sampled	Continuous Monitors	Sampled	Continuous Monitors
Alabama	16	0		
Alaska	0	1		
Arizona	79	0	34	0
Arkansas	82	11	1	10
California	833	3	24	3
Colorado	75	2	1	0
Florida	408	9	17	7
Georgia	21	0		
Hawaii	7	0	12	0
Idaho	612	0	3	0
Illinois	2	0		
Indiana	20	0	9	0
Iowa	160	10	1	0
Kansas	191	18		
Kentucky	1	10	5	2
Louisiana	109	5		
Maryland+Delaware+DC	78	6		
Michigan	2	0		
Minnesota	102	28		
Mississippi	57	11		
Missouri	64	0	12	2
Montana	14	0	23	0
North Carolina	51	3		
North Dakota	60	0		
Nebraska	124	23		
Nevada	89	4	31	0
New England	380	16		
New Jersey	91	0	1	0
New Mexico	156	3	8	0
New York	285	45	2	0
Ohio	29	0		
Oklahoma	15	0	1	0
Oregon	27	9	1	0

Table 2-2.2.1 Wells and springs for which water-quality samples were analyzed in water year 2006 by the USGS and cooperators, entered into the National Water Information System database, and made available on the Internet.—Continued

	Ground water		Springs	
	Wells Sampled	Continuous Monitors	Sampled	Continuous Monitors
Pennsylvania	245	0	10	0
Puerto Rico	0	0		
South Carolina	62	1		
South Dakota	75	0	2	0
Tennessee	13	1	5	0
Texas	173	4	19	3
Utah	169	0	10	0
Virginia	18	0		
Washington	76	0		
West Virginia	35	0		0
Wisconsin	120	0		
Wyoming	11	0	1	0
Total	**5,237**	**223**	**233**	**27**

2-2.3 Summary of Water-Level Information in the State/Regional Ground-Water Monitoring Networks Report

The following information on water-level monitoring is summarized from the report "State/Regional Ground Water Monitoring Networks – Results of 2007 Survey" (Association of American State Geologists and others, 2007).

Program Management

The ground-water networks are intended to provide specific management information, and the top six management issues and the number of responses identified were:

- trends in ground-water levels over time 40 of 40
- current unstressed ground-water condition 38 of 40
- changes in ground-water levels over time 32 of 40
- effects of drought and climate change 29 of 40
- effects of over pumping of aquifers 27 of 40
- effectiveness of ground-water management programs 19 of 40

The existing networks could be used to answer the following issues. The top 6 of 10 responses are shown below. Note that the issues are the same identified above but are arranged in a different order.

- current unstressed ground-water condition 7 of 40
- trends in ground-water level over time 6 of 40
- effects of drought and climate change 5 of 40
- changes in ground-water levels over time 5 of 40
- effects of over pumping of aquifers 9 of 41
- effectiveness of ground-water management programs 7 of 41

The 40 responders identified 11 State/regional and Federal agencies that either manage or share management responsibilities with other agencies. Eight State agencies and three Federal agencies are involved, with the USGS participating in many of the management groups. The USGS involvement probably is substantial because it partners with many State, County, and local agencies through the USGS Cooperative Water Program (CWP).

• U.S. Geological Survey	13 of 40
• State Geological Survey	10 of 40
• Department of Natural Resources	8 of 40
• Department of Water Resources	6 of 40
• Department of Environmental Protection/ Environmental Quality	4 of 40
• State Engineers Office	4 of 40
• Regional Government Agency	3 of 41
• State Department of Agriculture	2 of 41
• Others (Department of Environment and Natural Resources, Natural Resource Conservation Service, Texas Water Conservation Board)	3 of 40

State/regional ground-water level networks are funded primarily by State, County, and local agencies. The 40 responses indicated funding as follows:

• mostly State, County, and local (27 States)	29 of 40
• about 50/50 Federal/State, County, and local	7 of 40
• other (mixtures of Federal/State, County, and local)	8 of 40
• mostly Federal funds	2 of 40

The responses indicate that over half (at least 22) of the responding agencies have Cooperative Programs with the USGS for ground-water level monitoring activities. Fourteen indicate that the USGS participates in the management of water-level monitoring. Two State/Regional efforts are mostly supported by Federal funds, and seven have approximately 50 percent support.

Program Design

Network designs are based mainly on aquifers, political subdivisions, and physiography or some combination of the three. Twenty-two States/regions use a single criterion—16 are based on aquifers, 2 on political subdivisions, 1 on watersheds, 1 on climate response, 1 on soil types, and 1 on particular units in the State. Twenty-two States use multiple criteria. Table 2-2.3.1 illustrates the variety of considerations used to design the networks of 19 selected States.

Wells and other observation points are used for determining ground-water levels. Dedicated monitoring wells are used by 38 of the 40 networks to measure ground-water levels (figure 2-2.3.1). Ten States use dedicated monitoring wells exclusively (Delaware, Florida, Indiana, Massachusetts, Missouri, Nebraska, New Jersey, New York, Rhode Island, and South Carolina). It is likely that most of the wells are inherited rather than drilled specifically for water-level measurements. Non-well observation points are used in addition to wells, for example, stream base-flow measurements and springs. The agencies operating the networks are very inventive in assembling various combinations of wells and observation points for their networks as 24 combinations were reported. The combinations vary from two to six combinations of wells and observation points per network, with the most "popular" being the combination of dedicated-domestic-irrigation-public water-supply wells that is used by Georgia, Louisiana, Mississippi, and Wyoming. Oklahoma and Texas do not use any dedicated ground-water level monitoring wells.

Table 2-2.3.1 Multiple criteria used for network design by States/regions.

Criteria used	State/region
Aquifer-physiography	Minnesota, Massachusetts
Aquifer-watershed	Florida, Colorado, New Jersey, Indiana
Aquifer-political subdivision	Virginia, Wisconsin
Aquifer-watershed-physiography	New York, Massachusetts, Washington
Aquifer-political subdivision-pumpage	Texas
Aquifer-watershed-physiography-political subdivision	Delaware, California
Physiography-designated ground-water basin	Arizona
Physiography-watershed-political subdivision	New York
Other	Wyoming, Oregon, Rhode Island

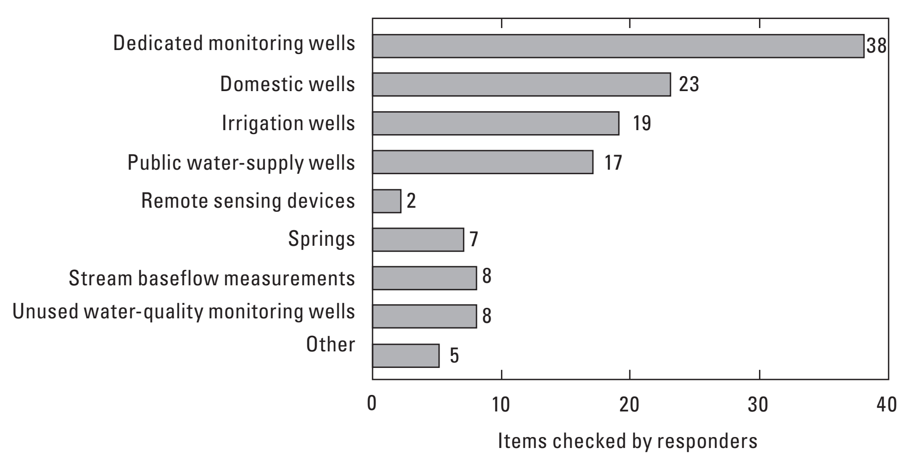


Figure 2-2.3.1 Ground-water level observation points used by statewide/regional networks.

Water-Level Measurement Frequencies

Responders from 40 States and the USGS reported data on 44 networks about the frequencies that ground-water levels are measured (section 2-2.5). The responses include both statewide and regional networks. The data summarized include two State networks in Delaware and both statewide and regional networks in Florida and Ohio. Also included are five States—Connecticut, Indiana, Iowa, Pennsylvania, and Utah—in which the USGS manages and operates statewide networks. States reporting neither a statewide nor a regional network, however, may have a significant number of ground-water level wells operated by the USGS, including New Mexico (38 wells), Tennessee (115 wells), Kentucky (81 wells), Maine (38 wells), and Alaska (24 wells).

Frequency of measurement data was tabulated in the following categories: annual only, semiannual only, quarterly only, monthly only, weekly only, daily only, and real time. Some States focused on annual and semiannual measurements (e.g., Kansas, Maryland, Mississippi, Nebraska, Nevada, and Texas). Others preferred quarterly (Louisiana, Montana, North Carolina, and Virginia) or monthly (Massachusetts, North Dakota, and South Dakota) measurements. Daily and real time are a focus of Florida, New Jersey, Ohio, and Wyoming. Figure 2-2.3.2 illustrates the number of wells in statewide/regional networks measured at least annually. The wells in most networks have a minimum of 5 years of data.

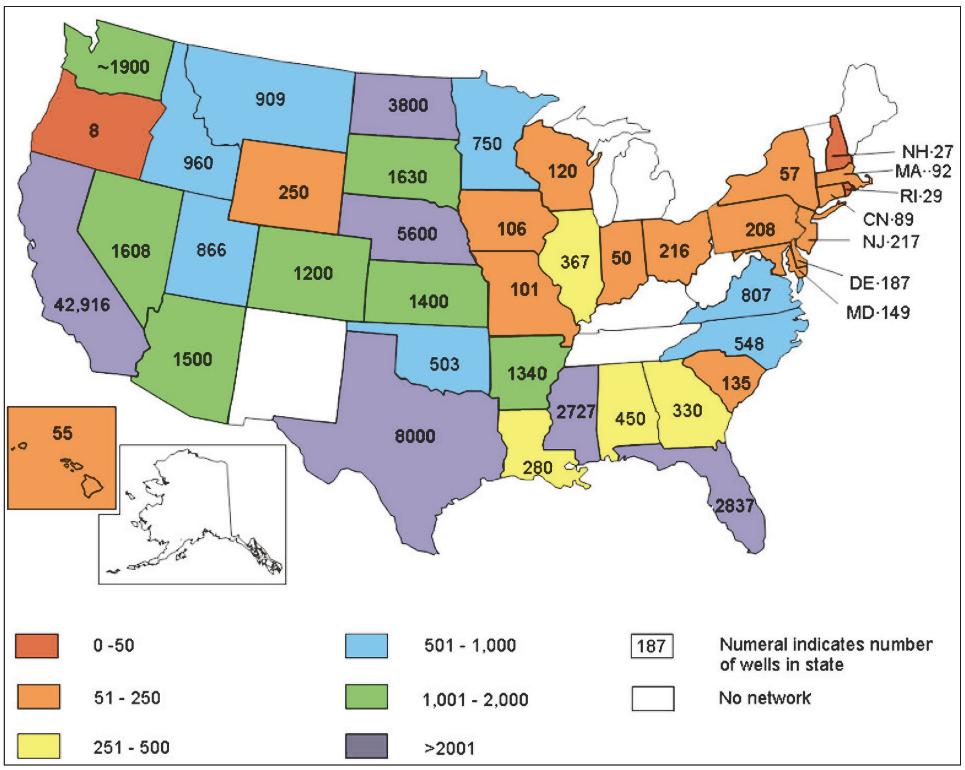


Figure 2-2.3.2 Number of wells in statewide/regional networks measured at least annually.

Of the 44 networks reporting, the primary frequency that is used varies from 5 years to real time (table 2-2.3.2). Twelve networks used one sampling frequency 90 percent or more of the time, and 39 networks favored using one frequency 50 percent or more of the time. The focus on a particular frequency measurement cycle probably depends on the objective of the specific network and staffing requirements.

Ground-water level information for the State and regional networks is collected primarily by State employees, USGS staff, and regional/local employees (figure 2-2.3.3). As might be expected, the bulk of the data is being collected by agencies who are managing/operating the networks. In two States (New Hampshire and Wisconsin), volunteers also participate.

Table 2-2.3.2. Ground-water level measurement frequencies.

Primary frequency measured	Number of networks	Network
5 years	2	Florida, Illinois
Annual	14	Alabama, Arizona, Arkansas, Colorado, Idaho, Indiana, Iowa, Kansas, Mississippi, Nebraska, Nevada, Oklahoma, Texas, Utah
Semiannual	3	Maryland, Washington, Wisconsin
Quarterly	10	Connecticut, Delaware, Delaware, Hawaii, Louisiana, Montana, North Carolina, Oregon, South Carolina, Virginia
Monthly	8	Massachusetts, Minnesota, New Hampshire, New York, North Dakota, Rhode Island, South Dakota, Ohio
Daily	5	Florida, Georgia, New Jersey, Ohio, Wyoming
Real Time	2	Missouri, Pennsylvania

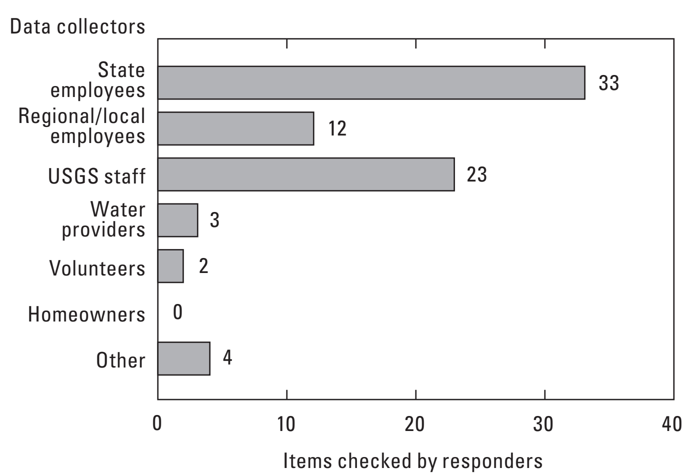


Figure 2-2.3.3 Collectors of ground-water level data for State/ regional networks (41 responders).

Data Availability

Twenty-three of 34 information items that generally are available for wells and observation points are considered important by half (21 or more) of the responders (figure 2-2.3.4). Most of the responders (35 of 40) consider the following information to be necessary: well number, county code, lat/long, land-surface elevation, date drilled, well depth, water-level available, and casing diameter. Items of potential interest with less than 20 responders include land use in the area (4), weather/climate at time of measurement (2), primary water use (20), and water quality available (13).

Standard operating procedures (SOPs) used for field data collection and data management and storage are critical to securing comparable data; however, the lack of written SOPs was substantial for both activities—8 of 40 (in 8 States) for field data collection (figure 2-2.3.5) and 12 of 41 (12 States) for data management and storage (figure 2-2.3.6). USGS and State agencies were the primary agencies that developed the SOPs, 38 of 40 (in 35 States) for field data and 29 of 40 (in 27 States) for data management and storage. Of particular interest is the almost complete underdevelopment of SOPs by State, regional, or local agencies for field data (0 of 40) and data management and storage (1 of 41). Two States show underdevelopment at the State level (Washington and Wyoming).

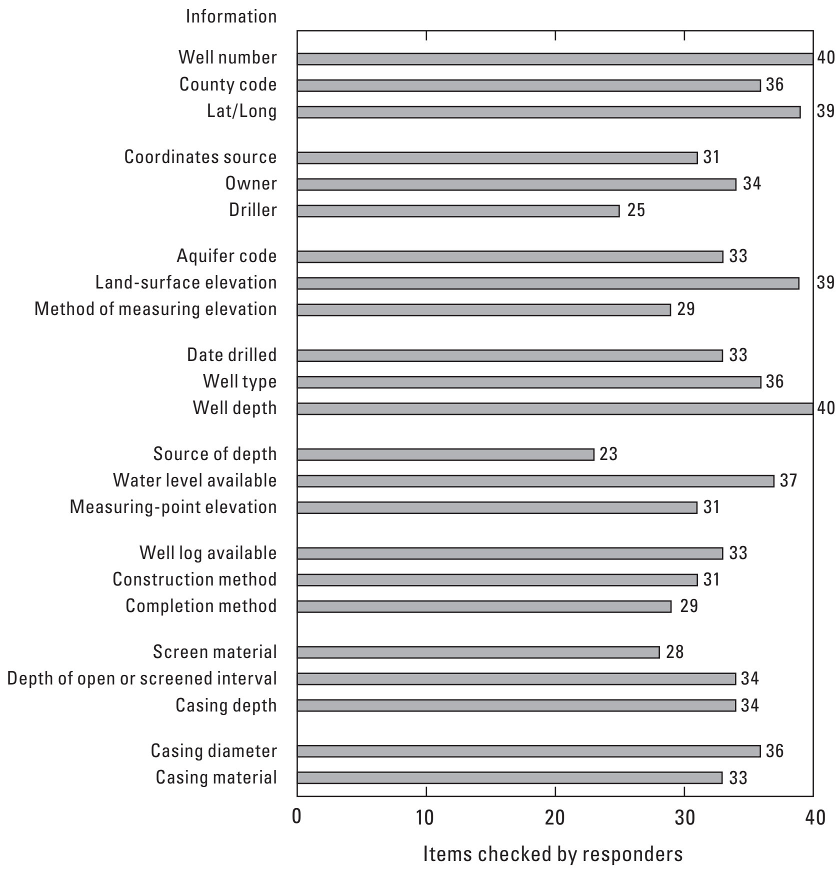


Figure 2-2.3.4 Information available for wells or observation points (41 responders).

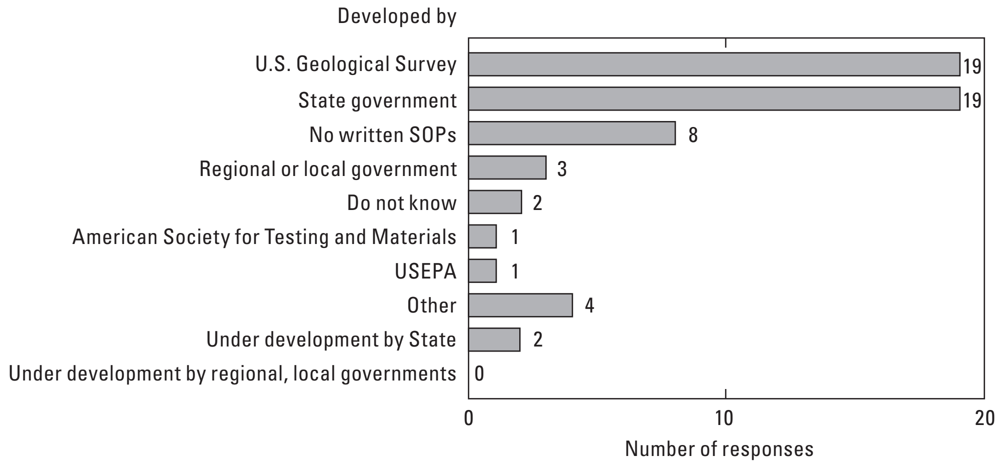


Figure 2-2.3.5 Who developed standard operating procedures for field data collection (41 responders)?

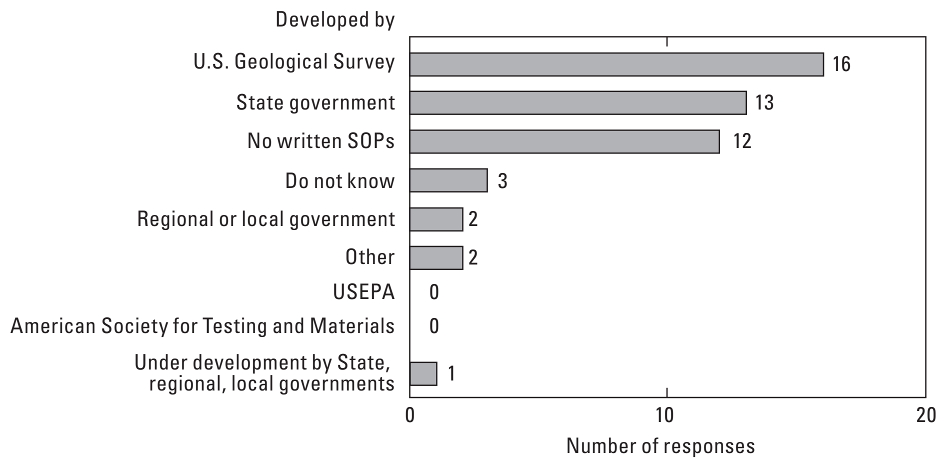


Figure 2-2.3.6 Who developed standard operating procedures for data management and storage (41 responders)?

A key issue concerns the storage of water-level data in a database (figure 2-2.3.7) and the availability of those data to the public. Thirty-six States entered and maintained some or all of the data for one or more statewide and (or) regional ground-water level monitoring networks in a computer database. Thirty-eight of 40 responders entered and maintained their data in a computer database (figure 2-2.3.7), and only one State did not. Thirty-six of 40 responders made all or some of the data available on a Web site (figure 2-2.3.8), and only 3 of 40 did not do so.

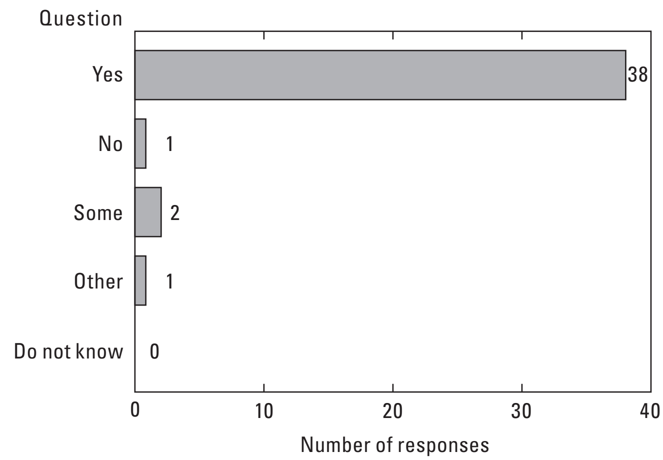


Figure 2-2.3.7 Data collected, entered, and maintained in a computer database (41 responders).

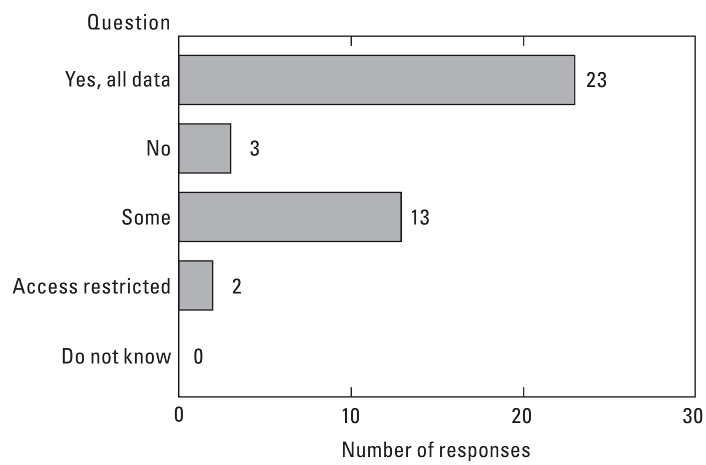
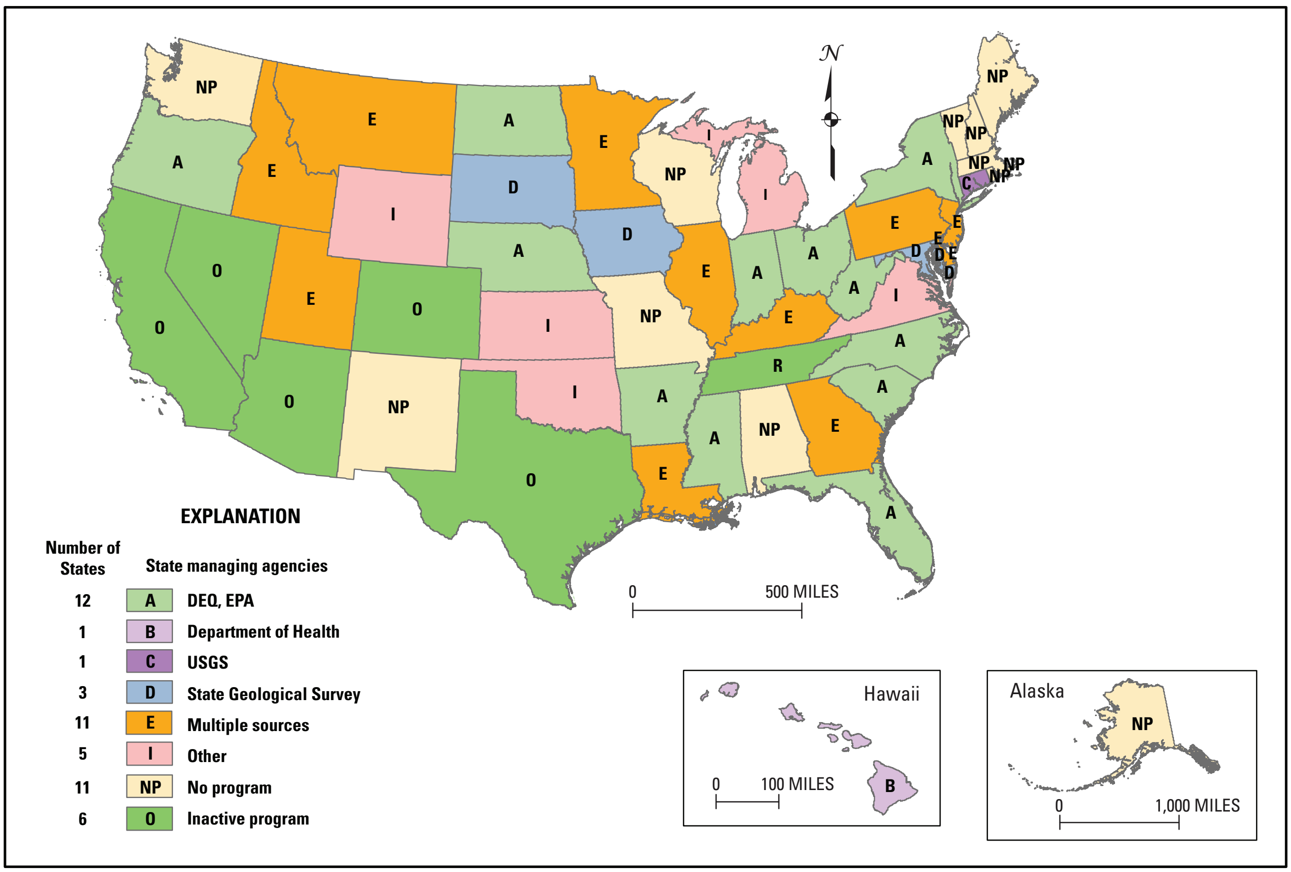


Figure 2-2.3.8 Web accessibility of data to the public (41 responders).

2-2.4 Summary of Water-Quality Information in the State/Regional Ground-Water Monitoring Networks Report

The following information on water-quality monitoring is summarized from the report "State/Regional Ground Water Monitoring Networks – Results of 2007 Survey" (Association of American State Geologists and others, 2007).

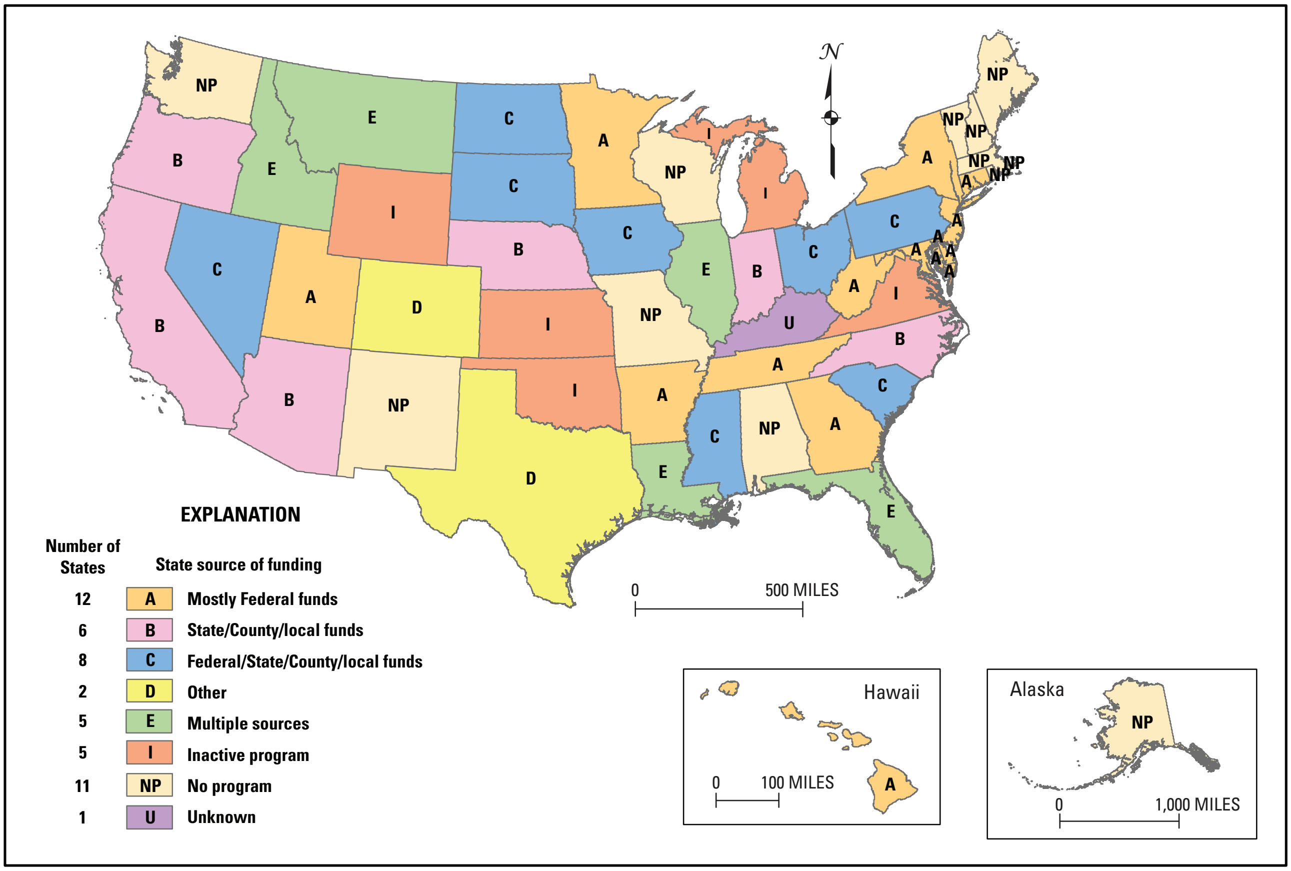
Program management – In 12 of the 33 States that have active ground-water quality sampling programs, the State Department of Environmental Quality or State Environmental Protection Agency manages the program (figure 2-2.4.1). The State Geological Survey is the sole program manager in three States (Iowa, Maryland, South Dakota), and program management is shared in four other States (Delaware, Montana, Nebraska, New Jersey). In 11 States, program management is split between two or more agencies (State Departments of Environmental Quality, USGS, State Departments of Agriculture, State Geological Surveys). In Hawaii, the statewide ground-water quality monitoring program is managed by the State Health Department. In Connecticut, the USGS is the sole manager of the statewide program. In four other States (Illinois, Louisiana, Michigan, Utah), the USGS is a cooperating agency. In six States with active programs, other agencies manage the program(s). The State Department of Agriculture manages regional ground-water quality sampling programs in five States (Delaware, Idaho, Illinois, Montana, Pennsylvania) and statewide programs in three States (Colorado, Nevada, Tennessee).



Base from: Ground water data-U.S. EPA (2006)
State boundaries-U.S. Census Bureau (2012)

Figure 2-2.4.1 Agencies that manage the State Water-Quality Monitoring Program.

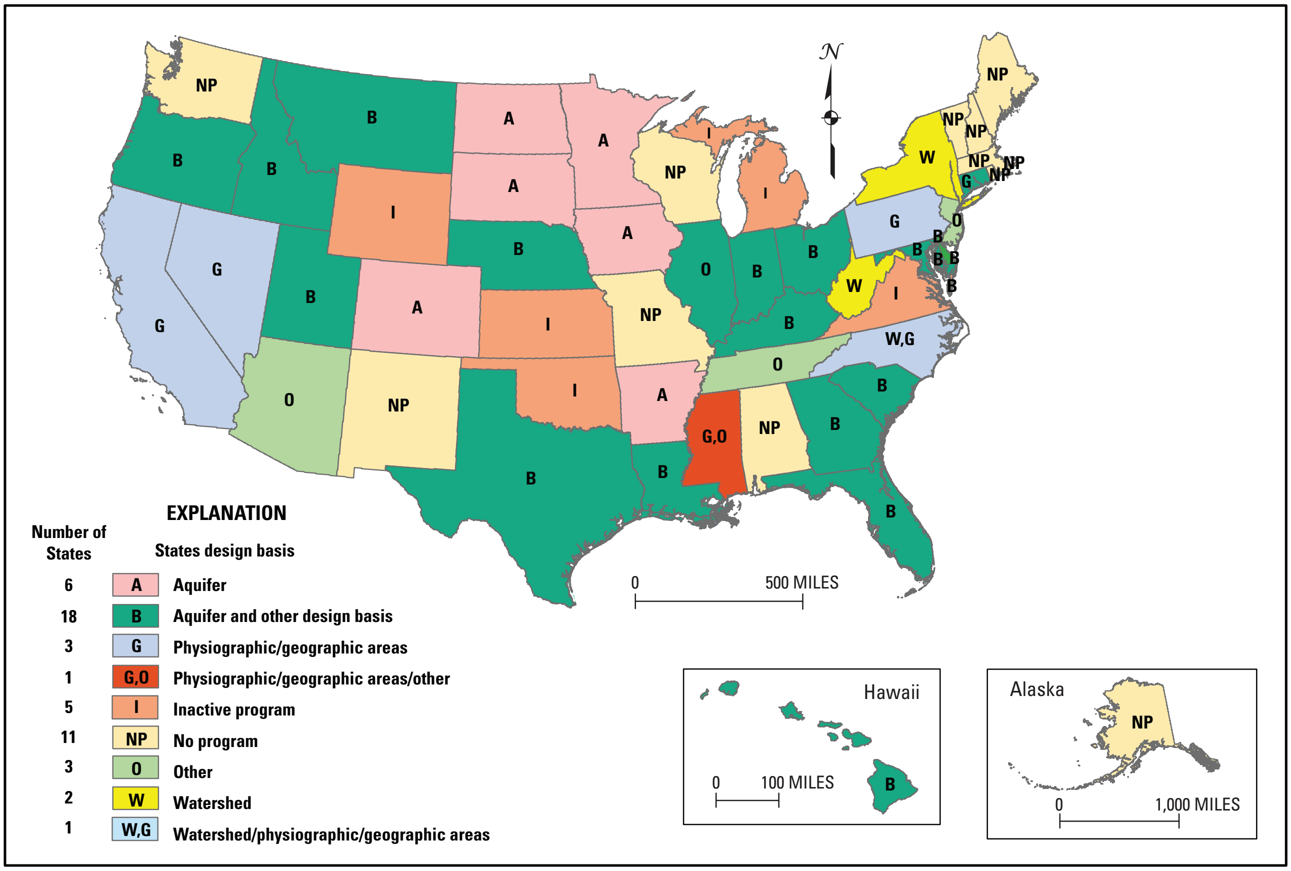
Program funding – Funding sources for managing State ground-water quality monitoring programs include Federal (USGS or U.S. Environmental Protection Agency (USEPA)), State, and local government funds (figure 2-2.4.2). Twelve States rely solely on Federal funding, and six States rely solely on State funding. Twelve States reported that funding was split between Federal and State funds. Funding for the three other States that have active ground-water quality monitoring programs is obtained from other sources.



Base from: Ground water data-U.S. EPA (2006)
State boundaries-U.S. Census Bureau (2012)

Figure 2-2.4.2 Source of funding for State Ground-Water Quality Monitoring Networks.

Program design basis – Monitoring locations, sampling schedules, and analyte lists for specific ground-water quality sampling programs are determined on the basis of the overall design and objectives of the program. In six States (Arkansas, Colorado, Iowa, Minnesota, North Dakota, South Dakota), the design of the ground-water quality sampling program is based solely on aquifers (figure 2-2.4.3). Eighteen other States based their design on aquifers and a combination of watersheds, geographic regions, and political subdivisions. Two States utilized watershed boundaries when designing the ground-water quality monitoring programs, five States considered political subdivisions, one State used a combination of watersheds and geographic areas, and 16 States considered geographic areas. It is apparent from figure 2-2.4.3 that a number of factors influence program design; however, in most States, the sampling programs are designed primarily to focus on specific aquifers.



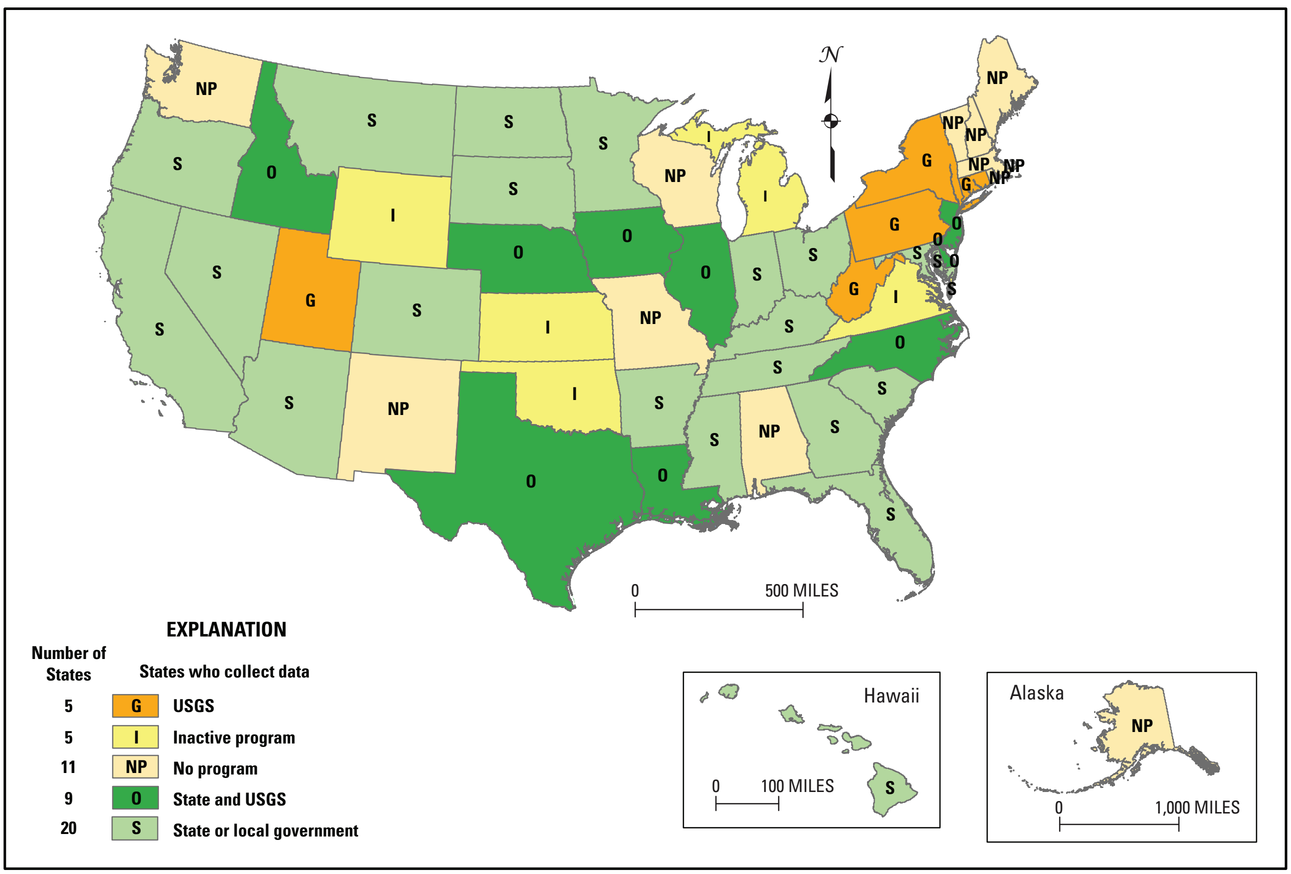
Base from: Ground water data-U.S. EPA (2006)
State boundaries-U.S. Census Bureau (2012)

Figure 2-2.4.3 Design basis for Ground-Water Quality Networks.

Type of observation points – The questionnaire included data on the types of wells and other observation points used for the State ground-water quality sampling program(s). Types of sampling locations include domestic wells, irrigation wells, and public water-supply wells. The questionnaire also asked if dedicated water-quality monitoring wells were used; however, the questionnaire did not include a definition of "dedicated." This constrains the data on dedicated wells. Only 3 States indicated the use of only dedicated wells in the State sampling program (Nevada, New Jersey, South Dakota); however, 15 States indicated that some dedicated wells were used in the sampling program(s) along with other types of sampling locations. Fifteen States indicated that there were no dedicated wells in the State program(s).

Analytes – The questionnaire included data on seven groups of analytes that are included in State ground-water quality sampling programs. The analyte groups include basic field parameters, cations/anions, nutrients, radionuclides, pesticides, trace metals, and organics, which are commonly used groups of analytes; however, an individual State may have a slightly different list of analytes for a given analyte group than other States. All 33 States with an active program indicated that basic field parameters were included in the program(s). Thirty-two States include basic cations/anions, 30 States include nutrients, 26 States include pesticides, 22 States include trace metals, and 20 States include organics. These data indicate that the State ground-water quality sampling programs are sampling for a wide variety of constituents in ground water. The data do not indicate that all sampling locations in a State program are sampled every time for all analyte groups. It is quite common to stagger sampling locations and analyte sampling over a period of months or years. Samples for some analyte groups may only be collected periodically.

Program operation – In 20 of the 33 States that have active ground-water quality sampling programs, the data are collected solely by State and local agency staff (figure 2-2.4.4). The USGS is charged with collecting the ground-water quality data in five States (Connecticut, New York, Pennsylvania, Utah, West Virginia). In nine States (Delaware, Idaho, Illinois, Iowa, Louisiana, Nebraska, New Jersey, North Carolina, and Texas), the ground-water quality data are collected jointly by the USGS and State agency staff.



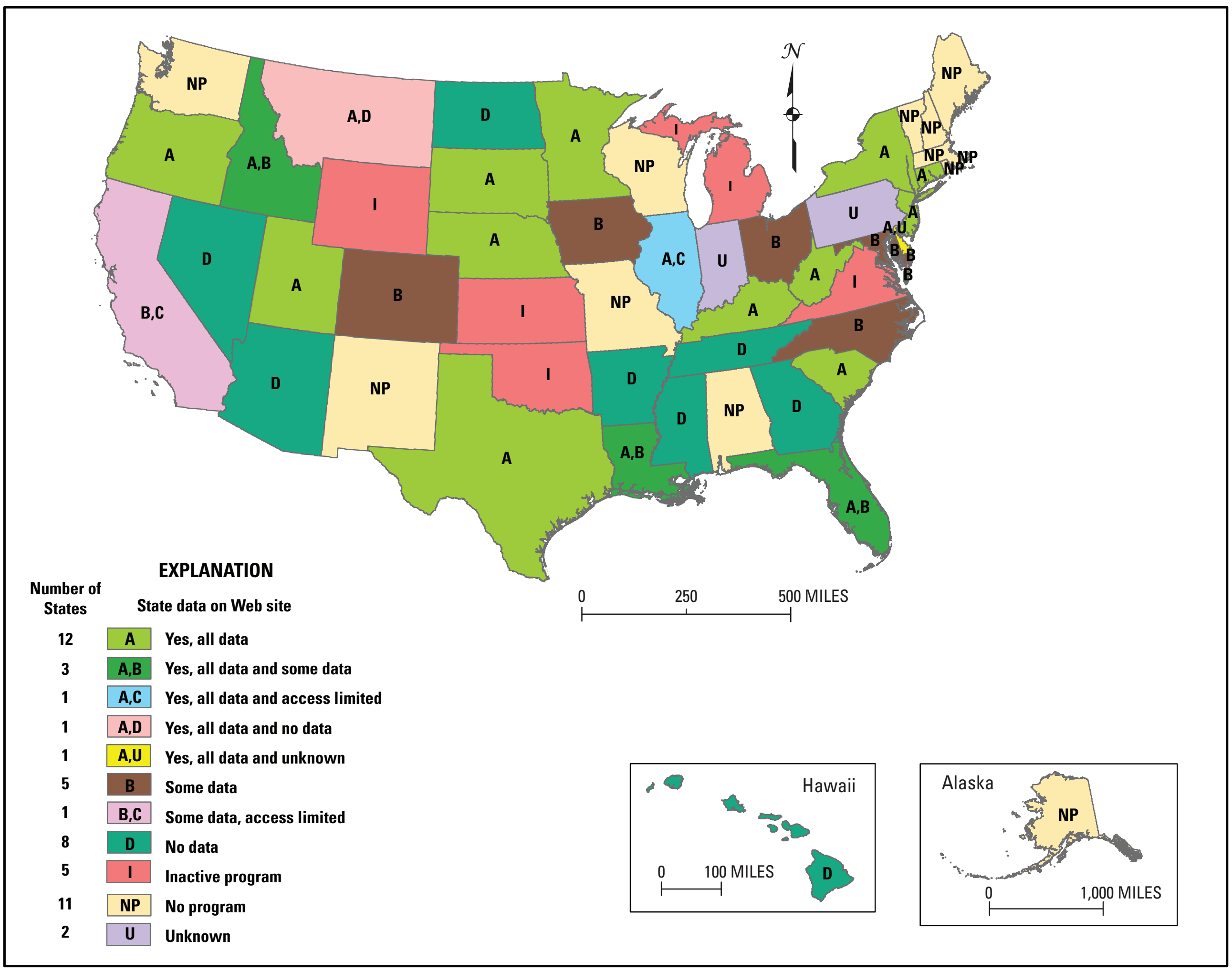
Base from: Ground water data-U.S. EPA (2006)
State boundaries-U.S. Census Bureau (2012)

Figure 2-2.4.4 Agencies that collect water-quality data for the State Ground-Water Quality Networks.

Who developed field-sampling SOPs? – Field-sampling SOPs that are used in State ground-water quality sampling programs were developed primarily by the appropriate State agency (11 States), the USGS (4 States), the USEPA (1 State), or developed jointly by the USGS, the USEPA, and the appropriate State agency (13 States). Four States (Arkansas, Colorado, Hawaii, Illinois) reported that field-sampling SOPs are currently being developed.

Who developed data-management SOPs? – As with field-sampling SOPs, the 33 States with active programs are using data-management SOPs developed by a State agency, the USGS, or the USEPA. Twelve of the 33 States use SOPs developed solely by the State, 5 States use SOPs developed solely by the USGS, 11 States use SOPs developed by both the State and the USGS or the USEPA. Three States (Arkansas, Hawaii, Illinois) reported that data-management SOPs are being developed. One State (California) reported that there are no SOPs for data management. Two States (Pennsylvania, Tennessee) reported that they have data-management SOPs, but it is unknown who developed the SOPs.

Are data from ground-water quality monitoring program available on a Web site? – The questionnaire included information on which States make the ground-water quality data available on a Web site. Twelve States reported that all data are posted on a Web site (figure 2-2.4.5). Eight States (Arizona, Arkansas, Georgia, Hawaii, Mississippi, Nevada, North Dakota, Tennessee) reported that no data are posted on a Web site. Five States (Colorado, Iowa, Maryland, North Carolina, and Ohio) reported that some but not all data are posted on a Web site. Two States (California, Illinois) reported that data are posted on a Web site, but access to the Web site is limited.



Base from: Ground water data-U.S. EPA (2006)
State boundaries-U.S. Census Bureau (2012)

Figure 2-2.4.5 Availability of ground-water quality data online.

Sampling frequency –

States with more than 5 years of data for their program:

Annually – 20 States
Semiannually – 15 States
Quarterly – 8 States

States with less than 5 years of data for their program:

Less than annually – 18 States
Annually – 23 States
Semiannually – 16 States
Quarterly – 14 States

2-2.5 State/Regional Ground-Water Monitoring Networks Report

This report is reproduced below and is also available as a separate document from the National Ground Water Association Web site: *http://www.ngwa.org/Documents/Awareness/Form5.pdf*.

State/Regional Ground Water Monitoring Networks – Results of 2007 Survey

Joint Project of:

Association of American State Geologists

Ground Water Protection Council

Interstate Council on Water Policy

National Ground Water Association

TABLE OF CONTENTS

Joint Project Organizations

The **Association of American State Geologists (AASG)** represents the State Geologists of the 50 United States and Puerto Rico. Founded in 1908, AASG seeks to advance the science and practical application of geology and related earth sciences in the United States and its territories, commonwealths, and possessions

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The **Ground Water Protection Council (GWPC)** is a national association of state ground water and underground injection control agencies whose mission is to promote the protection and conservation of ground water resources for all beneficial uses, recognizing ground water as a critical component of the ecosystem.

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The **Interstate Council on Water Policy (ICWP)** is the national organization of state and regional water resource management agencies. It is the mission of the ICWP to enhance the stewardship of the nation's water resources

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The **National Ground Water Association (NGWA)** is a not-for-profit professional society and trade association for the ground water industry. Its 14,000 members include some of the country's leading public and private sector ground water scientists, engineers, water well contractors, manufacturers, and suppliers of ground water related products and services. The Association's vision is to be the leading community of ground water professionals that promotes the responsible development, use and management of ground water resources.

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Acknowledgements

The project sponsors thank the state and regional ground water monitoring staff who generously shared their time to respond to the surveys. Without their assistance, this information would not be available.

Introduction

Ground water is vital to public health, the environment, and the economy. Approximately 75% of community water systems rely on ground water.[1] Nearly all of rural America, as well as large metropolitan areas, use ground water supplied water systems. Ground water feeds streams and rivers, especially during periods of drought or low flow. The agricultural industry uses ground water for irrigation. The percentage of total irrigation withdrawals from ground water increased from 23 percent in 1950 to 42 percent in 2000.[2] According to a U.S. Government Accountability Office (GAO) report, 36 states anticipate water shortages statewide, regionally or locally in the next 10 years under normal conditions.[3] In the face of these expected shortages, the question is do states have programs that will monitor the ground water quantity and quality so they have information to take either proactive or reactive measures based on sound information? These surveys are intended, in part, to provide a broad overview of the current status of ground water monitoring being conducted by states and regional entities.

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[1] *U.S. Environmental Protection Agency, 2002. Community water system survey 2000, Volume I. Retrieved at* http://www.epa.gov/OGWDW/consumer/cwss_2000_volume_i.pdf.

[2] *Hutson, Susan S., Nancy L. Barber, Joan F. Kenny, Kristin S. Linsey, Deborah S. Lumia, and Molly A. Maupin. 2004. Estimated use of water in the United States in 2000. U.S. Geological Survey Circular 1268.*

[3] *U.S. Government Accountability Office. Freshwater Supply: State's Views of How Federal Agencies Could Help them Meet the Challenges of Expected Shortages (GAO-03-514), 2003.*

The Survey

Between August and October 2007, 174 emails went to state agencies in all 50 states targeting those agencies responsible for ground water quality and/or quantity regulations, and state geological surveys. The survey was sent simultaneously to different agencies in an effort to enlist a "shotgun" approach to ensure the highest number of respondents possible. The email requested that they complete an electronic survey on statewide or regional ground water monitoring programs in their states. Regional was defined for purposes of the survey as monitoring networks that cover large, (e.g., multi-county) areas within a state.

A separate survey was developed for ground water level monitoring programs and ground water quality monitoring programs. Forty-one states responded to the ground water level monitoring survey. Forty-nine states responded to the ground water quality monitoring survey. Although the surveys varied, the questions common to both surveys included:

- ✓ Program status
- ✓ Monitoring program objectives
- ✓ Who manages the program
- ✓ How is the program funded
- ✓ What types of wells are used in the network
- ✓ What are the numbers of wells sampled, the sampling frequency and the length of record
- ✓ Who collects the samples
- ✓ What metadata is collected
- ✓ Who developed the field practices standard operating procedures
- ✓ Who developed the data standards and data management standard operation procedures
- ✓ How are data stored

The survey results were also supplemented by contacts and information provided by the U.S. Geological Survey.

Summary of Findings

Table 1 identifies the status of statewide and regional ground water level monitoring networks. Map 1 identifies the status of statewide/regional ground water level monitoring programs by state.

Table 1 – Ground Water Level Networks

Number of States	Type Program
22	One or more statewide networks
15	One or more statewide and regional networks
5	One or more regional networks
8	No statewide or regional network
50	Total states

Map 1 – Ground Water Level Networks

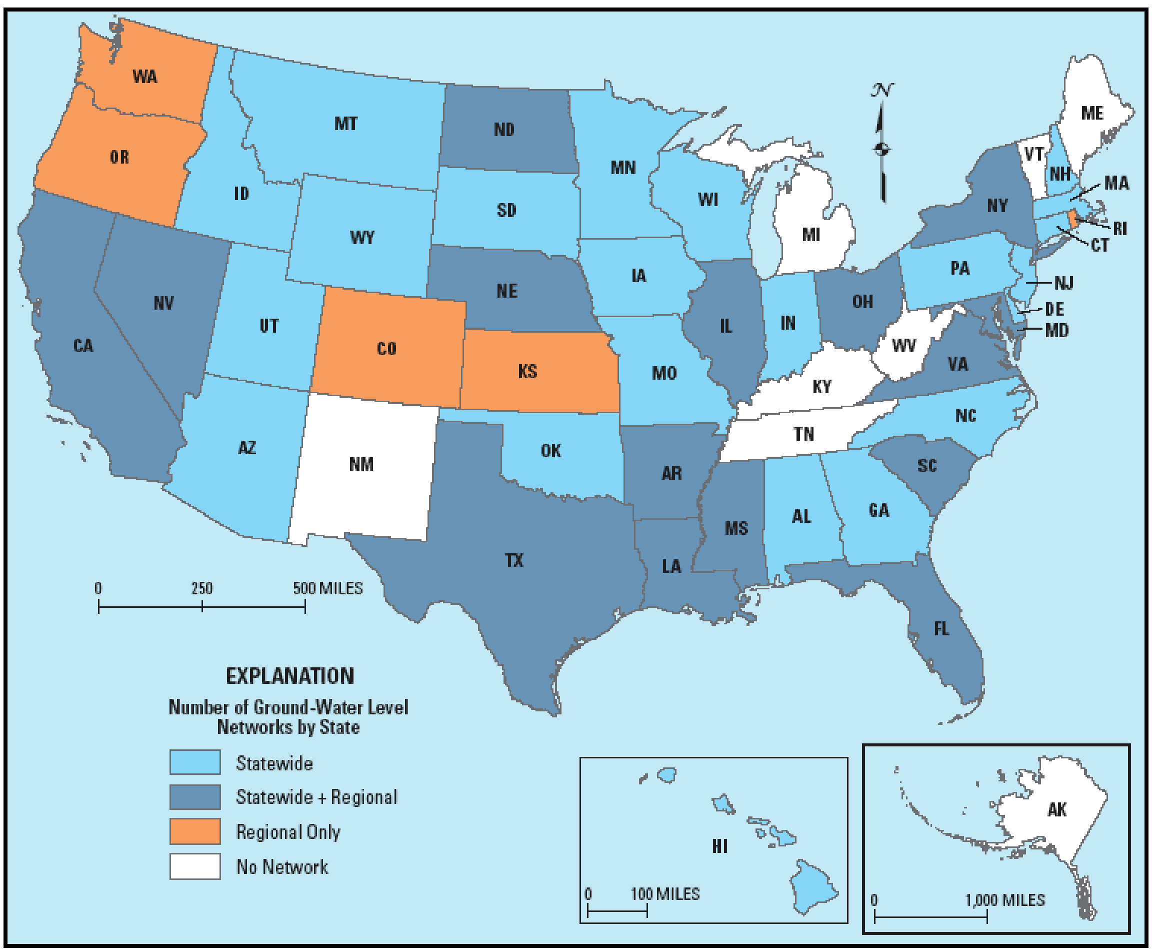
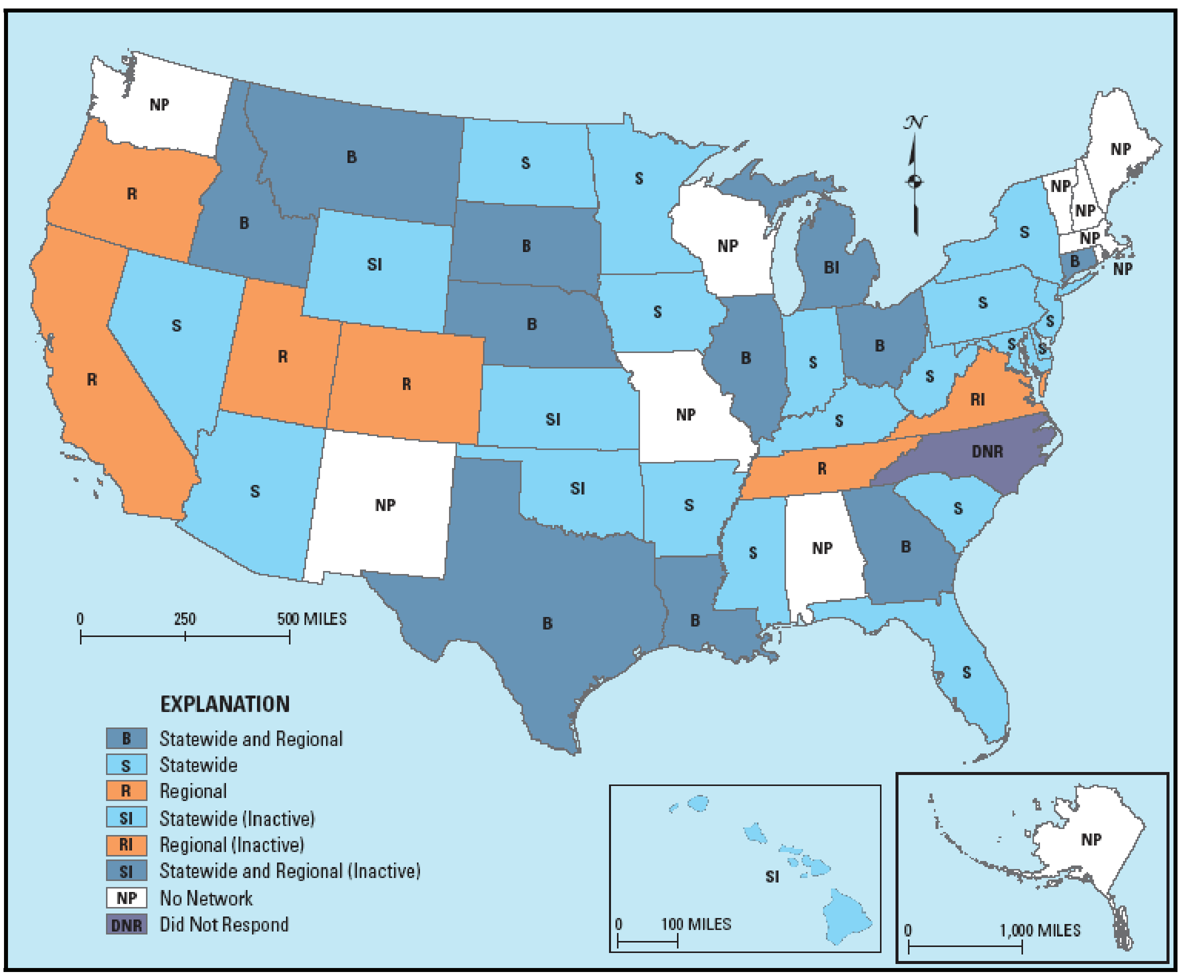


Table 2 identifies the status of statewide and regional ground water quality monitoring networks. Map 2 identifies the status of statewide/regional ground water quality monitoring programs by state.

Table 2 – Ground Water Quality Networks

Number of States	Type Program
18	One or more statewide networks
10	One or more statewide and regional networks
5	One or more regional networks
11	No statewide or regional network
5	Inactive either statewide or regional
1	No response
50	Total states

Map 2 – Ground Water Quality Networks

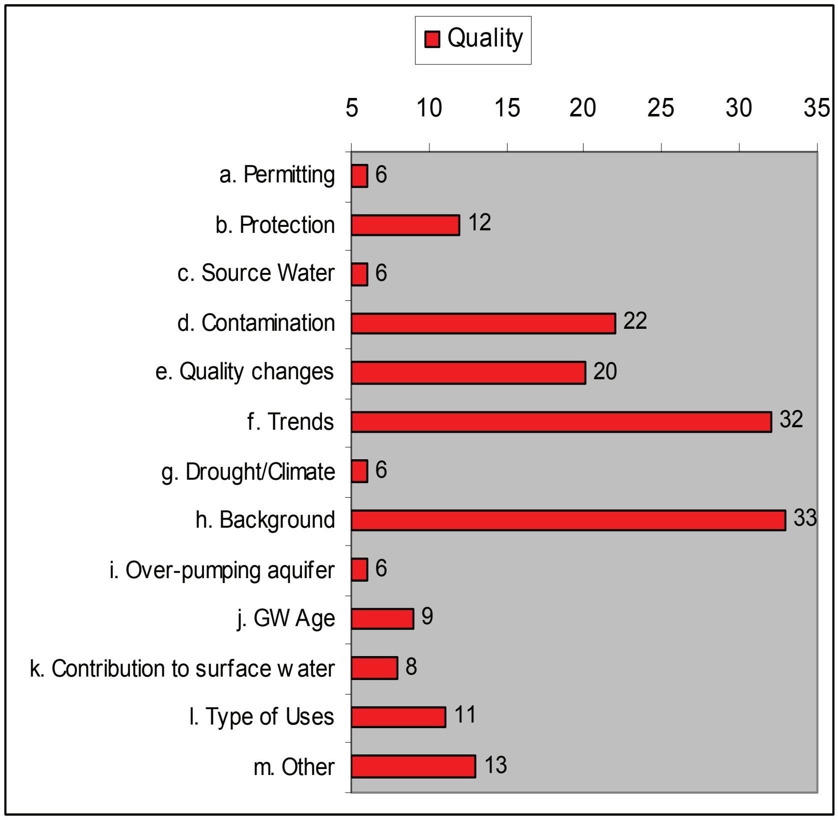


The following graphs represent a compilation of the *Ground Water Level Monitoring* survey and *Ground Water Quality Monitoring* survey responses. The responses are included on one graph for questions common to both surveys (including answer choices) and are indicated by different colored bars. For questions that differed between the surveys, an individual graph unique to that question is shown.

Question 4. Please indicate whether the existing state-wide/regional ground water quality monitoring network is intended to provide ground water level data to answer the following questions.

QUALITY

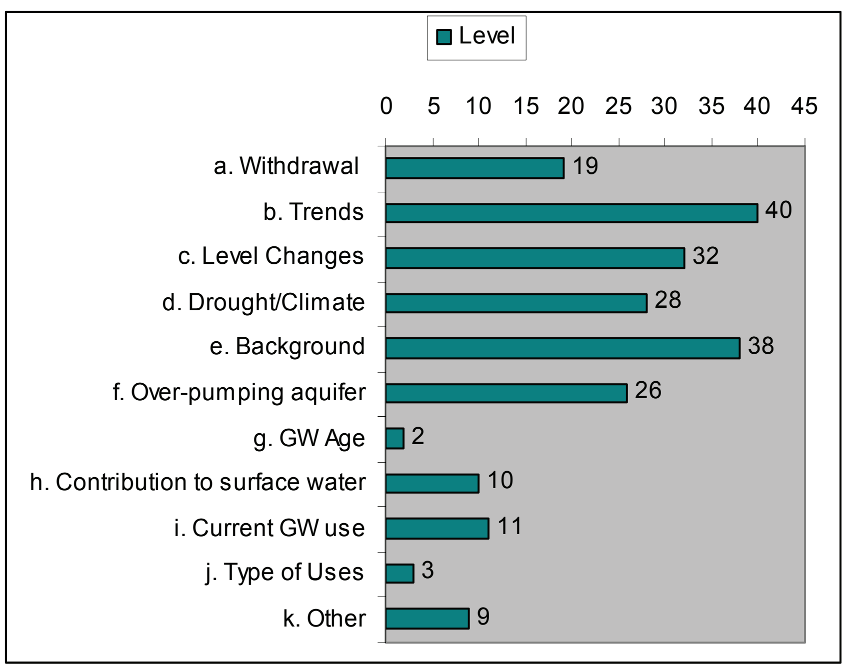
a. How effective are groundwater permitting programs in protecting water quality?
b. How effective are voluntary protection programs?
c. How effective are protection programs in source water protection areas?
d. What is the extent of ground water contamination?
e. How/why does a specific ground water quality parameter change over time?
f. What are the trends in ground water quality over time?
g. What are the effects of drought/climate change?
h. What is the current background (ambient) quality?
i. What are the impacts to ground water quality/level due to over-pumping of aquifers
j. What is the age of ground water within an aquifer?
k. What is the ground water quality/level contribution to surface water and vice versa?
l. What type(s) of uses (e.g. domestic, irrigation, livestock, industrial, etc) is ground water suitable for?
m. Other, please specify.



Question 4. Please indicate whether the existing state-wide/regional ground water level monitoring network is intended to provide ground water level data to answer the following questions.

LEVEL

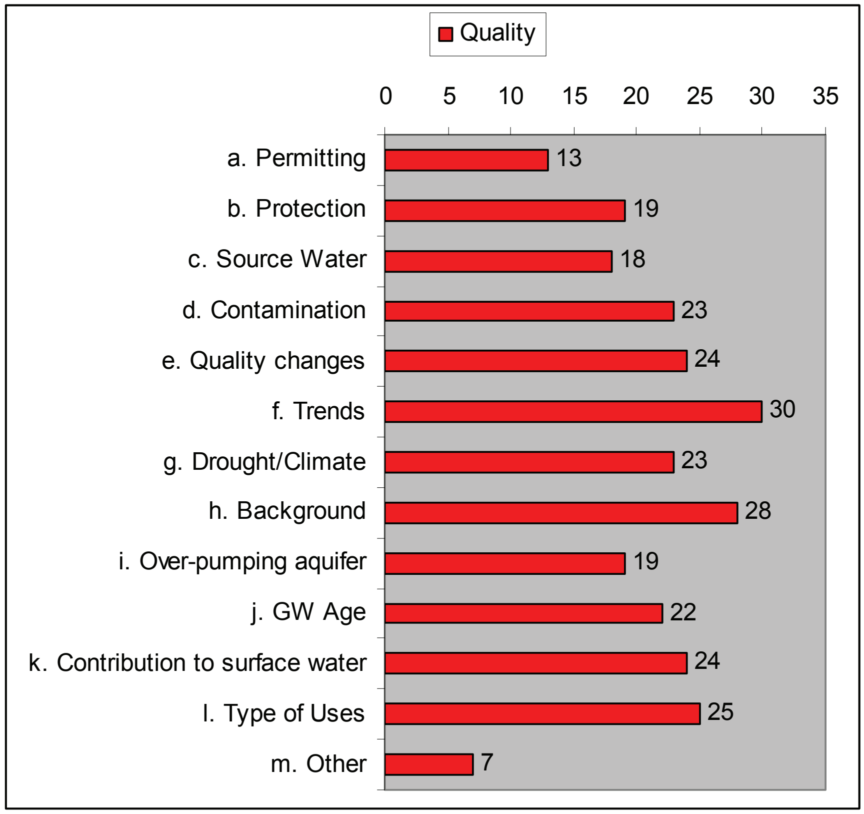
a. How effective are groundwater management programs in managing ground water withdrawals?
b. What are the trends in ground water quality/levels over time?
c. What are the effects of drought/climate change?
d. How/why do ground water levels change over time?
e. What is the current background (ambient) quality?
f. What are the impacts to ground water quality/level due to over-pumping of aquifers
g. What is the age of ground water within an aquifer?
h. What is the ground water level contribution to surface water and vice versa?
i. How much ground water is currently being used?
j. What type(s) of uses (e.g. domestic, irrigation, livestock, industrial, etc) is ground water suitable for?
k. Other, please specify.



Question 5. Please indicate whether the existing state-wide/regional monitoring network could be used to answer the following questions.

QUALITY

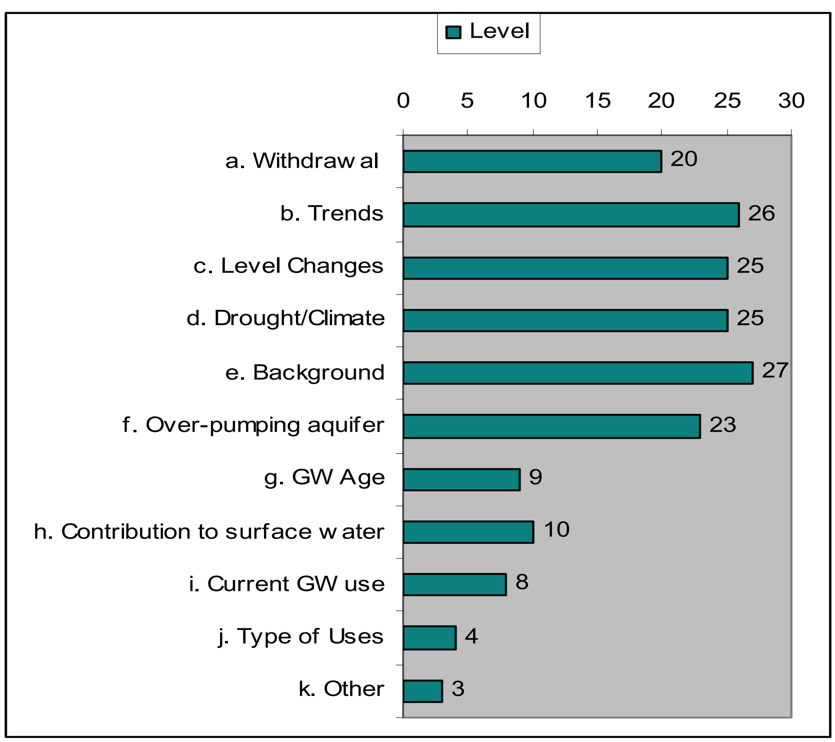
a. How effective are groundwater permitting programs in protecting water quality?
b. How effective are voluntary protection programs?
c. How effective are protection programs in source water protection areas?
d. What is the extent of ground water contamination?
e. How/why does a specific ground water quality parameter change over time?
f. What are the trends in ground water quality over time?
g. What are the effects of drought/climate change?
h. What is the current background (ambient) quality?
i. What are the impacts to ground water quality/level due to over-pumping of aquifers
j. What is the age of ground water within an aquifer?
k. What is the ground water quality/level contribution to surface water and vice versa?
l. What type(s) of uses (e.g. domestic, irrigation, livestock, industrial, etc) is ground water suitable for?
m. Other, please specify.



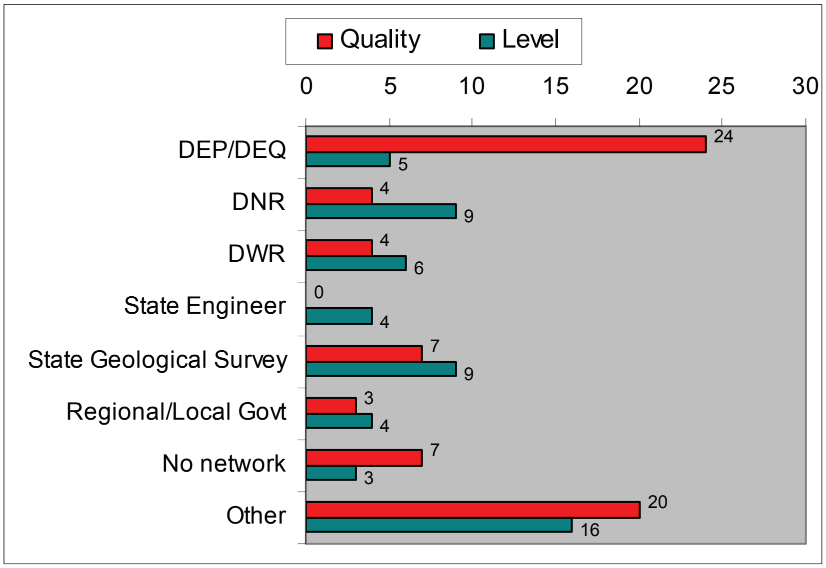
Question 5. Please indicate whether the existing state-wide/regional monitoring network could be used to answer the following questions.

LEVEL

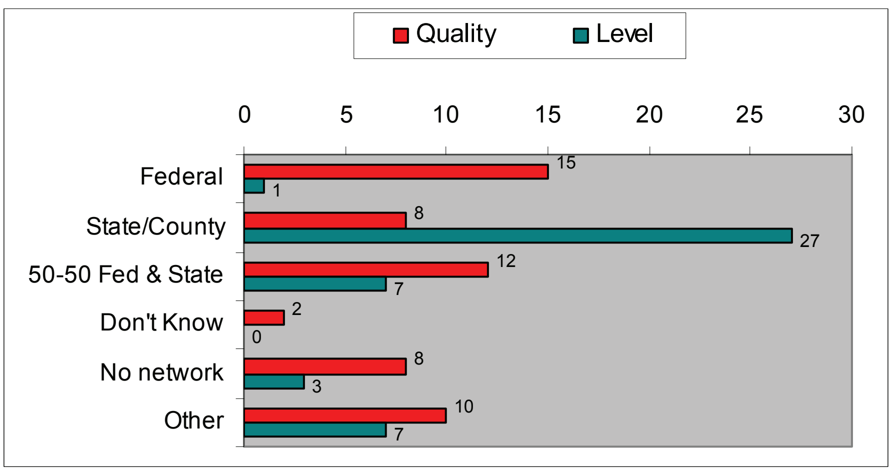
l. How effective are groundwater management programs in managing ground water withdrawals?
m. What are the trends in ground water quality/levels over time?
n. What are the effects of drought/climate change?
o. How/why do ground water levels change over time?
p. What is the current background (ambient) quality?
q. What are the impacts to ground water quality/level due to over-pumping of aquifers
r. What is the age of ground water within an aquifer?
s. What is the ground water level contribution to surface water and vice versa?
t. How much ground water is currently being used?
u. What type(s) of uses (e.g. domestic, irrigation, livestock, industrial, etc) is ground water suitable for?
v. Other, please specify.



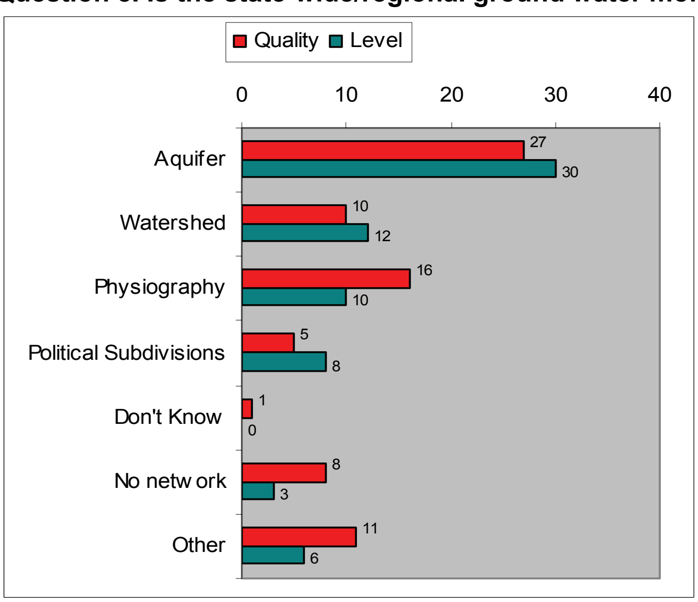
Question 6. Who manages the state-wide/regional ground water monitoring network?



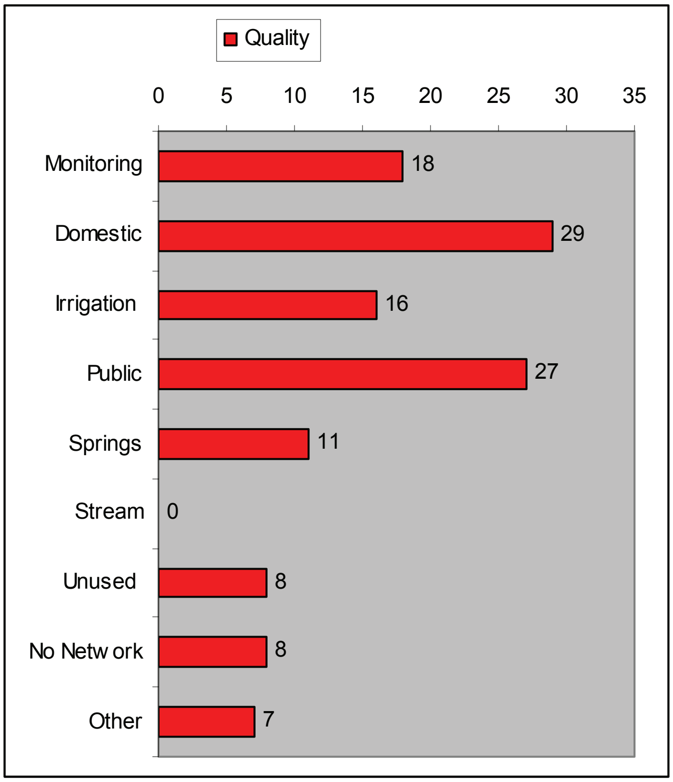
Question 7. How is the stated-wide/regional monitoring network funded?



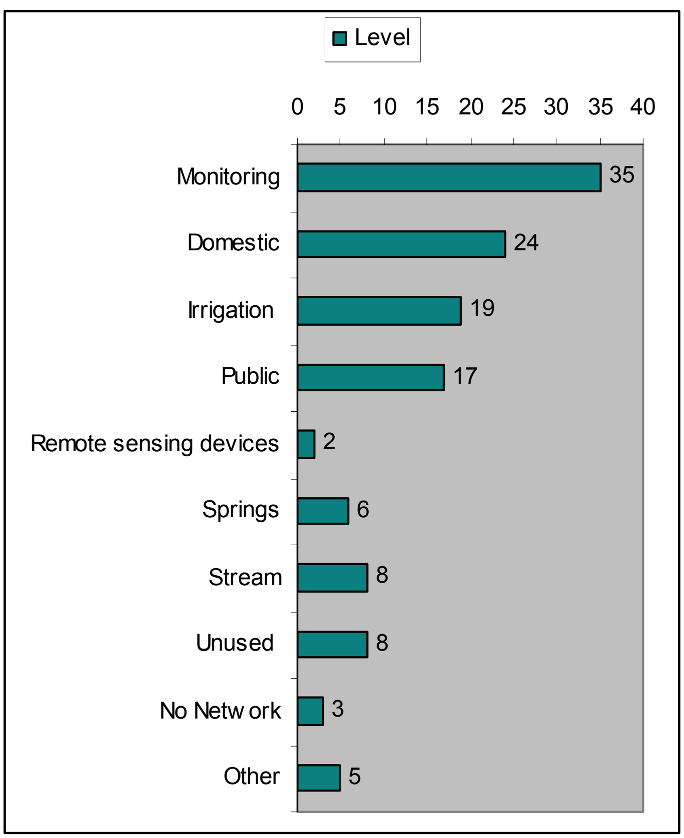
Question 8. Is the state-wide/regional ground water monitoring network designed based on:



Question 9. What wells or other observation points are used for statewide/regional ground water quality monitoring network?



Question 9. What wells or other observation points are used for statewide/regional ground water level monitoring network?



LEVEL	Question 10: Total Wells		Question 11: Wells Measured Once a Year		Question 12: Wells Measured Semi-Annually		Question 13: Wells Measured Quarterly	
State	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements
Alabama	450	430	450	430	19	19	19	19
Arizona	1500	1000	1200 - 1500	1000	90	40	90	40
Arkansas	1340	1250	1100	1000	400	350	50	50
California	42,916	8,245						
Colorado	1200	1200	1200	1200	105	105	0	0
Delaware	102	102	102	102	102	102	95	95
Delaware	85	70	85	70	85	70	85	70
Florida	1500	46	46	46	46	46	46	46
Florida	1337	953	1337	953	1337	953	1337	953
Georgia	180 continuous recorders; 150 annual	371 historical continuous recorders	about 150 annually	about 150 annually	60	60		
Hawaii	approximately 55	approximately 50					approx 55	approx 50
Illinois	500+	500+	~100	~100	~100	~100	~50	~50
Indiana	90	90	50	50	50	50	50	50
Kansas	1400	1400	1400	1400	~100	~100	~300	~300
Louisiana	280	180	280	180	280	180	275	175
Maine								
Maryland	149	140 (est.)	149	140 (est)	149	140 (est)	43	
Massachusetts	92	90	92	90	92	90	92	90
Minnesota	750	730	750	730	750	730	675	675
Mississippi			2202	1777	525	477	N/A	N/A
Missouri	101	70	101	70	101	70	101	70
Montana	909	878	0	0	0	0	784	758
Nebraska	5600	4800	5600	4800	105	105	12	12
Nevada	1608	1570	1397	1370	103	92	52	52
New Hampshire	27	26	27	26	27	26	27	26
New Jersey	217	210	217	210	166	159	166	159
New York	50	37	50	37	50	37	50	37
North Carolina	548 wells	~500	548	~500	548	~500	548	~500
North Dakota	3,800	3,600	495	495	65	65	693	693
Ohio	139	118			2	2		
Ohio	77	70	77	70	77	70	77	70
Oklahoma	503	503	503	503	0	0	0	0
Oregon	8	8	8	8	8	8	8	8
Rhode Island		29		29		29		29
South Carolina	135	69	135	69	135	69	135	69
South Dakota	1639	1639	1639	1639	1639	1639	1639	1639
Texas	about 8,000	85%	6000	85%	1500-2000	85%	1000	90%
Vermont	See USGS for info		See USGS for info		See usgs for info			
Virginia	404 active wells in the network	667 includes active and inactive wells	404	667	404	595	349	388
Washington	around 1000	around 700	around 750	around 700	around 500	around 500	around 250	around 200
Wisconsin	120	120	120	120	120	120		
Wyoming	approx. 250	approx 240	approx 200	approx 190	approx 200	approx 190	approx 200	approx 190

LEVEL	Question 14: Wells Measured Monthly		Question 15: Wells Measured Weekly		Question 16: Wells Measured Daily		Question 17: Wells Measured in Real Time	
State	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements
Alabama	18	18	18	18	18	18	0	0
Arizona	90	40	90	40	45	40	45	40
Arkansas	24	20	24	20	19	14	19	14
California					200	200	0	0
Colorado	0	0	0	0	0	0	0	0
Delaware	0	0	0	0	0	0	0	0
Delaware	45	45	18	14	18	14	1	1
Florida	0	0	0	0	0	0	0	0
Florida	1310	953	716	439	615	438	269	302
Georgia	180 continuous sites are measured every 2 months	180 continuous sites are measured every 2 months			180	180	25	20
Hawaii								
Illinois	~50	~50	maybe 6-12	0	maybe 6-12	0	0	
Indiana	40	40	38	38	38	38	5	5
Kansas	~20	~20	0	0	0	0	0	0
Louisiana	8	8	8	8	8	8	8	8
Maine								
Maryland	43		5 (recorders)		5 (recorders)		5	
Massachusetts	92	90	0	0	12	11	10	9
Minnesota	675	675	20	2	20	2	12	0
Mississippi	None	None	None	None	Only as needed for short-duration investigations.	No on-going studies.	None	None
Missouri	101	70	101	70	101	70	101	70
Montana	25	25	0	0	100	95	0	0
Nebraska	12	12	6	6	6	6	2	0
Nevada	38	38	9	9	9	9	9	9
New Hampshire	27	26	1		1		1	
New Jersey	163	156	163	156	163	156	20	14
New York	50	37	Get the info from http://groundwaterwatch.usgs.gov	Get the info from http://groundwaterwatch.usgs.gov	Get the info from http://groundwaterwatch.usgs.gov	Get the info from http://groundwaterwatch.usgs.gov	Get the info from http://groundwaterwatch.usgs.gov	Get the info from http://groundwaterwatch.usgs.gov
North Carolina	247	unsure	247	unsure	248	unsure	0	0
North Dakota	2547	2547	0	0	50	10	0	0
Ohio					137	116	10	7
Ohio	77	70	28	28	28	28	0	0
Oklahoma	0	0	0	0	0	0	0	0
Oregon	4	4	4	4	4	4	4	4
Rhode Island		29		None		None		None
South Carolina					40	40	0	0
South Dakota	1639	1639	60	60	60	60	0	0
Texas	500	92%	110	94%	same 110 as in no. 15	94%	91	95%
Vermont								
Virginia	80	46	80	46	80	46	60	2
Washington	a few hundred	not many	maybe 100	not many	maybe 100	not many	1	1
Wisconsin					20	20	3	3
Wyoming	approx 150	approx 140	approx 150	approx 140	approx 150	approx 140	3	3

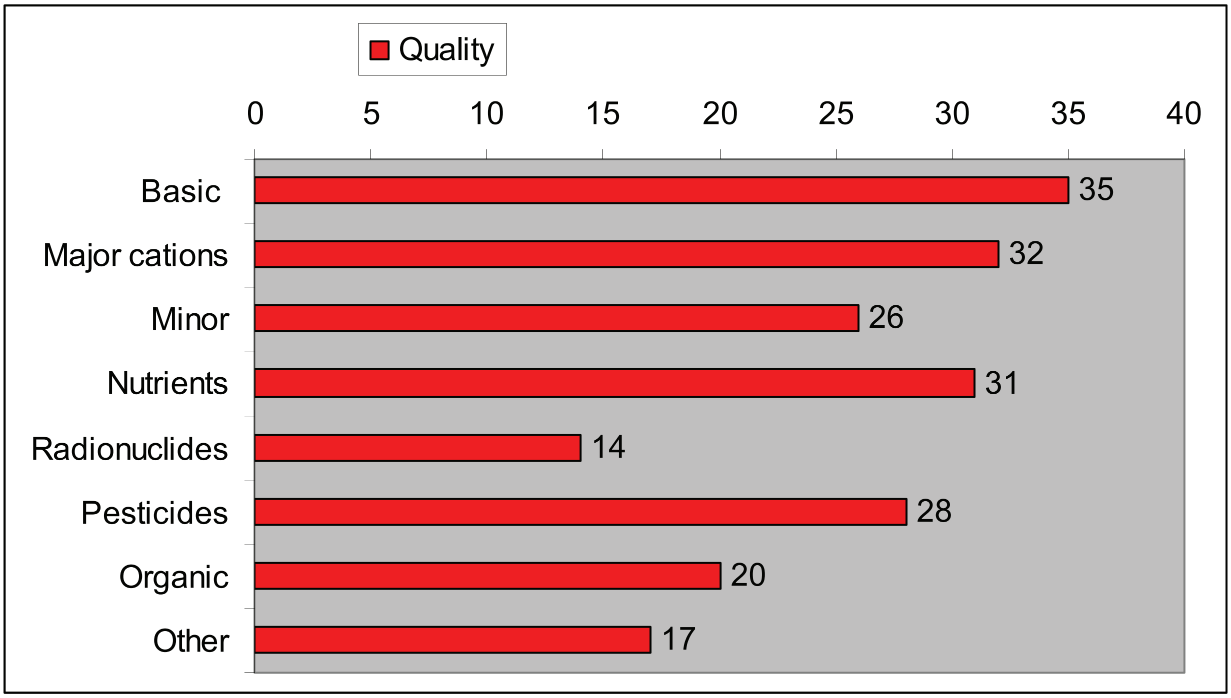
QUALITY	Question 10: Total Wells		Quesiton 11: Wells Measured Once a Year		Quesiton 12: Wells Measured Semi-Annually		Question 13: Wells Measured Quarterly	
State	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements
Alaska	NA	NA	NA	NA	NA	NA	NA	NA
Arizona	129	136	129	136	na	na	na	na
Arkansas	200	120	0	0	0	0	0	0
California	898	594	0	0	0	0	0	0
Colorado	approx. 130	apprx 75, but most data is on pesticides & nitrate	approx 130	apprx 75, but most data is on pesticides & nitrat	0	0	0	0
Connecticut	36	36	0	0	0	0	0	0
Delaware	Approx 40	Approx. 40	Approx 40	Approx 40	Approx 40	Approx 40	0	0
Delaware	103	103	103	103	50	50	0	0
Florida	150-180 per year; approximately 870 every 5 years	46	46	46	46	46	46	46
Florida	58	53	58	53	58	53	58	53
Georgia	180	0	0	0	0	0	0	0
Hawaii								
Idaho	1200	1200	1200	1200	80	80	40	40
Idaho	150	0	50	0	0	0	0	0
Idaho	500	100	100	100	30	0	30	0
Idaho	About 2000	98 or 99	100	98 or 99	0	0	0	0
Illinois	350	350	350	350	0	0	0	0
Illinois	18	18	0	0	0	0	0	0
Illinois	144	144						
Indiana	300	0	300	0	0	0	0	0
Iowa	150 annually; 2000 wells with one obs.	45	45	45	0	0	0	0
Kansas	>500 (two-year rotation)	300+ (two-year rotation)						
Kentucky	1000 (see comment)	150	380	150	380	150	300	150
Louisiana	285	255	0	0	0	0	0	0
Louisiana	about 90	about 90	about 90	about 90	about 55	about 55	0	0
Maine								
Maryland	77	about 50	0		0		0	
Massachusetts								
Michigan								
Minnesota	675	675	675	675	675	675	0	0
Minnesota	Current 400, new randomly selected wells each year	0	Building to 450	0 (2007 is 4th sampling year of current network)	0	0	0	0
Mississippi	1341	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Missouri								
Montana	42 dedicated pmw +	35			42 + special project wells (~30)	35	none at this time	15
Montana	900+/-	300 wells have >=2 samples; period >= 5 yrs						
Nebraska	1438	700 (estimated)	1000 (estimated)	500 (estimated)	250 (estimated)	200 (estimated)	100 (estimated)	75 (estimated)
Nevada	67	52	44	52	44	52	0	0
New Hampshire								
New Jersey	150	150 with at least one sampling event						
New Mexico								
New York								
North Dakota	1027	0 - Wells are sampled on a 5-year rotation	0	0	0	0	0	0
Ohio	200 Active Wells - 150 Inactive Wells	190 Active Wells	160	155	85	82	0	0
Oklahoma	1200	0	0	0	0	0	0	0
Oregon	120 wells sampled 6/year	500	120	120	120	120	120	120
Pennsylvania	approx. 30 per year	3	3	3	2	3	2	3
Rhode Island								
South Carolina	128	0	0	0	0	0	0	0
South Dakota	145	145	145	145	28	28	28	28
Tennessee	0	0	0	0	0	0	0	0
Tennessee	14	14	14	14	14	14	14	14
Texas	~8000	85%	6000	85%	1500 - 2000	85%	1000	
Utah	300	300	100	300	0	300	0	300
Vermont	N/A	N/A						
Virginia								
Washington								
West Virginia	296	0	0	0	0	0	0	0
Wisconsin								
Wyoming	296	0	296	0	0	0	0	0

QUALITY	Question 14: Wells Measured Monthly		Question 15: Wells Measured Weekly		Question 16: Wells Measured Daily		Question 17; Wells Measured in Real Time	
State	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements	Total Measured	Total w/at least 5 yrs. Measurements
Alaska	NA	NA	NA	NA	NA	NA	NA	NA
Arizona							na	na
Arkansas			0	0	0	0	0	0
California	0	0	0	0	0	0	0	0
Colorado	0	0	0	0	0	0	0	0
Connecticut	0	0	0	0	0	0	0	0
Delaware	0	0	0	0	0	0	0	0
Delaware	0	0	0	0	0	0	0	0
Florida	0	0	0	0	0	0	0	0
Florida	0	0	0	0	0	0	0	0
Georgia	0	0	0	0	0	0	0	0
Hawaii								
Idaho	25	25	0	0	0	0	0	0
Idaho	0	0	0	0	0	0	0	0
Idaho	0	0	0	0	0	0	0	0
Idaho	0	0	0	0	0	0	0	0
Illinois	0	0	0	0	0	0	0	0
Illinois	0	0	0	0	0	0	0	0
Illinois								
Indiana	0	0	0	0	0	0	0	0
Iowa	0	0	0	0	0	0	0	0
Kansas								
Kentucky	0	0	0	0	0	0	0	0
Louisiana	0	0	0	0	0	0	0	0
Louisiana	0	0	0	0	0	0	0	0
Maine								
Maryland	0		0		0		0	
Massachusetts								
Michigan								
Minnesota	0	0	0	0	0	0	0	0
Minnesota	0	0	0	0	10	0	0	0
Mississippi	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Missouri								
Montana	0	0	0	0	0	0	0	0
Montana								
Nebraska	0	0	0	0	0	0	0	0
Nevada	0	0	0	0	0	0	0	0
New Hampshire								
New Jersey								
New Mexico								
New York								
North Dakota	0	0	0	0	0	0	0	0
Ohio	0	0	0	0	0	0	0	0
Oklahoma	0	0	0	0	0	0	0	0
Oregon	0	0	0	0	0	0	0	0
Pennsylvania	0	0	0	0	0	0	0	0
Rhode Island								
South Carolina	0	0	0	0	0	0	0	0
South Dakota	0	0	0	0	0	0	0	0
Tennessee	0	0	0	0	0	0	0	0
Tennessee	14	14	0	0	0	0	0	0
Texas	500	85%	100	95%	100	95%	100	95%
Utah	0	300	0	300	0	300	0	300
Vermont								
Virginia								
Washington								
West Virginia	0	0	0	0	0	0	0	0
Wisconsin								
Wyoming	0	0	0	0	0	0	0	0

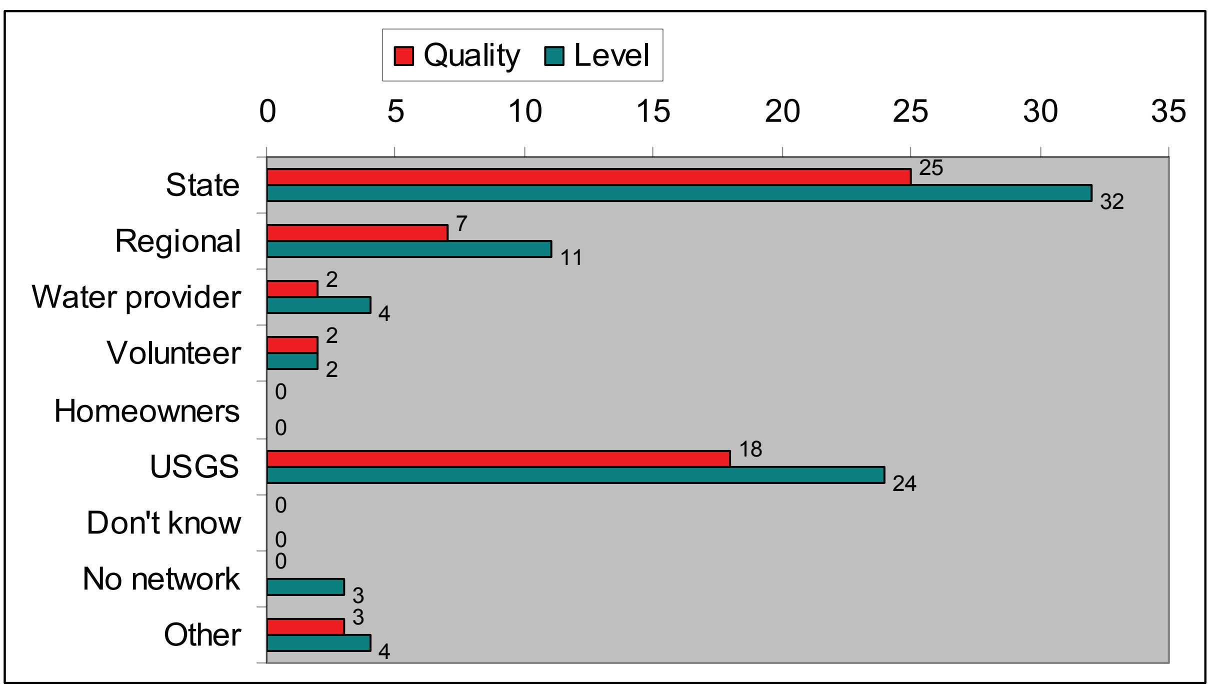
Cell: B25
Comment: :

The Kentucky Statewide Ambient Groundwater Monitoring Network is an "umbrella" title for integrating the various groundwater monitoring projects that we conduct. The network was established in 1995 and along with sites we've monitored regularly since then, we've incorporated other projects into this system, including CWA Section 319 Nonpoint Source groundwater studies, monitoring conducted through an MOA with the Division of Pesticides, as well as monitoring/sampling conducted for complaints, assistance, and in response to environmental spills. Most, if not virtually all, of the data collected on these latter projects really represents ambient groundwater conditions. By design, Kentucky's groundwater monitoring is a dynamic and flexible system, rather than a static network of sites. Furthermore, and importantly, all groundwater monitoring activities conducted by various agencies throughout the state are coordinated, per legislation passed in 1998, by the Interagency Technical Advisory Committee on Groundwater. This group of groundwater professionals from about a dozen entities with varying interests has proven to be an invaluable tool in our monitoring efforts.

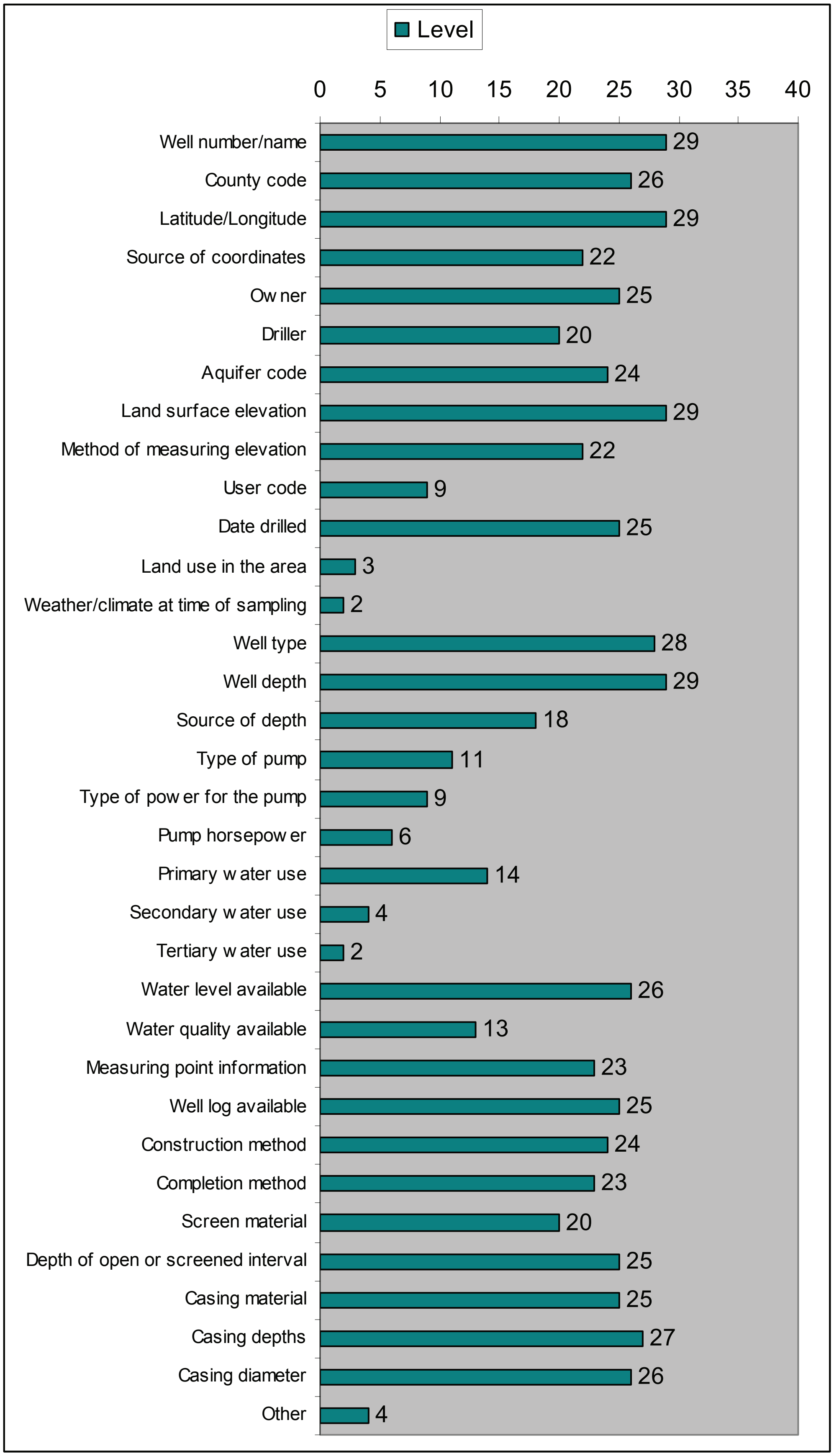
Question 18 - QUALITY. What analytes are included in the state-wide/regional ground water quality monitoring network?



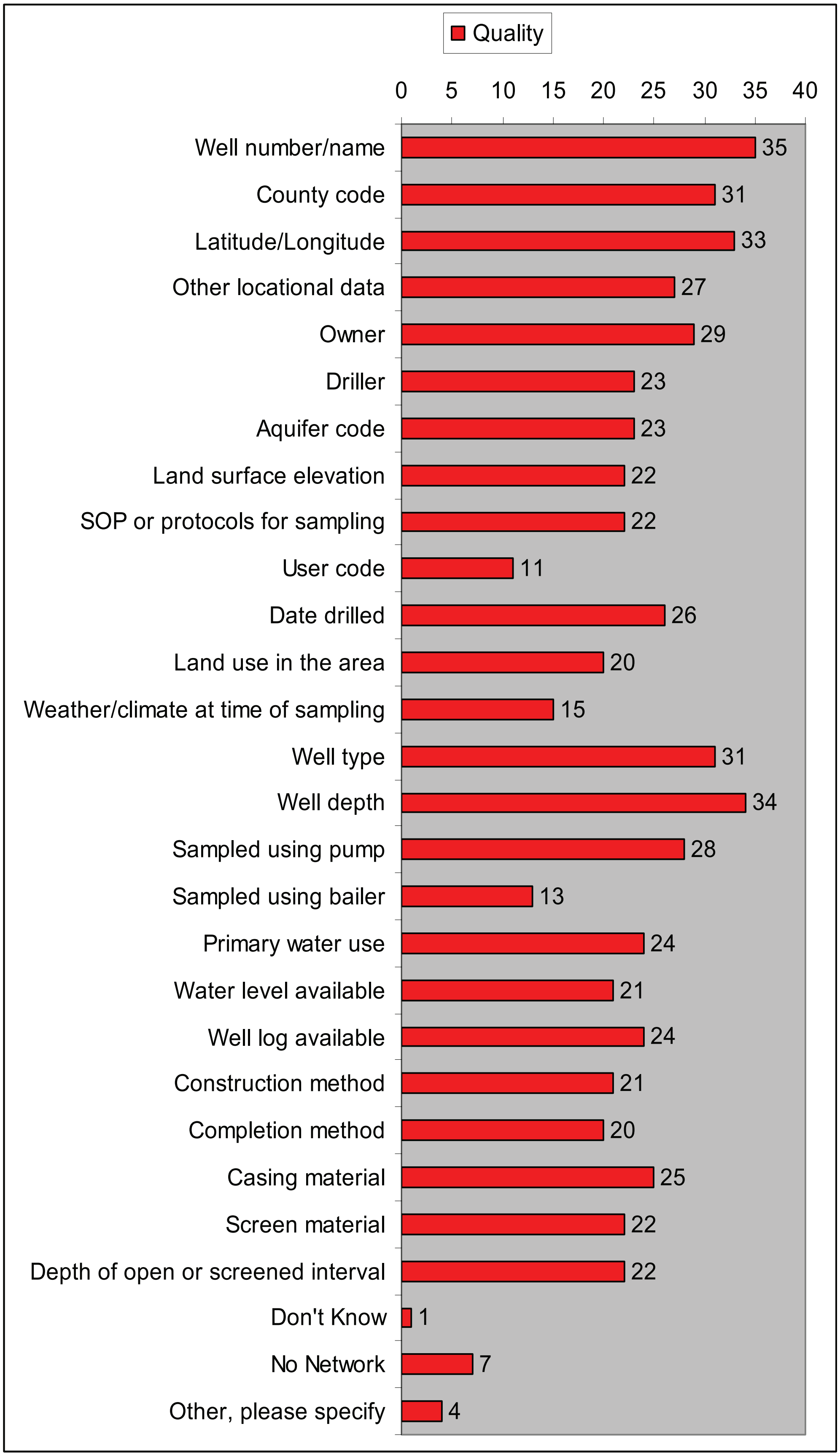
Question 18 – LEVEL/Question 19 – QUALITY. Who collects ground water data for the state-wide/regional ground water monitoring network?



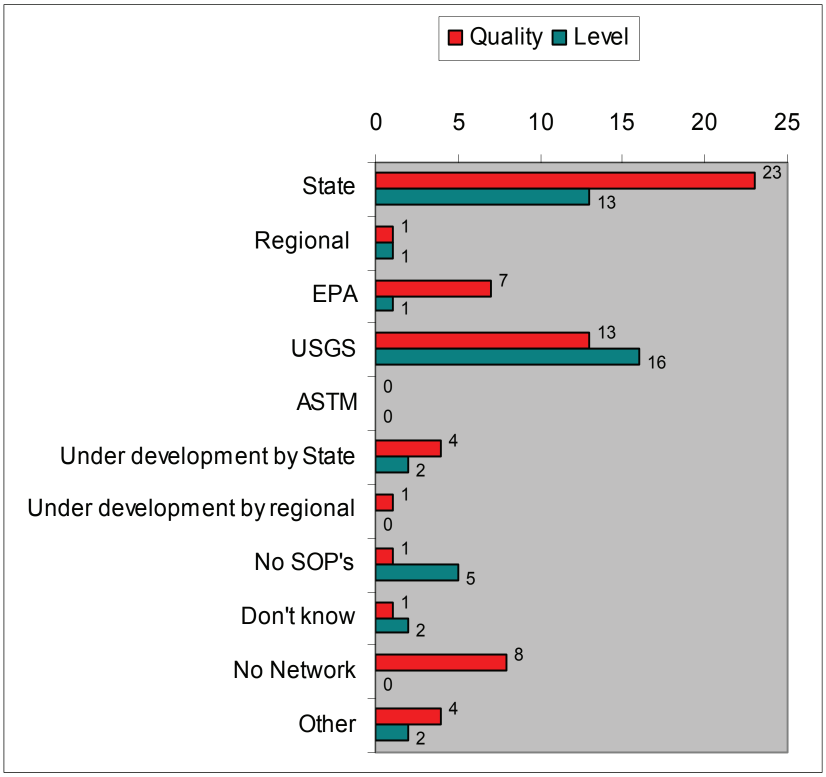
Question 19 - LEVEL. What information is typically available for wells or observation points in the state-wide/regional ground water level monitoring network?



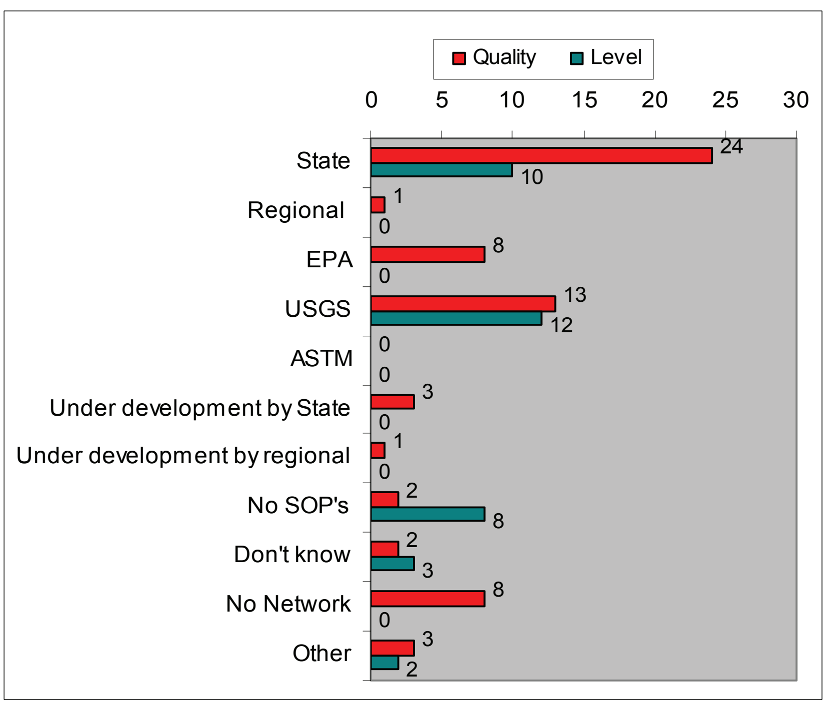
Question 20 – QUALITY. What information is typically available for wells or observation points in the state-wide/regional ground water quality monitoring network?



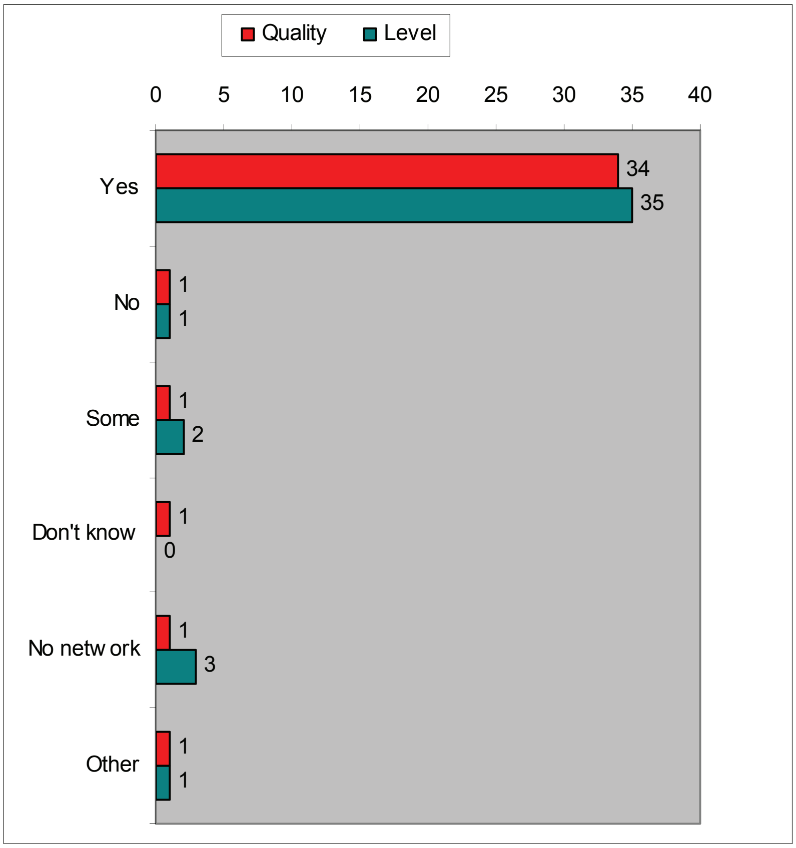
Question 20 –LEVEL/Question 21 – QUALITY. The written Standard Operating Procedures (SOP's) used for Field Data Collection for the state-wide/regional ground water monitoring network were developed by?



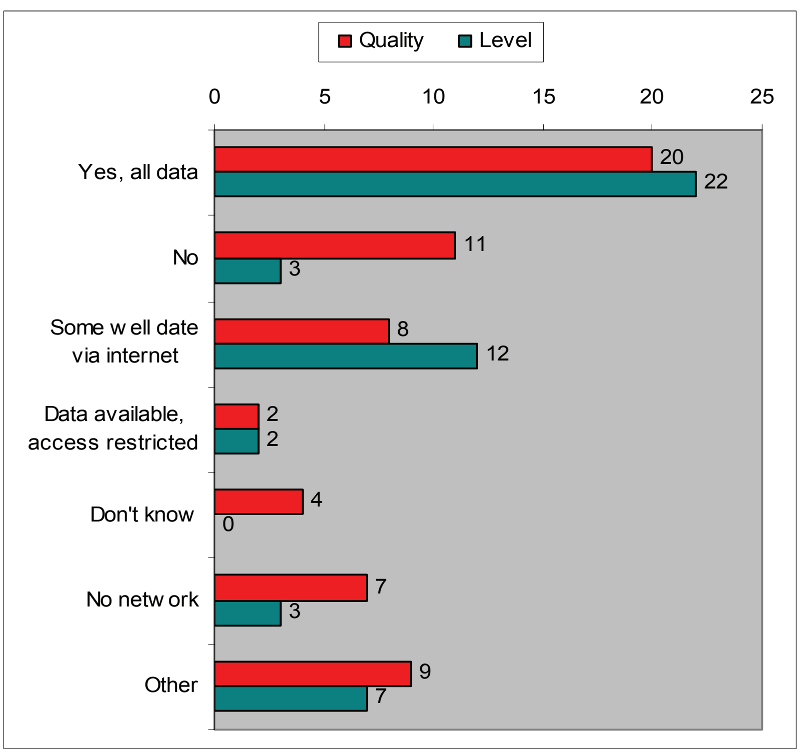
Question 21 – LEVEL/Question 22 – QUALITY. The written Standard Operating Procedures used for Data Management and Storage for the state-wide/regional ground water monitoring network were developed by?



Question 22 – LEVEL/Question 23 – QUALITY. Are the data collected for the state-wide/regional ground water monitoring network routinely entered/maintained in a computer data base?



Question 23 – LEVEL/Question 24 - QUALITY. Are the data available on a website accessible to the public?



Appendix 3. Glossary of Terms

The following terms are used in the Framework Report. Many are commonly used in the ground-water and data-management fields, but some have multiple meanings and thus are defined as used in this report.

Acceptable – Meets criteria described in Framework Document, or as subsequently revised.

Aquifer – A geologic formation from which useable quantities of ground water can be extracted.

a. **Principal** – A regionally extensive aquifer or aquifer system that is either currently used or has the potential to be used as a source of potable water.
b. **Major** – An aquifer or aquifer system that is used for abstraction in significant quantities for potable or other uses, such as irrigation, industrial, power generation, and mining by at least one State and may cross State or national boundaries.

Aquifer flow type – The Principal aquifer flow types are confined and unconfined. Within each of these primary flow types, flow may occur through granular porous media (e.g., sand), through fracture networks in consolidated rocks, or through dissolution channels in consolidated rock.

Background Subnetwork – The Background Subnetwork includes monitoring points that provide data from aquifers or parts of aquifers with no (or minimal) anthropogenic effects.

Baseline monitoring – Historic data or data from an initial monitoring period of up to 5 years used to describe initial conditions of ground water in an aquifer. Baseline can be thought of as a control. Once baseline is described, future datasets can be compared to the control dataset in order to determine if changes have occurred.

Casing depth – The total depth (in feet) to bottom of well casing from land surface rounded to the nearest foot.

Confined aquifer – An aquifer bounded above and below by confining beds.

Confining bed – A body of relatively less permeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

Core (Data elements) – "Core" data elements are a set of data fields accepted by data providers and users to encompass the range of data attributes most useful in documenting and understanding the particular activity that the data represent (see definition of "data element" below).

Core (Questions) – The fundamental (Level I) questions that the NGWMN is designed to answer.

Data elements – An item used to contain data values. A data element can be a field in a relational database, a column in a flat file, an attribute used to describe spatial data, or a row or column in a spreadsheet. Examples of data elements are name, date, length, time, or cost.

Data elements categories –Classification of different subsets of data elements based on recording information about sites, facilities, collection and analysis processes, and results. For ground-water monitoring, these categories include:

- Point of contact
- Site identification/description
- Geologic identification/description
- Well location
- Well characteristics
- Measurement/sampling event
- Water-quality results

a. **Field parameters** – data elements characterizing monitoring site location, conditions, facilities, equipment, and activities
b. **Analytes** – data elements characterizing the substances to be analyzed (e.g., name, CAS number, etc.)

Dedicated monitoring well – A well designed for the sole purpose of long-term monitoring.

Degree of confinement – The degree to which water flow to or from an aquifer is restricted by adjacent geologic units.

Depth – The distance below land surface, or below the measuring point, measured in feet.

Documented Change Subnetwork – The Documented Changes Subnetwork includes monitoring points that provide data from aquifers that have documented anthropogenic effects.

Elevation – Distance above a datum, measured in feet.

Ground water – Water occurring beneath the ground surface in the zone of saturation.

Ground-water level – The elevation (generally referenced to a specific datum) to which water in a tightly cased well screened at a given location will rise. The term is the preferred one for this document; however, other terms are occasionally used, such as ground-water elevation, hydraulic head, piezometric head, and potentiometric head.

Ground-water reserves – The volume of water present in an aquifer at any given time that can be extracted from the aquifer at reasonable cost.

Ground-water surface – The highest elevation at which ground water physically occurs in a given location in an aquifer (i.e., top of aquifer formation in a confined aquifer and the ground-water level in an unconfined aquifer).

Local – An area encompassing a few counties or less.

Metadata – Data describing context, content, and structure of records and their management through time ("data about data").

Minimum data elements – A subset of core data elements that are mutually agreed on by data providers and users as required and essential to be reported to enable basic data exchange and comparison.

NGWMN site – A well or spring assigned by a participating entity to be part of the National Ground-Water Monitoring Network.

Program implementation – Initiating and carrying out the activities related to the operation of the various aspects of the NGWMN program.

Region – An area that is not based on political boundaries.

Regional or Multistate regional network – A network of wells designed to monitor an area larger than a State and often include several States.

Representativeness – The degree to which data from a network accurately represent aquifer conditions. It is affected by factors such as the locations at which samples are collected, number of sampling locations, and sampling frequency.

Special studies – Studies tailored to special or specific questions being asked (as distinguished from surveillance or trend monitoring).

Surveillance monitoring – Ongoing monitoring at low frequency for as many wells in the NGWMN as practical. It is used to assess long-term trends over large areas (as distinguished from trend monitoring or special studies).

Surveillance site – A well or spring used to assist in characterizing ground-water conditions during a synoptic sampling event.

Suspected Change Subnetwork – The Suspected Changes Subnetwork includes monitoring points that provide data from aquifers that may have suspected or anticipated anthropogenic effects. These may be in areas where withdrawals are occurring, but regional water-level changes have not yet occurred or where land use has changed so that water-quality affects may be occurring. Also, wells in this subnetwork may be in areas where changes are anticipated.

Top of screen or open hole – Assuming well taps only one ground-water producing zone, it is the depth to the top of the screened or open hole interval measured in feet from land surface, rounded to the nearest foot.

Trend – A systematic change in ground-water conditions over time.

Trend monitoring – Monitoring subsets of NGWMN wells at higher frequencies than used for surveillance monitoring. The purpose is to evaluate temporal trends that occur more rapidly than can be observed in surveillance monitoring.

Unconfined aquifer – An aquifer in which the ground-water level near the ground-water surface is equal to the ground-water surface. An alternative and equivalent definition is an aquifer in which the ground-water surface is at atmospheric pressure.

Unstressed – Ground-water conditions (quantity and quality) that have not been altered by anthropogenic influence (or detrimental amount of alteration).

Unstressed area – A region where the ground-water conditions have not been altered by anthropogenic influences.

Water-use categories or types

- **Domestic –** Water used for residential, commercial, institutional purposes.
- **Public –** Water used for all purposes by the public.
- **Irrigation –** Water artificially applied on lands to assist the growing of crops and pastures or in the maintenance of recreational lands, such as parks and golf courses.
- **Livestock –** Water used by horses, cattle, sheep, goats, hogs, poultry, and other commercially important animals.
- **Mineral exploration and extraction –** Water used (1) in the extraction or washing of minerals, (2) in quarrying and milling, and (3) for the extraction for crude petroleum and natural gas.
- **Industrial –** Water used in the manufacture of metals, chemicals, paper, and allied products.
- **Hydroelectric and thermoelectric power –** Water used by plants fueled by fossil fuels or nuclear generation and used to drive turbines that generate electric power.

Appendix 4. State and Regional Monitoring Designs

4-4.1 Montana's Network – Framework and Overview

Montana's Ground-Water Assessment Program, which includes a statewide monitoring network, was established by the Montana Legislature in 1991. Statute specifically requires that Montana's nonregulatory geological survey, the Montana Bureau of Mines and Geology (MBMG), systematically monitor and characterize Montana's ground water. The Legislature's goal was to improve the quality and availability of ground-water information so that Montana citizens could better develop, protect, and manage ground-water resources. MBMG operates the Ground-Water Information Center (GWIC) database (*http://mbmggwic.mtech.edu*) where program data and many other ground-water data are easily accessible. The Ground-Water Assessment Program is funded at about $770,000 annually.

Within the assessment program, MBMG has established a statewide, 900-well, monitoring network designed to generate long-term records of ground-water quantity and quality. MBMG employees and cooperators travel to network wells each calendar quarter to measure water levels, service about 100 water-level recorders, and collect water-quality samples.

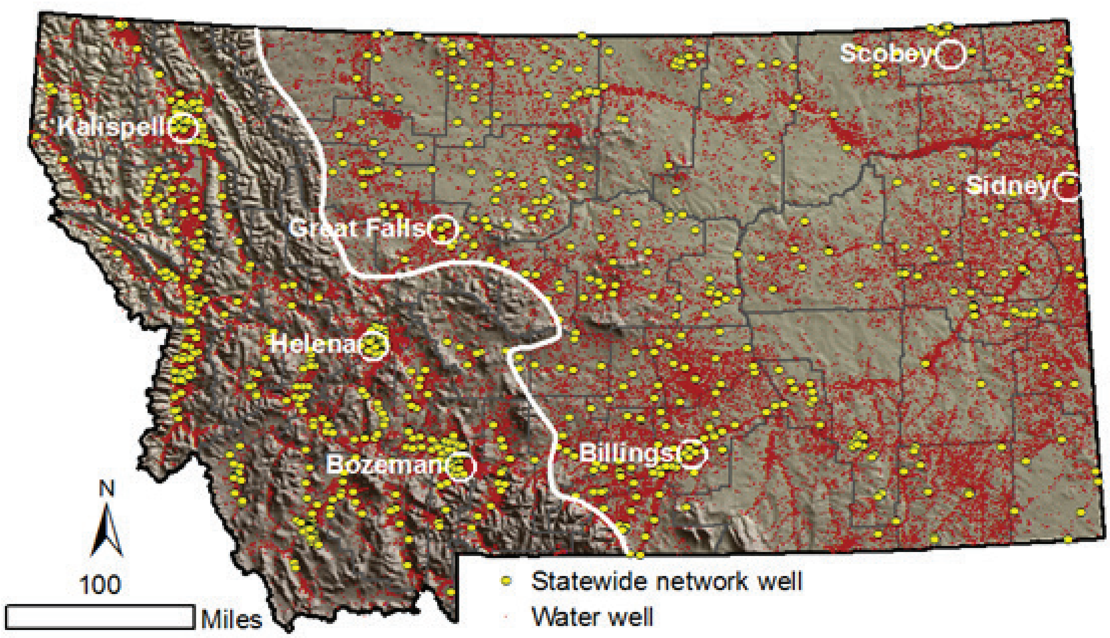


Figure 4-4.1.1 Montana's statewide monitoring network (yellow points) provides data from heavily used intermontane basin aquifers in the west and widely used alluvial, Lower Tertiary, Upper Cretaceous, Lower Cretaceous, and Paleozoic aquifers in the east. Red points mark the locations of more than 210,000 water wells. The northwest-southeast white line designates the general boundary between intermontane basin aquifers in the west and regionally extensive bedrock aquifers in the east.

4-4.1.1 Network Design

Montana's network design is based primarily on aquifer distribution and level of development; therefore, statewide monitoring spatially reflects Montana's geology and those areas where ground water is heavily developed. Monitoring locations may also be based on local interests and identified needs for focused monitoring. An example of a focused segment within Montana's network is a cluster of monitoring points due north of Scobey in northeast Montana as shown in figure 4-4.1.1. Coal mining in Saskatchewan, immediately north of the United States–Canada border, presents potential quantity and quality issues to this area of Montana.

The scope of the monitoring program is controlled by budgets and the overall purpose to generate long-term data on a generally aquifer-wide basis. Early network designs called for inclusion of about 700 wells, but since inception in 1991, the network has grown to about 900 wells, primarily through new locations resulting from Ground-Water Characterization Program studies and the construction of dedicated monitoring wells by local water-quality districts.

Montana's complex geology of intermontane basins in the west connected by thin alluvial deposits along river valleys and regionally extensive bedrock sandstone and carbonate rock aquifers in the east required different design approaches.

Western Montana: Western Montana monitoring wells are distributed within the intermontane basin aquifers west of the northwest-southeast line shown in figure 4-4.1.1. Where available, potentiometric surface and geologic maps for an intermontane basin guided monitoring well selections so that up-gradient recharge, mid-basin storage, and down-basin discharge areas would be represented. Network well distribution in a typical western Montana intermontane basin is shown in figure 4-4.1.1.1.

Eastern Montana: Eastern Montana aquifers are located in alluvial deposits along rivers and streams and in extensive bedrock formations of Lower Tertiary to Paleozoic age east of the northwest-southeast line shown in figure 4-4.1.1. These aquifers are in outcrop or relatively near land surface near structural highs but are sometimes more than 1,000 feet (ft) below land surface in structural basins. Because there are relatively few wells deep in the basins, most of the bedrock aquifers are monitored near their outcrop. The Fox Hills/Hell Creek aquifer as shown in figure 4-4.1.1.2 is an example.

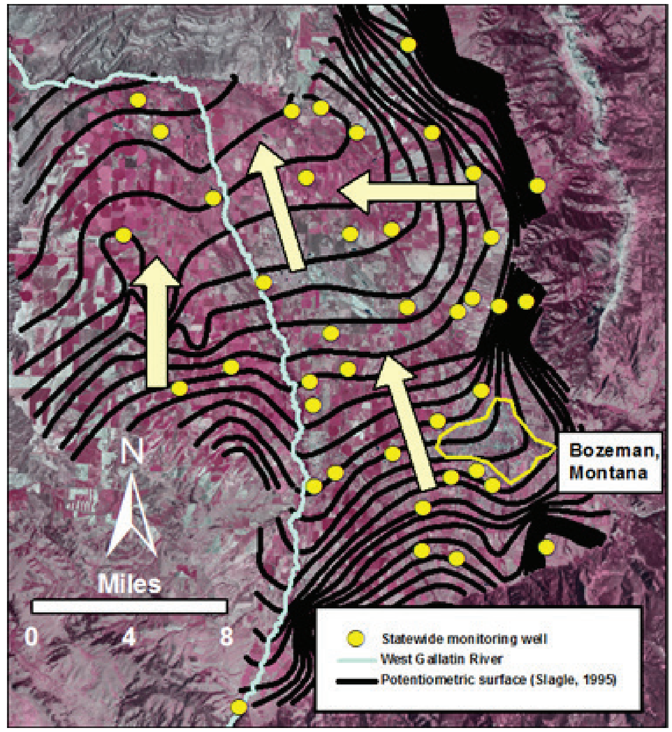


Figure 4-4.1.1.1 Monitoring wells in southwest Montana's Gallatin Valley provide water-level and water-quality data in the valley-wide flow system. The arrows show general direction of ground-water flow. The wells are measured under a cooperative agreement with the Gallatin Valley Local Water Quality District.

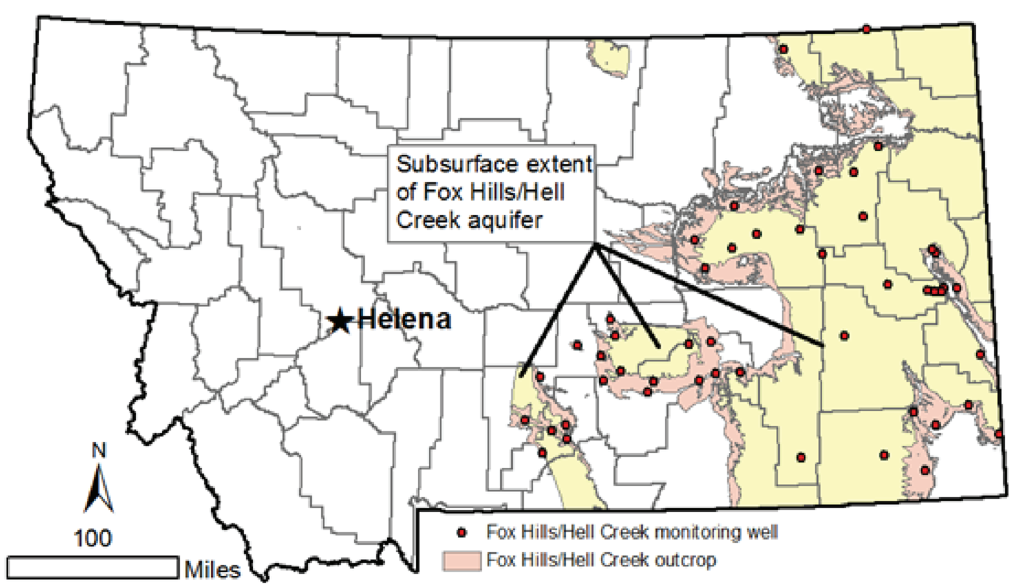


Figure 4-4.1.1.2 The Fox Hills/Hell Creek Formations and associated rocks form an extensive aquifer in eastern Montana. Most statewide monitoring wells are near outcrops where the formation is relatively near land surface. Wells distant from the outcrop range in depth from 600 ft in the south to 1,500 ft in the north.

4-4.1.2 Monitoring Wells

The Montana Legislature did not provide funding to construct dedicated monitoring network wells when it established the Ground-Water Assessment Program; therefore, MBMG used existing wells that met the following criteria to build the network:

- available driller's log or other documentation for well construction,
- low demand for water production (dedicated monitoring wells),
- good access for measurement and that were likely to remain accessible for the indefinite future, and
- a pre-existing water-level record to build upon.

Sometimes well selection presented tough choices. For example, a well might have good access, be completed in an aquifer of interest, have a long period of previous measurements, but because of its age have poor to few construction records. All other factors being equal and if there was reasonable certainty about the aquifer in which the well was completed, precedence was given to period of record because historic record cannot be recovered in any other manner.

A long-term goal is to reduce the number of production wells that are part of the network, but in some areas production wells will always be present. For example, some production wells in eastern Montana are at remote farmsteads, are used only seasonally for stock watering, and often are hundreds of feet deep. Aquifer stresses, therefore, are low and at a quarterly sampling frequency, water levels are usually static at the time of measurement.

In the 15 years since the network has been established, some county-based local water-quality districts have constructed dedicated monitoring well networks within their boundaries. Cooperative agreements between MBMG and the Gallatin, Lewis and Clark, and Missoula County local water-quality districts have resulted in inclusion of 73 county-owned wells in the statewide network.

About 50 percent of the network is dedicated monitoring wells, unused production wells, or very low-use production wells. Examples of very low-use wells are those that serve remote one-room schools in eastern Montana, or highway department maintenance shops. Most other network wells produce water for domestic and stock purposes. The distribution of dedicated, unused, and low-use wells is shown in figure 4-4.1.2.1.

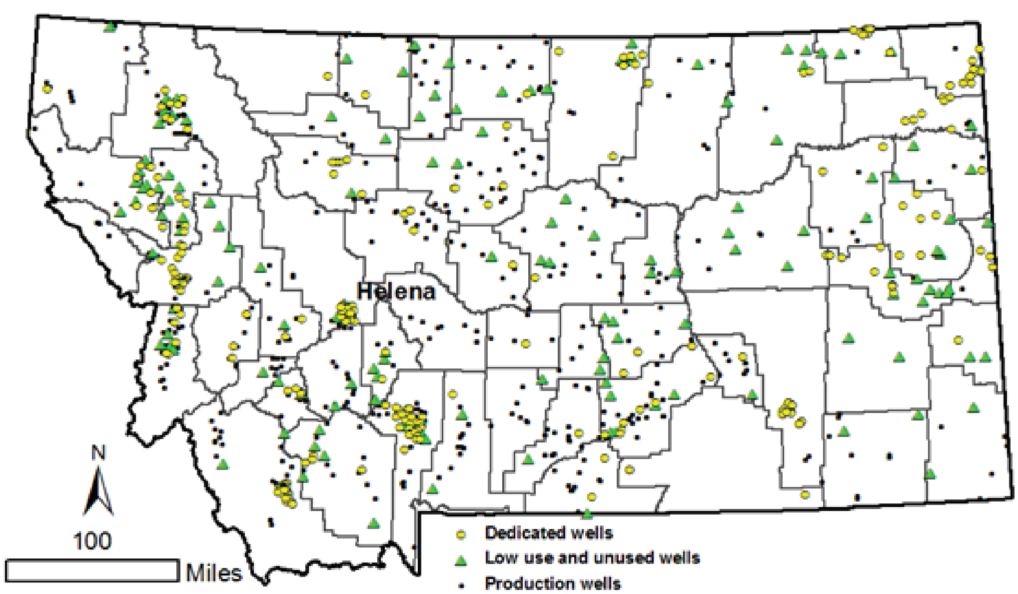


Figure 4-4.1.2.1 The Montana network contains about 30 percent dedicated monitoring wells. Another 20 percent of wells are unused or of very low use. The remainder is mostly production wells that produce water for stock and domestic purposes.

4-4.1.3 Monitoring Frequency and Period of Record

Monitoring program staff and cooperators visit each network well quarterly to measure water levels and service water-level recorders. MBMG staff collect inorganic water-quality samples from about 70 sites annually, concentrating on groups of wells that have not been sampled during the previous 10–12 years. Water-level data are entered into the GWIC database remotely or in Butte by using Web-based tools and are available in the database for public access usually within 1 week of measurement or instrumental download. Water-quality results are added to the database when released by the laboratory.

Figure 4-4.1.3.1 shows the spatial distribution of water-level measurement frequencies within the Montana network. About half of the network wells have between 11 and 15 years of record (table 4-4.1.3.1). The median number of measurements for all network wells is four per year, but the range is from about once annually for a few wells that have not been measured consistently across their periods of record to hourly for wells that have data loggers. The frequency of measurement during a period of record may vary, depending on installation of recorders, cooperative agreements, or other factors.

MBMG staff and cooperators use standardized field methods to make sure that static-water levels are measured consistently, but some wells produce data that at times are influenced by nearby pumping or other factors. If a well is pumping or in recovery at the time of a site visit, measurements are either not made, not kept, or flagged as non-static. Data users, depending on their purposes, can choose whether or not to include non-static water-level data analyses.

About 70 samples for common constituents and trace metals are collected from network wells each year. Because there are about 900 wells in the network, each well is sampled every 10–12 years. Network wells can also be included temporarily in short-term projects and may be sampled on a more frequent basis. Standard sampling procedures require that multiple casing volumes be pumped and that field conductance, pH, and temperature stabilize before water is bottled for the laboratory. Samples are filtered and preserved in the field for dissolved metals analysis, and nitrate-nitrogen samples are preserved with sulfuric acid to extend holding times.

Table 4-4.1.3.1 About 120 statewide monitoring wells in Montana have periods of record greater than 25 years. Most wells are measured between 3 and 12 times annually.

Period of record			Frequency of measurement		
Period (years)	Wells	Percent	Measurements per year	Wells	Percent
0–5	55	6.0	0–1	3	0.3
6–10	138	15.2	2–3	160	17.8
11–15	428	47.0	3–4	311	34.6
16–20	63	6.9	5–12	286	31.8
21–25	105	11.5	12–24	12	1.3
>25	121	13.3	>24	127	14.1
Totals	910	100		899*	100

*Eleven wells have less than 1 year of record.

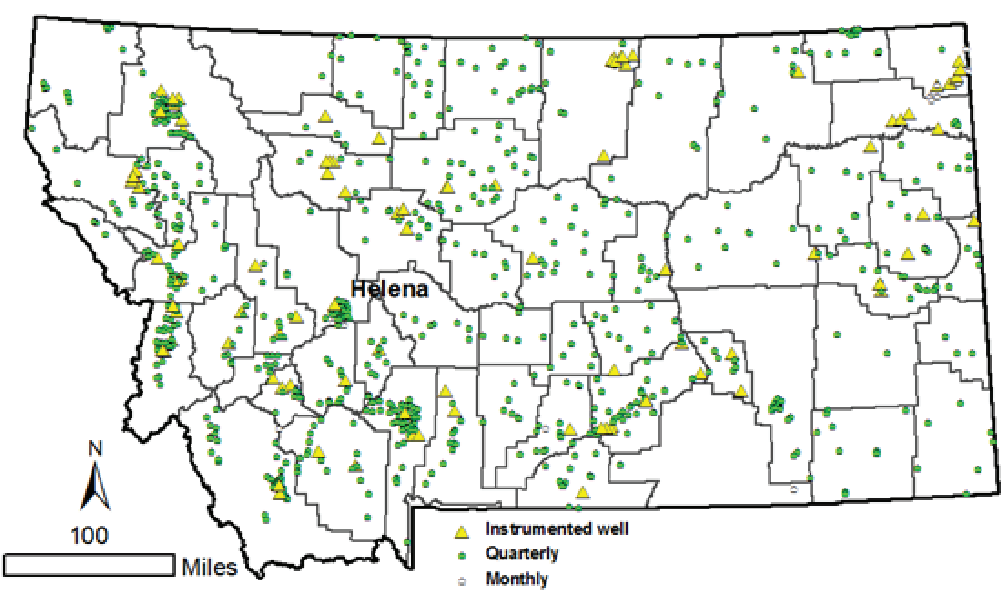


Figure 4-4.1.3.1 Measurement frequencies in the statewide Montana network range from monthly, to quarterly, to hourly from some instrumented wells.

4-4.1.4 Cooperative Agreements

Most network operations are conducted by MBMG personnel, but water-level data from about 160 wells are obtained through cooperative agreements between MBMG and local water-quality districts, Indian tribes, and the U.S. Geological Survey (USGS). Most of the statewide network wells monitored by cooperators are also part of local or substate networks that address other purposes. County water-quality districts have data-collection/research missions similar to that of MBMG, and the alignment in agency purposes makes the cooperative agreements more productive.

The USGS operates 10 water-level recorders for MBMG at remote locations and measures another 9 wells quarterly. The quarterly measurements come from wells along the lower Clark Fork River Valley in northwest Montana. USGS personnel travel to the same area monthly to service surface-water measurement stations at a number of dams; therefore, this alignment of data-collection missions is an efficient way to service this part of the network.

4-4.1.5 Products and Data Dissemination

All network-generated water-level and water-quality data are stored in the GWIC databases at MBMG (*http://mbmggwic.mtech.edu*). The database contains more than 2.1 million water levels from about 11,600 of 210,000 wells in Montana. System users can obtain well-construction, water-level, and water-quality data from individual wells or for groups of wells in areas as large as drainage basins. Figure 4-4.1.5.1 shows part of the main menu screen for GWIC's Web site.

Users have multiple ways to access water-level data and, once a location is selected, can retrieve hydrographs showing how water levels change with time (figure 4-4.1.5.2). GWIC hydrographs also contain departure from annual or quarterly precipitation charts for comparison to the water-level data. Figure 4-4.1.5.2 is a hydrograph from a well completed in northwest Montana's Flathead Valley near Kalispell. There are about 16,000 wells in Flathead County where this well is located, mostly in the Kalispell Valley. Measurements were collected between about 1965 and 1990 by the USGS under various cooperative agreements. Montana's Ground-Water Assessment Program has measured the well since 1991. The long-term record shows a downward water-level trend, which is likely related to development, but the record also shows a period between 1995 and 1998 when water levels rose, apparently in response to wetter than normal climate.

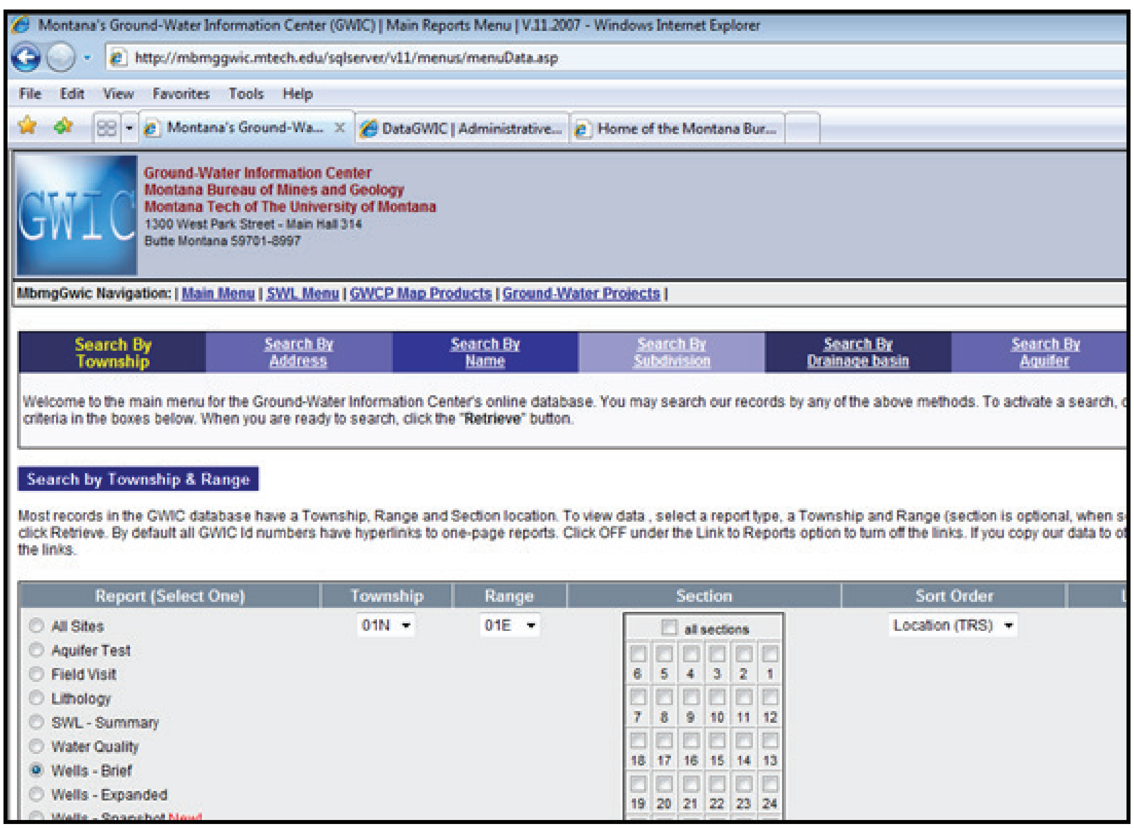


Figure 4-4.1.5.1 Ground-water data for Montana are available through MBMG's GWIC database. Users can select from multiple search-and-report options to locate well-construction, water-quality, water-level, and aquifer-test data.

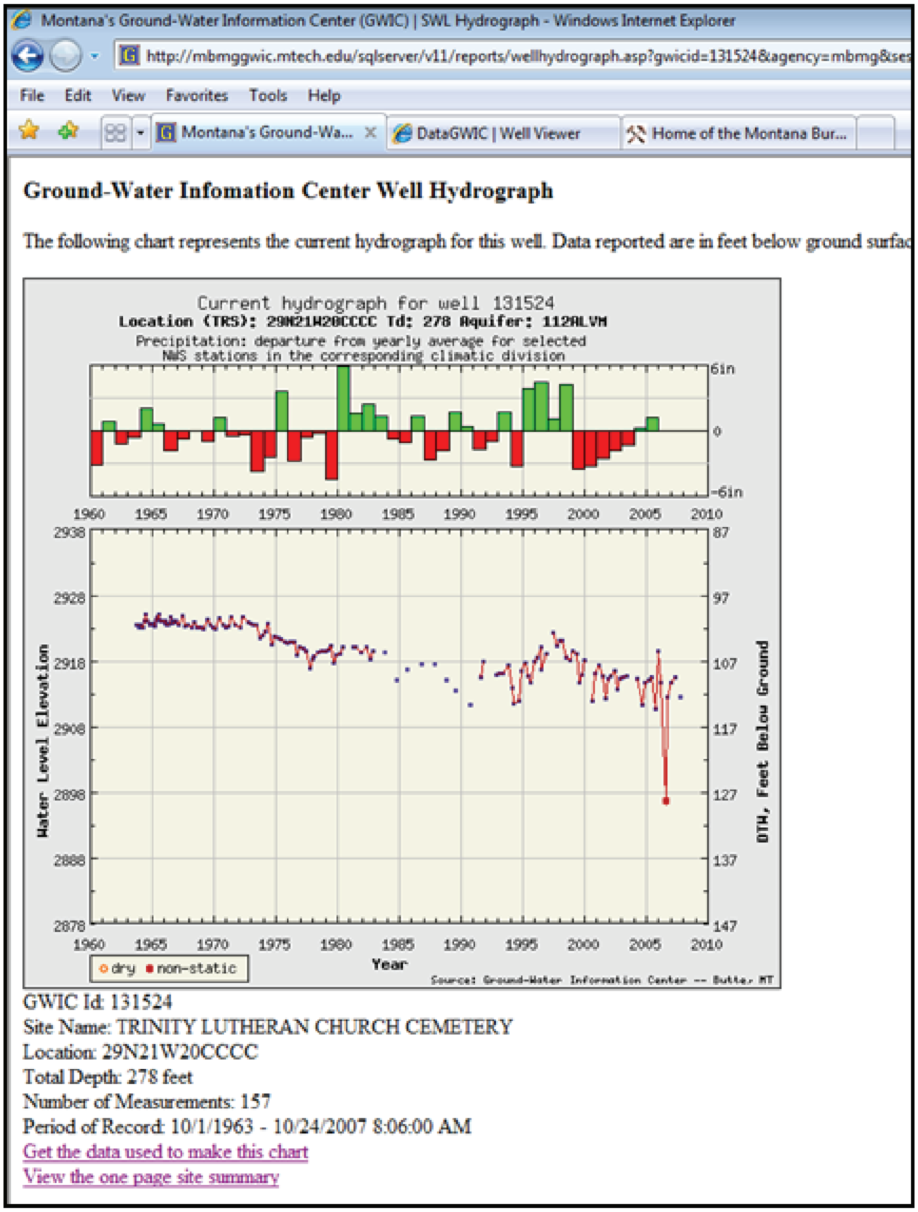


Figure 4-4.1.5.2 Hydrograph of water levels in a long-term monitoring well in northwest Montana's Flathead Valley showing the status of the aquifer prior to extensive development beginning in the early 1970s. A long-term downward trend appears to have begun in about 1973. Superimposed on this trend are influences caused by general pumping in the aquifer and response to wetter than normal climate between 1995 and 1998. A single "recovering" water level measured in 2006 is flagged as a "non-static" measurement.

Links at the bottom of the hydrograph provide access to the well-log report or allow the user to download the data used to make the water-level graph. Once the water-level data are downloaded, users can make presentation hydrographs in styles appropriate to their needs or otherwise process the information. If the user retrieves the well log, a well-log report shown in figure 4-4.1.5.3 allows evaluation of the well's construction details. In this case, the well is open only at the bottom of the casing at 278 feet below land surface.

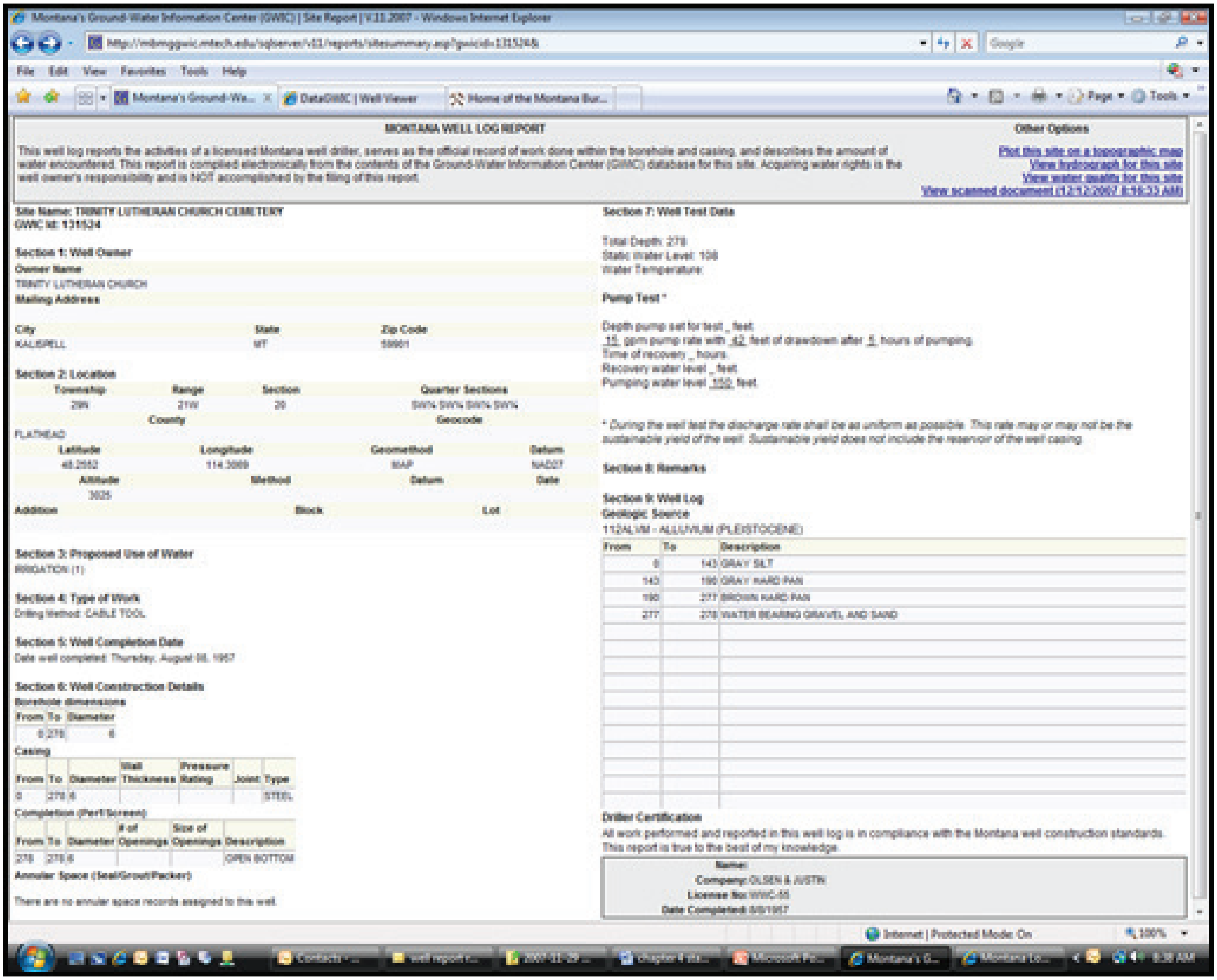


Figure 4-4.1.5.3 The GWIC well-log report provides construction details for the monitored well as well as links that allow a user to plot the well on maps or photographs, access water-quality results, access the hydrograph, and view a scanned image of the original well-log document.

4-4.1.6 Summary

Montana operates an extensive statewide monitoring network that generally is aquifer based and dedicated to gathering long-term water-level and water-quality datasets. Although the majority of the network is managed directly by MBMG personnel, subnetworks managed at the county level are included through cooperative agreements. All data generated are provided to Montana's GWIC, where they are accessible through the Internet. Since January 1, 2007, more than 22,100 hydrographs have been downloaded from the GWIC Web site.

4-4.2 Florida's Network – Introduction

In 1983, the Florida Legislature passed the Water Quality Assurance Act (Florida Statutes, Chapter 403.063). A portion of the Act required the Florida Department of Environmental Protection (FDEP) to establish a ground-water quality monitoring network designed to detect or predict contamination of the State's ground-water resources. Regarding the operation of the network, the Act also required FDEP to work cooperatively with other State agencies, Federal agencies, Florida's five water-management districts (WMDs), and its counties (figure 4-4.2.1). The Act defined the three basic purposes of the monitoring program:

1. Determine the background ground-water quality of Florida's major aquifer systems,
2. Detect or predict changes in ground-water quality that may result from the various land uses and potential sources of contamination, and
3. Disseminate ground-water quality data generated by the network to local governments and to the public.

FDEP management later stipulated that, in addition to data, it would also disseminate interpretative results based on data generated by the network.

Three important structural elements of the network are:

1. Because of the high cost of installing new monitoring wells, the statewide network consists, overwhelmingly, of existing wells,
2. In order for a well to be included in the network, construction data are required, as well as an access agreement, and
3. Although the network primarily is designed as a ground-water quality network, it has always obtained ground-water level data.

It should be noted that existing wells include a variety of well types: from dedicated monitoring wells for specific projects, to domestic supply wells, to large production wells.

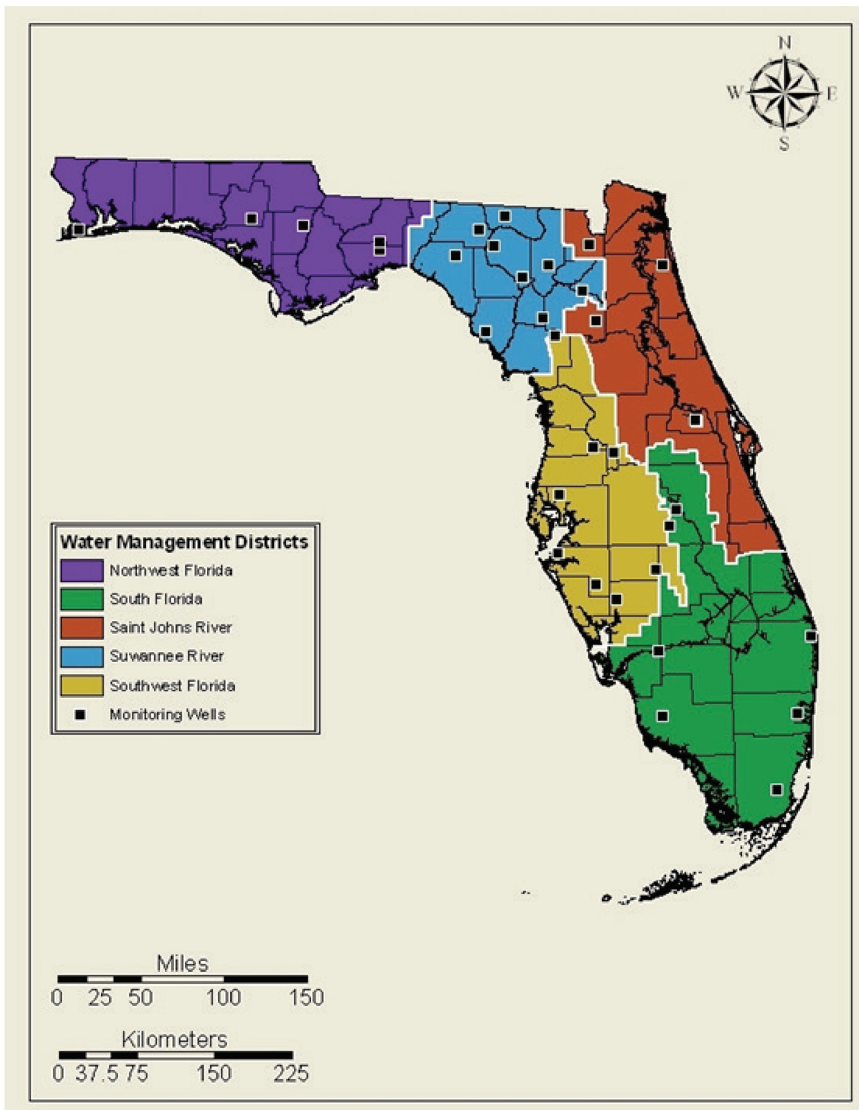


Figure 4-4.2.1 Five water-management districts, 67 counties, and the locations of temporal variability monitoring wells in Florida.

4-4.2.1 Overview of Florida's Hydrogeology

Florida's ground-water resources are located in a complex lateral and vertical sequence of sediments of Cenozoic age composed of both siliciclastics and carbonates. Three major freshwater aquifer systems, made up of one or more aquifers, are present (Southeastern Geological Society, 1986). The three systems are the surficial aquifer system (SAS), the intermediate aquifer system and (or) intermediate confining unit (IAS/ICU), and the Floridan aquifer system (FAS).

The SAS is made up primarily of carbonate rocks in the south, whereas in the north and northwest it is made up of siliciclastic material. The SAS is thin to absent near where Florida's peninsula and panhandle meet (figure 4-4.2.1.1), but it can be more than 100 ft thick in other areas. Throughout Florida, the SAS provides small yields to many wells as depicted by the distribution of monitoring wells (figure 4-4.2.1.2). The aquifer system, however, is heavily used as a source of ground water in southeast Florida's Biscayne aquifer and in northwest Florida's sand and gravel aquifer (figure 4-4.2.1.1).

The upper portion of the IAS/ICU is mostly siliclastic sediments, whereas its lower sequence is most generally carbonate rocks. The aquifer system is thin to absent where the peninsula and panhandle merge but does exist across much of Florida. In southwest Florida (figure 4-4.2.1.1), the IAS/ICU is a major source of ground water but is only a secondary source of water in northeast Florida and over much of the panhandle (figure 4-4.2.1.2).

The FAS occurs within carbonate rocks and is one of the principle aquifers/aquifer systems of the United States. It extends from Mississippi to South Carolina (figure 4-4.2.1.1). The carbonate rocks have been altered extensively by karst processes causing extreme variations in permeability. Generally, the FAS is extremely productive and, except in the southern third of the peninsula (figure 4-4.2.1.2) where the depth to the Floridan and high dissolved solids ground water inhibit its water use, serves as the primary source of drinking water for most Floridians.

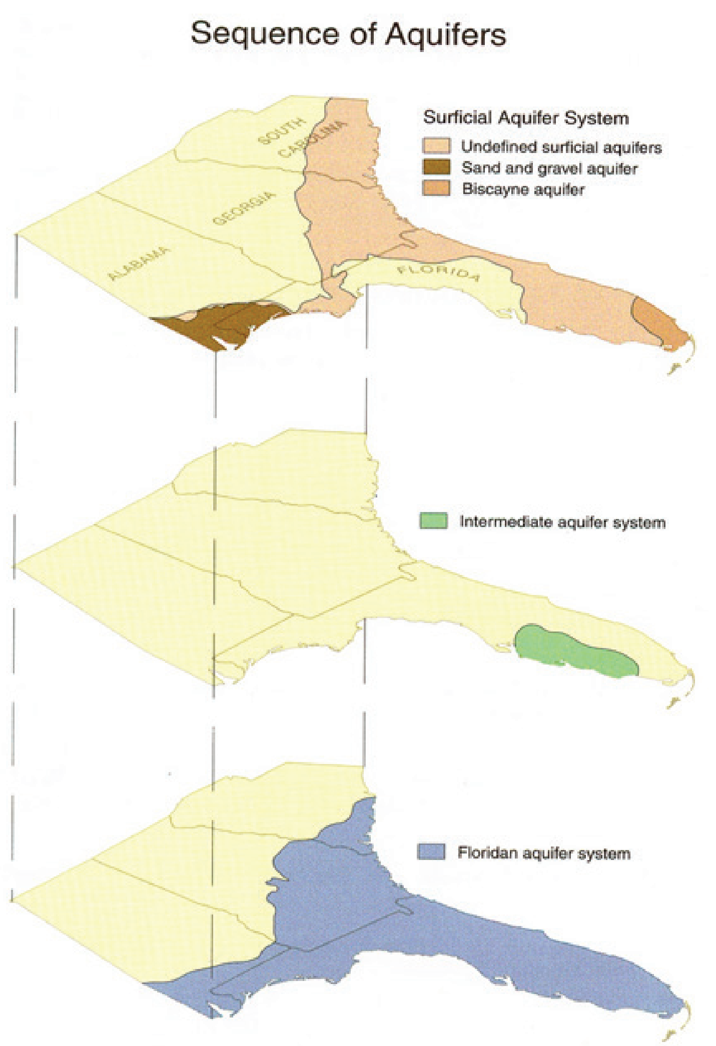


Figure 4-4.2.1.1 Florida's major freshwater aquifer systems, displaying areas where they are sources of significant ground-water use (from Berndt and others, 1998).

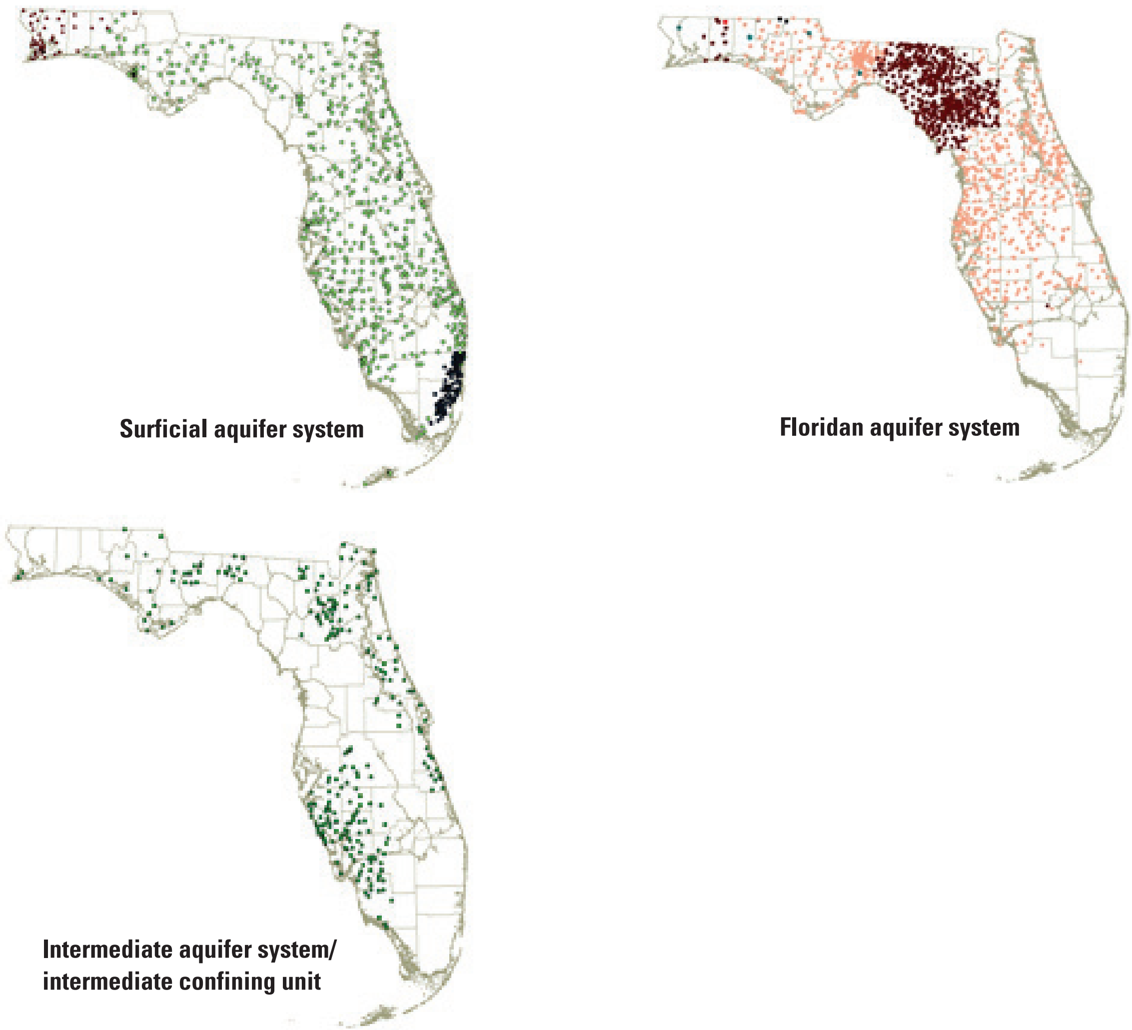


Figure 4-4.2.1.2 Distribution of monitoring wells by aquifer system (circa 1996).

4-4.2.2 Establishment, Operation, and Design of Florida's Ground-Water Quality Network – Phases I and II

The monitoring program began actual operations in 1984 and since that time has gone through several operational phases. Design changes in the program have made it better able to address Florida's evolving ground-water protection priorities.

Phase I began in 1984 and continued through 1990. During this phase, the Ground Water Quality Monitoring Network was fully established and slowly evolved from a series of separate monitoring activities into a cohesive statewide monitoring program. The network was aquifer-system based and included monitoring wells completed in the SAS, IAS/ICU, or the FAS. The network was designed to address ground-water questions pertaining to those aquifer systems.

During Phase I, FDEP was the lead agency determining the network's goals and strategies, setting priorities, and coordinating the overall effort; however, FDEP worked closely, through cooperative agreements, with the WMDs, several counties, the USGS, and the Florida Geological Survey (FGS). The WMDs and counties did most of the field work and provided local technical expertise. The USGS provided technical support. The FGS provided technical support and installed many network wells.

By 1991, baseline (initial) ground-water quality conditions were defined (Upchurch, 1992), and two major subnetworks were established. Each subnetwork had its own unique monitoring priorities and objectives.

The Background Network (*http://www.dep.state.fl.us/water/monitoring/bn_net.htm*) was designed to define background ground-water quality in each of Florida's three major aquifer systems. By late 1990, the Background Network had grown to include more than 1,500 wells. Figure 4-4.2.1.2 shows the well density within each aquifer system.

The Very Intense Study Area (VISA) Network was designed to monitor the effects of various land uses on ground-water quality within specific aquifers (*http://www.dep.state.fl.us/water/monitoring/visa_net.htm*). By the end of 1990, four general land-use categories—(1) agriculture, (2) urban/suburban, (3) industrial, and (4) mining—were being monitored by more than 20 VISAs.

The Temporal Variability Network is a subset of the Background Network (*http://www.dep.state.fl.us/water/monitoring/trend.htm*). Since 1991, approximately 46 wells (figure 4-4.2.1) have been sampled on a "high frequency" basis (either monthly or quarterly). Temporal Variability Network "high frequency" monitoring within VISAs varied, depending on data needs in individual VISAs.

The monitoring program entered Phase II in 1991, which continued until 1999. Between 1991 and 1993, approximately 500 Background Network wells were sampled annually for a standard set of analytes, consisting of field parameters, major cations and anions, nutrients, and some miscellaneous parameters. In addition, the network wells were sampled for an extended list of synthetic organic compounds. By the end of 1993, the entire State had been sampled for the standard and extended analyte list. Between 1994 and 1996, approximately 500 additional Background Network wells were sampled for the standard list of analytes. In this sampling phase, the extended list of analytes consisted of pesticides rather than synthetic organics. Between 1997 and 1999, a final set of about 500 Background Network wells was sampled. The standard list did not change, but the extended list consisted of trace metals.

The changing extended lists allowed Florida to economically sample for numerous potential contaminants. In the early 1990s, the plan was to continue the 3-year cycles. In that way, complete statewide "sweeps" of the State for the standard list would be completed every 3 years, and statewide "sweeps" of each extended list would be completed every 9 years.

4-4.2.3 Integration with Surface-Water Monitoring – Phase III

By the late 1990s, FDEP management recognized the importance of integrated ground-water and surface-water monitoring. Two separate monitoring programs within FDEP were merged and an efficient, multiresource, comprehensive monitoring network was created. The revised, integrated network (Status Network) had six major objectives (Copeland and others, 1999):

1. Identify, document, and predict the conditions of Florida's water resources,
2. Establish the water quality in relatively "pristine" reference sites for comparison with affected water bodies,
3. Document potential problem areas,
4. Identify water-quality changes over time in pertinent water bodies,
5. Provide information to managers, legislators, agencies, and the public, and
6. Determine the proportion of Florida's water bodies that regularly meet water criteria.

The FDEP and its cooperators were, and currently still are, responsible for monitoring the following water-resource categories: (1) large streams, (1) small streams, (3) large lakes, (4) small lakes, and regarding ground water, (5) confined ground water, and (6) unconfined ground water (including water from leaking artesian aquifers). Thus, the ground-water network changed from being aquifer (aquifer system) based to being aquifer "condition" based.

For the monitoring program's third phase (2000–2008), Florida was divided into 29 geographical regions (reporting units). It should be noted that reporting units are large surface-water basins and that the analytes monitored for each resource were designed to be as similar as possible.

Each year, coordinated sampling occurs in all six resource categories within five or six geographic reporting units. In this integrated manner, approximately 20 percent of the State is monitored annually. The sampling effort produces a report for each geographic reporting unit relaying the water quality of each of the six water-resource categories. After 5 years, the entire State is sampled, and a report containing an analysis of statewide water quality is generated.

The monitoring design for each of the six water-resource categories is based on probabilistic sampling, and each design has many similarities (Copeland and others, 1999). In Florida during a given year and for each sampled reporting unit, 30 sampling points are randomly selected for each resource category. Phase III of the program began operations in 2000 (*http://www.dep.state.fl.us/water/monitoring/status.htm*) with the initiation of the Status Monitoring Network.

With regard to ground water within an individual reporting unit, as many as 30 samples were collected from wells tapping confined ground water and as many as 30 samples were collected from unconfined (or leaky confined) ground water. Thus, as many as 60 wells were sampled during Phase III.

In order for probabilistic sampling to produce the most representative results, it is desirable to have a selection list of wells tapping as many portions of each aquifer system, in both area and space, as possible. The enhanced well distribution increases the probability of obtaining a representative sample of ground water in three dimensions.

For this reason in the late 1990s, Florida increased the number of wells to be included in a list of potential sampling sites. During the last half of the 1990s, the number of wells increased to more than 10,000. Currently there are nearly 20,000 wells that potentially can be sampled.

Temporal Monitoring: It should be noted that in spite of the design change for special monitoring, Florida continues to monitor ground water temporally. For example, FDEP continues monthly and quarterly monitoring of 46 Temporal Variability wells (figure 4-4.2.1). In addition, because of increasing nutrient concentrations in Florida's spring water (Florida Spring Task Force, 2000) in 2001, FDEP began quarterly sampling 60 of Florida's major springs.

Aquifer "condition"-based versus aquifer-based monitoring: The NGWMN is aquifer based, whereas Florida's design is currently aquifer "condition" based. Wells were tagged as tapping either confined or unconfined (including leaky artesian) aquifers. The aquifer (aquifer system) tapped by each well also was tagged. Because of the tagging efforts, Florida is able to monitor both aquifer "conditions" and aquifer systems.

4-4.2.4 Phase IV

Beginning in 2009, the program will enter its fourth phase. The design of the network will remain very similar to Phase III but for economical reasons, fewer samples will be collected from each resource category. Instead of sampling five or six reporting units yearly, Florida will sample a water-resource category across the entire State annually. Thus, instead of reporting on the status of 20 percent of the State each year and a statewide assessment every 5 years, Florida will make statewide annual assessments for each resource category but will not assess individual reporting units.

4-4.2.5 Products Over the Years

Phases I and II -

- The Generalized Well Information System (GWIS) was first released in June of 1987 and was designed to provide easy and inexpensive access to the data collected by the Ground Water Quality Monitoring Network. Information was distributed by way of compact disc (CD) and included a compiled application, which allowed retrieval of Ground Water Quality Monitoring Program data from data tables included on the CD.
- A description of Florida's hydrogeologic framework and a description of Florida's Ground Water Quality Monitoring Program are available at *http://www.dep.state.fl.us/water/monitoring/sp32.htm.*
- A description of Florida's background and baseline hydrogeochemistry is available at *http://www.dep.state.fl.us/water/monitoring/sp34.htm.*
- Information regarding the VISA Network is available at *http://www.dep.state.fl.us/water/monitoring/visa_net.htm.*

Phases III and IV –

- Ground-water chapters are submitted to the U.S. Environmental Protection Agency (USEPA) as part of the biannual statewide water-quality report as required by the Clean Water Act. The 2006 report is available at *http://www.dep.state.fl.us/water/tmdl/docs/2006_Integrated_Report.pdf.*
- Basin (reporting unit) reports are being written and posted online for each of the 29 basins sampled for the Status Monitoring Network, *http://www.dep.state.fl.us/water/monitoring/basins.htm*.

4-4.3 South Dakota – Overview

The Geological Survey Program, South Dakota Department of Environment and Natural Resources, operates and maintains a ground-water quality monitoring network. The network is designed to provide information about nonpoint-source pollution and ambient water quality in several surface, or near surface, aquifers. The network presently consists of 150 wells at 85 sites in 26 aquifers (figure 4-4.3.1).

Implementation of the formal monitoring network commenced in 1994 through the drilling and installation of monitoring wells and through the incorporation of older wells that had been installed for previous projects. Drilling and installation of wells for the initial network continued through 1998.

All wells in the monitoring network were installed using the Geological Survey Program's drilling equipment and personnel. Thirty-six of the wells were incorporated from previous projects, and 14 of those are 2 inches in diameter. The remaining wells in the network are 4 inches in diameter. The format for a typical well identifier shown in figure 4-4.3.1 is R20-89-54. In this example, "R20" refers to the drilling rig that was used to drill the boring in which the well is constructed. The "54" and "89" indicate that the well was constructed in the 54th boring drilled by that rig in 1989. The three oldest wells were drilled (one in 1980 and two in 1983) using the mud rotary method, and the hollow stem auger method was employed for the other wells using the Geological Survey Program's Mobile B-61 drilling rig (figure 4-4.3.2).

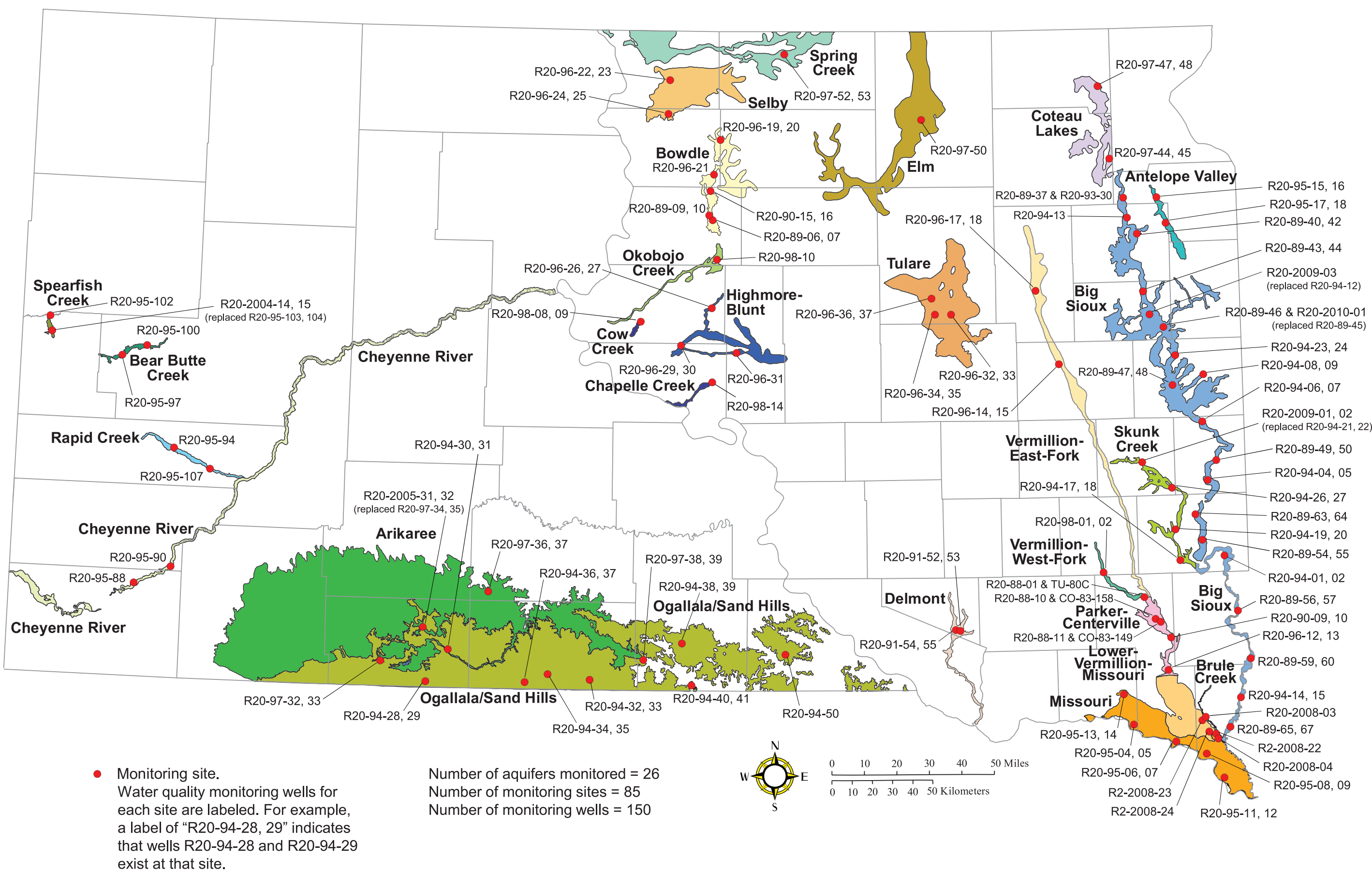


Figure 4-4.3.1 South Dakota's statewide ground-water quality monitoring sites.

Figure 4-4.3.2 The Geological Survey Program's Mobile B-61 drilling rig.

All wells were constructed using polyvinyl chloride (PVC) casing and screen. A schematic of typical well construction is provided in figure 4-4.3.3. Each well has dedicated sampling equipment installed to maximize efficiency of collecting water samples and to minimize the potential of accidentally introducing trace contaminants into a water sample (figure 4-4.3.4).

Several criteria were used in the selection of monitoring sites within the targeted shallow aquifers and are as follows:

- The site must be representative of typical land use over the aquifer.
- The site must not be near any known or suspected point source of pollution.
- The site, if possible, should be over a part of the aquifer that is thick enough to accommodate nested wells.
- The site must be readily accessible to the drilling equipment of the Geological Survey Program and must be reasonably accessible in inclement weather for sampling.

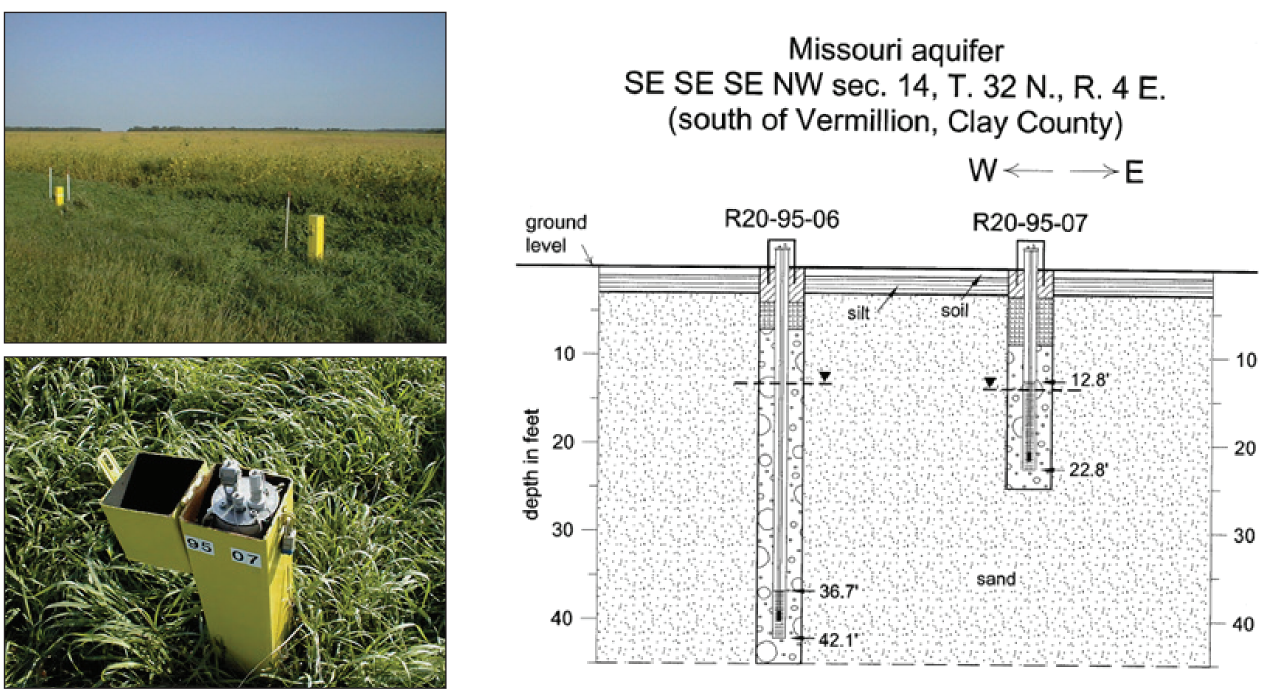


Figure 4-4.4.3 A typical monitoring site in eastern South Dakota.

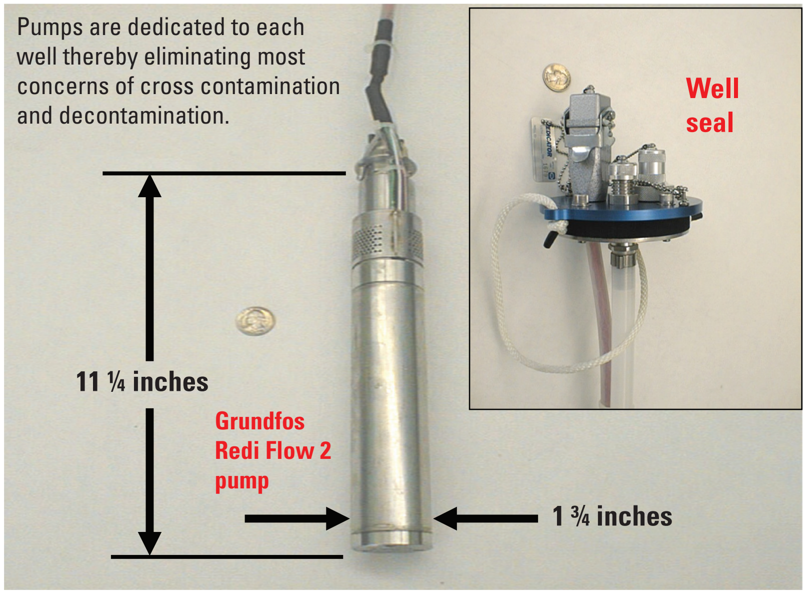


Figure 4-4.3.4 Dedicated sampling equipment used in each well in the monitoring network.

Water samples collected from the network are analyzed for the following parameter categories, plus cyanide.

- Common inorganics (includes nitrate)
- Trace metals
- Radionuclides
- Volatile organic compounds (VOCs)
- Pesticides

For the parameter category of "Radionuclides," analyses are performed only for gross alpha unless the concentration is found to be equal to or exceeding 5 picocuries per liter (pCi/L). Where the concentration of gross alpha is equal to or exceeds 5 pCi/L, then the water sample will also be analyzed for the presence of Radium 226 (Ra 226). If the concentration of Ra 226 is equal to or exceeds 2 pCi/L, then the water sample will also be analyzed for the presence of Radium 228. If the total gross alpha concentration of the water sample is equal to or exceeds 15 pCi/L, then the water sample will also be analyzed for the presence of uranium. Each of the above listed parameter categories presently includes the analytes listed in the table below.

Each monitoring site is sampled about the same time every year to eliminate concerns of seasonal variability. The frequency of sampling for the various parameter categories is as follows.

- Common Inorganics – once per year
- Trace Metals – once per year
- Pesticides – once per year
- Cyanide – once per year
- Radionuclides – once every 5 years
- Volatile Organic Compounds (VOCs) – 25 percent of an aquifer's wells every 5 years

Pesticides and (or) nitrate are sampled for three additional times during the growing season at approximately 15 to 20 monitoring sites each year.

Common Inorganics		
Alkalinity - M Alkalinity - P Ammonia Calcium Chloride Conductivity	Fluoride Iron Magnesium Manganese Nitrate + nitrite pH	Phosphorous, total Potassium Sodium Solids, dissolved Sulfate
Trace Metals		
Antimony Arsenic Barium Beryllium	Cadmium Chromium Copper Lead	Mercury Nickel Selenium Thallium
Radionuclides		
Gross Alpha Radium 226	Radium 228	Uranium
Volatile Organic Compounds (VOCs)		
Benzene Bromobenzene Bromochloromethane Bromodichloromethane Bromoform Bromomethane N-Butylbenzene sec-Butylbenzene tert-Butylbenzene Carbon tetrachloride Chlorobenzene Chloroethane Chloroform Chloromethane 2-Chlorotoluene 4-Chlorotoluene Dibromochloromethane 1,2-Dibromo-3-Chloropropane 1,2-Dibromoethane Dibromomethane	1,3-Dichlorobenzene o-Dichlorobenzene para-Dichlorobenzene Dichlorodifluoromethane 1,1-Dichloroethane 1,2-Dichloroethane 1,1-Dichloroethylene trans-1,2-Dichloroethylene 1,2-Dichloropropane 1,3-Dichloropropane 2,2-Dichloropropane 1,1-Dichloropropene cis-1,3-Dichloropropene trans-1,3-Dichloropropene Ethylbenzene Hexachlorobutadiene Isopropylbenzene Isopropyltoluene Methylene chloride Naphthalene	N-Propylbenzene Styrene 1,1,1,2-Tetrachloroethane 1,1,2,2-Tetrachloroethane Tetrachloroethylene Toluene 1,2,3-Trichlorobenzene 1,2,4-Trichlorobenzene 1,1,1-Trichloroethane 1,1,2-Trichloroethane Trichloroethylene Trichlorofluoromethane 1,2,3-Trichloropropane Trihalomethanes, total 1,2,4-Trimethylbenzene 1,3,5-Trimethylbenzene Vinyl chloride m,p-Xylene o-Xylene Xylenes, total
Pesticides		
2,4-D Acetochlor Alachlor Atrazine desethyl Atrazine desisopropyl Atrazine Bentazon	Carbofuran Cyanazine Dicamba Extraction procedure 525 Glyphosate Malathion MCPA	Metolachlor Metribuzin Picloram Simazine Trifluralin

Results of water-quality analyses are available online at *http://www.sddenr.net/waterdb/*. Results of water-quality analyses can be obtained by selecting “Project Name” as the search criterion from the pull-down menu at the above listed Web address and by entering “statewide monitoring” into the “contains” box to the right. For those wells from previous projects (installed pre-1994) that were incorporated into the monitoring network, water-quality information will be available under a “Project Name” in addition to “statewide monitoring.” The earlier water-quality information can be obtained for all pre-1994 wells, except one, by selecting “SDGS Well” from the pull-down menu and by entering the well name (see figure 4-4.3.1) into the “contains” box to the right. The exception is well TU-80C. For this well, select “Water Rights Well” from the pull-down menu as the search criterion and enter the well name “TU-80C” into the “contains” box.

4-4.4 Regional High Plains Aquifer: Example of Regional-Scale Ground-Water Level and Ground-Water Quality Monitoring Networks – Introduction

The following information is modified from McGuire and others (2003; *http://pubs.usgs.gov/circ/2003/circ1243/#pdf*).

The High Plains (or Ogallala) aquifer underlies a 111-million-acre area (173,000 square miles) in parts of eight States—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (figure 4-4.4.1). The area that overlies the aquifer is characterized as varying “between a semiarid to arid environment and a moist subhumid environment” (Lohman, 1953) with gently sloping plains, fertile soil, abundant sunshine, few streams, and frequent winds. Though the area can receive a moderate amount of precipitation, generally the amount of precipitation in most of the area is inadequate to provide an economically sufficient yield of typical crops—alfalfa, corn, cotton, sorghum, soybeans, and wheat. The 30-year average annual precipitation ranges from about 14 inches in the western part of the area to about 32 inches in the eastern part. The High Plains aquifer generally is composed of unconsolidated alluvial deposits. About 94 percent of the water pumped from the aquifer in 1995 was used for irrigation.

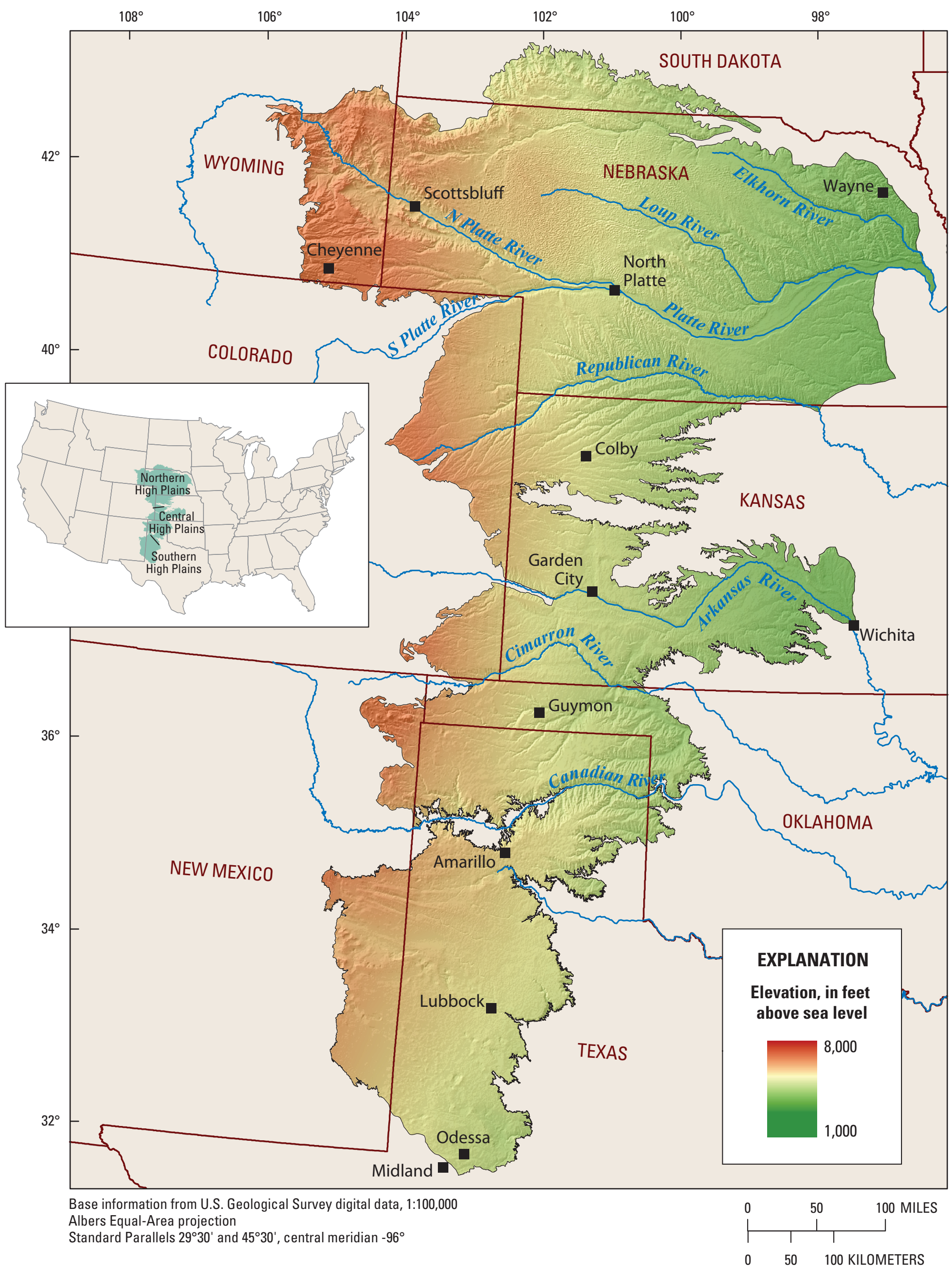


Figure 4-4.4.1 Location of the High Plains aquifer (from Reilly and others, 2008).

4-4.4.1 Regional Water-Level Monitoring Network

A network of 8,641 wells has been used to monitor water levels in the High Plains aquifer in 2000 (figure 4-4.4.1.1). This network consists of many smaller networks of wells measured by numerous agencies. State and local agencies are responsible for the majority of the water-level measurements.

Most of the wells in the network are measured one or two times each year—in winter or early spring and fall. Winter or early spring measurements generally represent nonpumping conditions, when the water level should show maximum recovery from pumping during the previous growing season. Fall measurements made after the end of the pumping season represent the maximum effect from pumping. In 2000, 127 of the wells were equipped with instruments that continually measure and record water levels; the locations of these recorder wells are shown in figure 4-4.4.1.1.

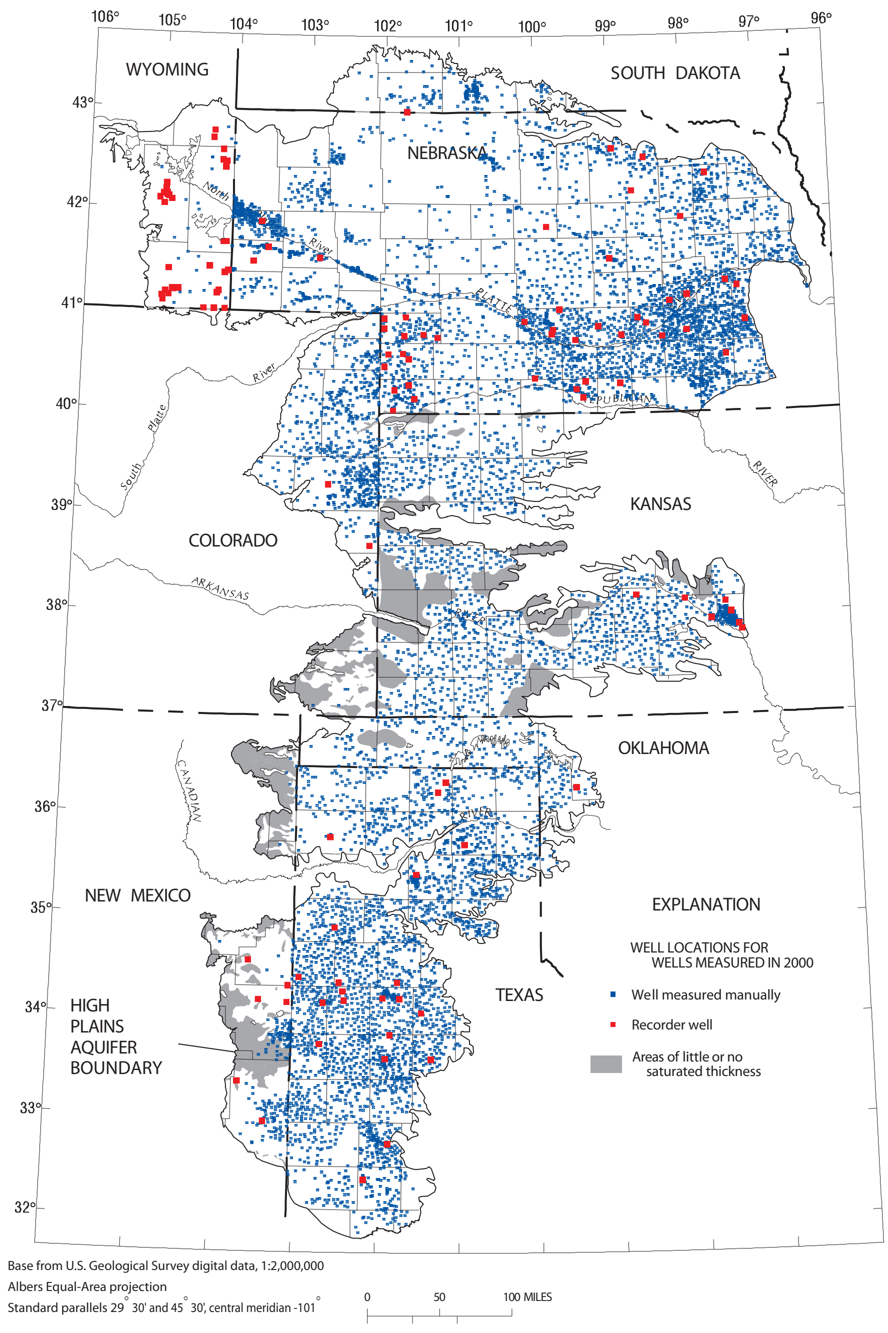


Figure 4-4.4.1.1 Well locations for wells screened in the High Plains aquifer and measured in the year 2000 (from McGuire and others, 2003).

Analysis of water-level data from this network includes assessment of the available water in the High Plains aquifer in 2000 and the changes that have taken place in recent decades (figure 4-4.4.1.2).

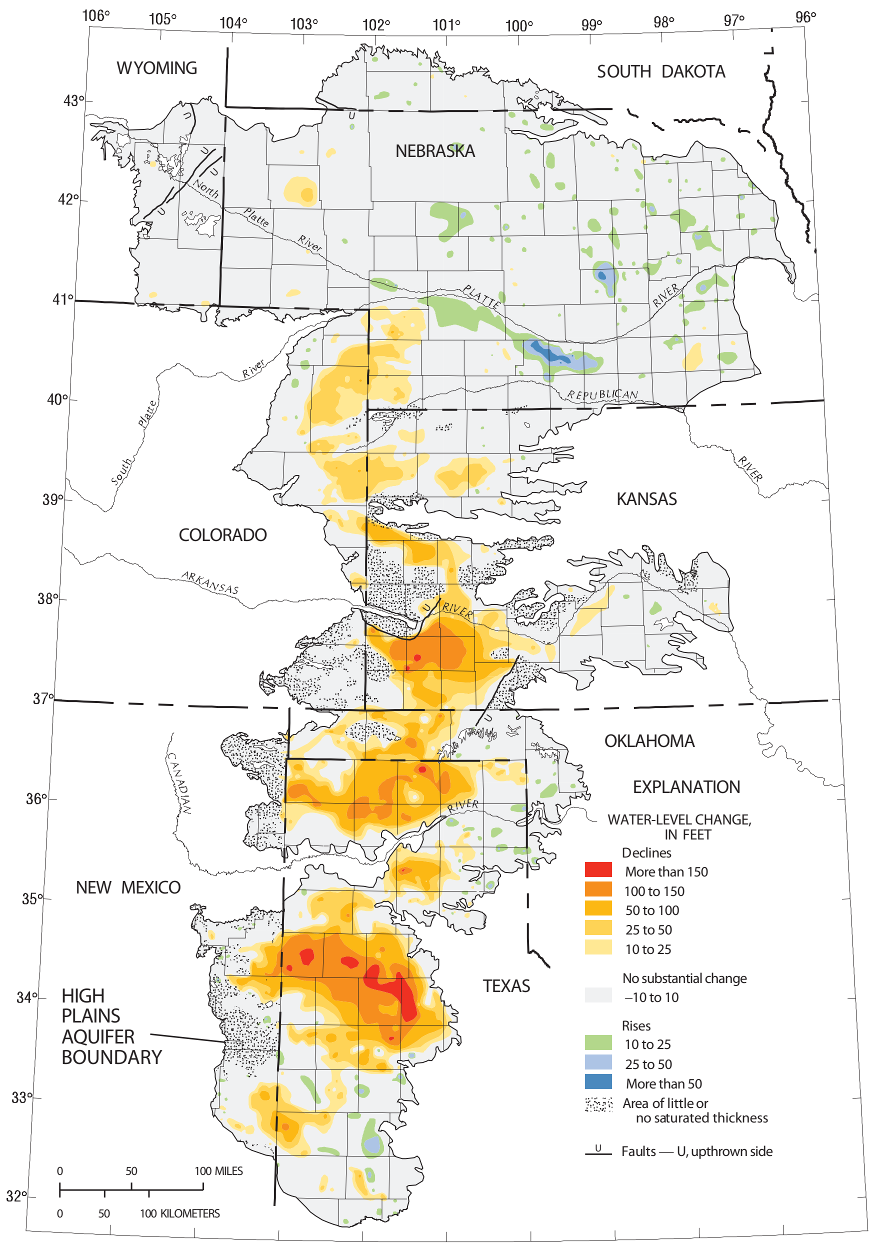


Figure 4-4.4.1.2 Water-level changes in the High Plains aquifer, predevelopment to 2000 (from McGuire and others, 2003).

4-4.4.2 Regional Water-Quality Monitoring Network

The USGS NAWQA Program has established and sampled a network of domestic wells across the High Plains aquifer to determine the occurrence and distribution of a broad suite of inorganic and organic compounds (figure 4-4.4.2.1). The network was designed using a grid-based, random selection procedure with each well selected meeting minimum criteria for well construction and for suitability for sampling.

Water-quality findings from sampling the network of domestic wells shown in figure 4-4.4.2.1 are described in McMahon and others (2007). Results of other findings are available at *http://co.water.usgs.gov/nawqa/hpgw/HPGW_home.html*.

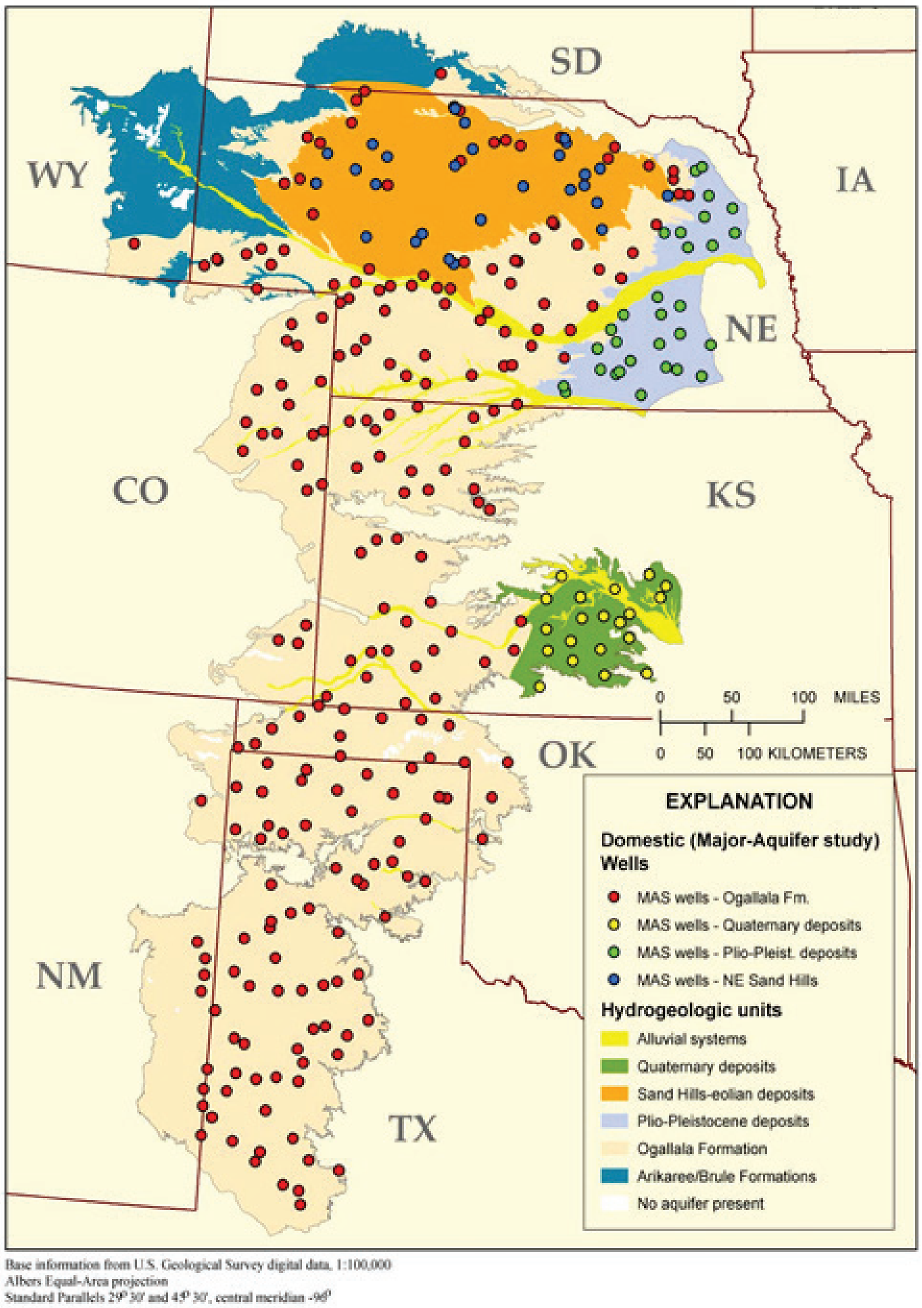


Figure 4-4.4.2.1. Map showing domestic-well network in the High Plains aquifer used to determine the occurrence and distribution of a broad suite of inorganic and organic compounds (from McMahon and others, 2007; figure 58).

Appendix 5. Field Practices for Ground-Water Data Collection

5-5.1 Field Practices for Ground-Water Levels

5-5.1.1 Minimum Field Standards

The following section outlines various methods and techniques used to make consistent periodic and continuous water-level measurements. The field collection of ground-water levels includes a number of important elements to ensure data quality, including

- Training
- Pre-collection site review and preparation
- On-site preparation
- Water-level collection and data recording

Field-sampling procedures must take these elements into account in order to ensure that

- Water levels are being taken at the correct location, source, and time
- Water-level data are handled in a manner that preserves their integrity and data value
- Information recorded during measurements contains all of the information needed to normalize and compare analysis results
- Measures are taken to ensure the accuracy of the result

This appendix outlines specific procedures and documents most of the minimum elements needed to define the standards of a successful field exercise; however, the elements of the water-level program should be defined in a written set of procedures specific to the field exercise.

5-5.1.1.1 Training

Operator training is necessary prior to field collection of ground-water levels to ensure consistent data quality. This document and the documents referenced herein can serve as the fundamental basis for that training. Appropriate training includes formal training classes through universities or vendors and hands-on field experience through mentoring, on-site (on the job), and follow-up training to ensure that data are being collected consistently and correctly. Examples of training include

- Establishment of measurement point
- Water-level measurement with electric or steel tape
- Field measurements with a continuous recorder or pressure transducers
- Decontamination of field equipment
- Data recording and entry
- Safety
- Decontamination methods

5-5.1.1.2 Pre-Collection Site Review and Preparation

Preparation for water-level measurements includes the gathering of equipment and supplies. Creating a checklist of the equipment and supplies needed for each measurement trip will help the measurer avoid delays and prevent the collection of invalid measurements. For example, a checklist should include all equipment such as wrenches, keys, site folder, including photographs, maps, etc., and field computer (if applicable). Additionally, equipment that will be used to collect continuous water levels should be calibrated and tested to ensure accuracy. Decontamination and calibration of steel and electric tapes should be conducted as near in time as practical to field measurement. A record of decontamination and calibration should be maintained for all equipment. Sheets for recording water-level measurements should include space for the name of the well, date, time, water level below measurement point, land-surface correction, elevation of measurement point, etc.

A recommended list of equipment and materials for miscellaneous water-level measurements follows: A suitable map (optionally, an aerial photograph and a town plat/lot number map), compass or handheld global positioning system (GPS), site form for recording site information, water-level measurement form (figure 5-5.1.1.2), steel tape (graduated in feet, tenths, and hundredths of feet) optionally with an attached weight made of brass, steel, or iron, blue carpenters chalk and clean rags, an electric water-level measurement tape, pen (blue or black ink), at least two adjustable wrenches, Allen wrenches, hammer or other tools needed for well access, a bottle of sodium-hypochlorite for disinfection, and latex-free vinyl gloves.

Prior knowledge of measurement-site conditions is essential to the successful collection of measurements. For example, prior knowledge of water-level depth below measurement point can be helpful to determine length of steel tape to be chalked.

5-5.1.1.3 Minimum Data Elements

Each water-level measurement site has inherent data elements that need to be verified and recorded preferably prior to water-level measurements. The person making the water-level measurement should check to ensure minimum data elements are available, accurate, and up to date before going to the field. Corrections and updates to the information should be made prior to making the measurement.

The American Society for Testing and Materials (ASTM) has a recommended list of minimum data elements for inclusion in a ground-water level network (American Society for Testing and Materials, 1993 (Reapproved 2006), 1992 (Reapproved 2004 and 2010)) as does the U.S. Geological Survey (USGS; Cunningham and Schalk, 2011), U.S. Environmental Protection Agency (USEPA), and other regional and State agencies. A compiled list of minimum data elements for reporting water-level results for a National Ground-Water Monitoring Network is described in appendix 6.

5-5.1.1.4 Onsite Preparation

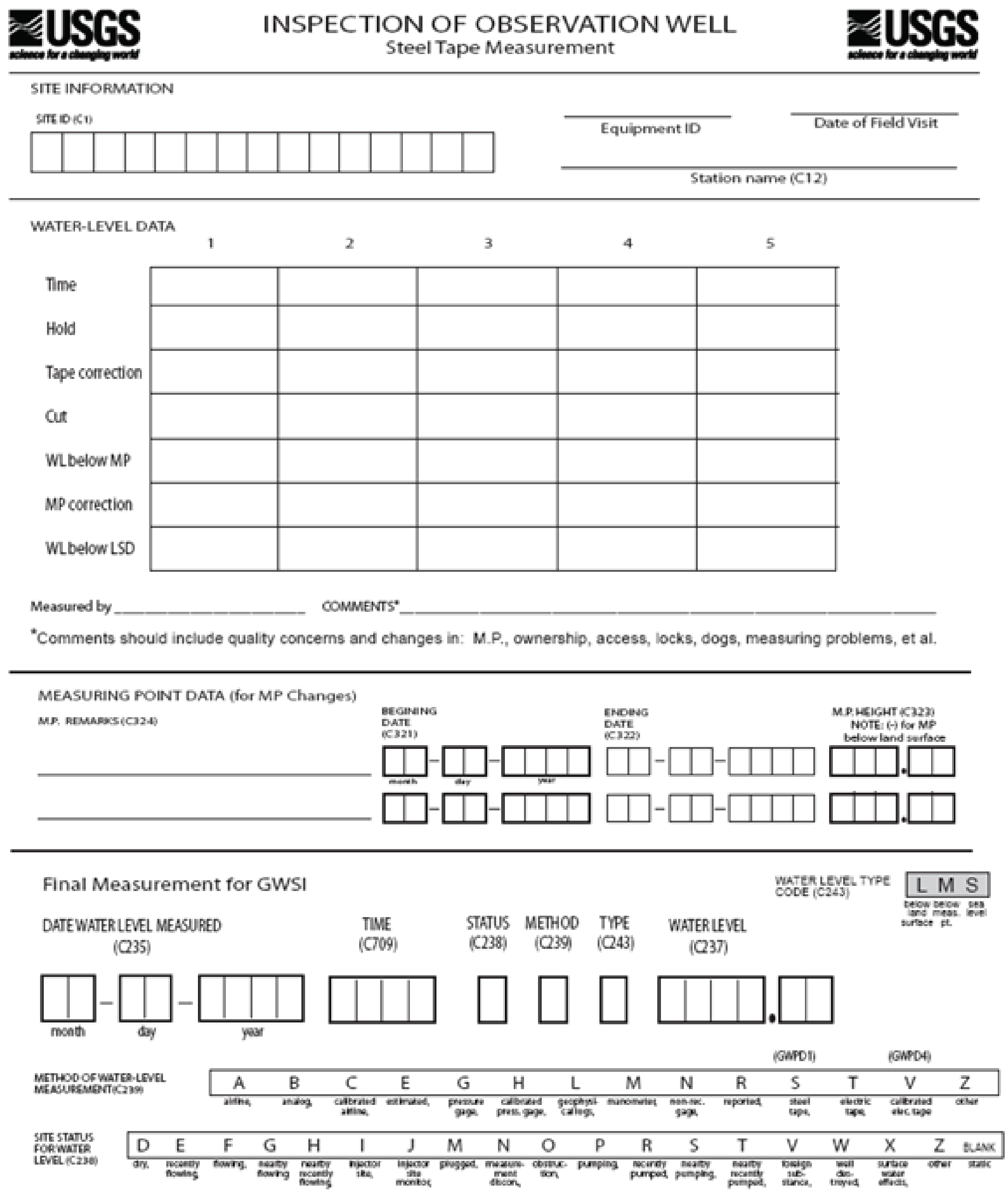
Preparing the site for measurement should include the following elements:

- Site verification. This can be accomplished in several ways including having made a previous visit to the site, comparing the site to a known grid reference using GPS equipment, comparing photographs of the listed site to the actual site, or identifying the site by a physical label on the wellhead or identifying sign.
- Equipment decontamination. Equipment must be decontaminated between water-level collections to prevent cross contamination between wells. The degree of decontamination required will depend on contaminants present at the well.
- Site condition notations. These include the date and time of day, weather conditions (rain, snow, etc.), measurement-point condition, damage, deterioration, and any other factors that could affect the results of the current water-level measurement or future measurements.
- Site access. This may include access to the property (gate opening, etc.) and opening the cap or shelter that encloses the well.
- Establishing a site measurement point. (See Cunningham and Schalk, 2011, USGS Groundwater Procedures Document (GWPD) 3 – Establishing a permanent measuring point and other reference marks).

5-5.1.1.5 Water-Level Measurements

Numerous technical documents have been written to describe the procedures to use when measuring water levels, either manually or with recorders designed to automatically measure water levels on a continuous basis. Procedures from USEPA, USGS, ASTM, and World Meteorological Organization (WMO) were evaluated. Because these technical procedures do not appreciably vary in terms of the quality of data that would result, the following sections refer to the technical procedures already documented by these organizations.

All measurements should be recorded either on a computer/personal data assistant (PDA) or on paper forms (see figure 5-5.1.1.2). If electronic recording of measurements is chosen, all information required on the paper form also should be available electronically. Electronic files should be downloaded upon returning from the field and backed up as a method for retaining original field measurements. Field measurements recorded on paper should be electronically entered into available databases shortly after returning from the field. Paper forms should be filed appropriately and not returned to the field.


USGS science for a changing world

INSPECTION OF OBSERVATION WELL
Steel Tape Measurement

SITE INFORMATION

SITE ID (C1)

Equipment ID

Date of Field Visit

Station name (C12)

WATER-LEVEL DATA

	1	2	3	4	5
Time					
Hold					
Tape correction					
Cut					
WL below MP					
MP correction					
WL below LSD					

Measured by ____________ COMMENTS* ____________

*Comments should include quality concerns and changes in: M.P., ownership, access, locks, dogs, measuring problems, et al.

MEASURING POINT DATA (for MP Changes)

M.P. REMARKS (C324)

BEGINING DATE (C321) month day year

ENDING DATE (C322)

M.P. HEIGHT (C323) NOTE: (-) for MP below land surface

Final Measurement for GWSI

WATER LEVEL TYPE CODE (C243) L M S — below land surface, below meas. pt., sea level

DATE WATER LEVEL MEASURED (C235) month day year

TIME (C709)

STATUS (C238)

METHOD (C239)

TYPE (C243)

WATER LEVEL (C237)

METHOD OF WATER-LEVEL MEASUREMENT (C239)

A	B	C	E	G	H	L	M	N	R	S (GWPD1)	T	V (GWPD4)	Z
airline,	analog,	calibrated airline,	estimated,	pressure gage,	calibrated press. gage,	geophysical logs,	manometer,	non-rec. gage,	reported,	steel tape,	electric tape,	calibrated elec. tape	other

SITE STATUS FOR WATER LEVEL (C238)

D	E	F	G	H	I	J	M	N	O	P	R	S	T	V	W	X	Z	BLANK
dry,	recently flowing,	flowing,	nearby flowing	nearby recently flowing	injector site,	injector site monitor,	plugged,	measurement discon.,	obstruction,	pumping,	recently pumped,	nearby pumping,	nearby recently pumped,	foreign substance,	well destroyed,	surface water effects,	other	static

Figure 5-5.1.1.2 Ground-water level measurement form for steel tape.

5-5.1.1.5.1 Manual Water-Level Measurements

All manual water-level measurements should be designed to have repeatable and accurate methods of determining the elevation of the water-level surface. Manual (or discrete) water-level measurements can be made by using several methods, including the graduated steel or wetted tape method (U.S. Environmental Protection Agency, 2001; Cunningham and Schalk, 2011 (GWPD 1); American Society of Testing and Materials, 1987 (Reapproved 2001)), the electric-tape method (U.S. Environmental Protection Agency, 2001; Cunningham and Schalk, 2011 (GWPD 4); American Society of Testing and Materials, 1987 (Reapproved 2001)), the air-line method (Cunningham and Schalk, 2011 (GWPD 13)), or recent noncontact methods, such as sound waves and radar waves (see the main body of the report, Section 5.4—New Technologies).

The method one chooses to use depends on the conditions of the site (such as well construction, well diameter, depth of the well, and accessibility) and status of the water level (for example, flowing wells require different methods than nonflowing wells; see Cunningham and Schalk, 2011 (GWPD 12)).

5-5.1.1.5.2 Automated Water-Level Measurements

Automated water-level measurements are made so that a continuous (or near-continuous) record of water levels can be obtained with minimal human intervention. Automated (continuous or near-continuous) water-level measurements can be made with pressure transducers (Cunningham and Schalk, 2011 (GWPD 16)) or float-activated recorders (U.S. Geological Survey, 1981; Rantz and others, 1982). Regardless of the method of measurement, care should be taken to ensure that the entire expected range of water levels can be measured with the device at the expected accuracy. For example, a well with a relatively shallow water level (<30 feet (ft)) and small (<10 ft) change in water level might require a lower rated (0–5 pounds per square inch (psi)) pressure transducer to ensure accuracy to within 0.01 ft (Freeman and others, 2004). Use of a higher rated (10–30 psi) pressure transducer might limit the accuracy of the data.

Generally, the water-level recorder should be placed in a well and calibrated against a manual water-level measurement. A calibration worksheet (for example, see Freeman and others, 2004) and other documentation should be maintained to ensure accurate measurements, including date/time of calibration; the type, serial number, and range of measurement device; and what units are being measured (feet, pounds per square inch, meters). A field form should be located in the shelter house or wellhead, or taken to the field for future water-level measurements and calibration.

5-5.1.2 Minimum Data Standards

The following section outlines various standards to which water-level measurements should adhere, to ensure a nationally consistent level of data quality. Various types of water-level measurements can be made, and the standards vary with the type of equipment used to make the measurements.

5-5.1.2.1 Manual Water-Level Measurements

In general, manual water-level measurements should be made repeatedly to ensure the measurement is accurate to within at least 0.02 ft between consecutive measurements. For electric-tape measurements, the USGS (Cunningham and Schalk, 2011) recommends that at least three measurements be made, with two consecutive measurements within 0.02 ft. Some methods of manual measurement (acoustic, air-line, flowing wells) will not have that level of repeatability. Regardless of the method of measurement, all measurements should be recorded for the record or the archive, and the accuracy of the water-level measurements (based on the repeatability of the measurements) should be made and documented.

5-5.1.2.2 Automated Water-Level Measurements

The accuracy of automated (continuous) water-level measurements should be at least 0.02 ft. Instrument drift and faulty instrumentation can affect the accuracy and limitations of the data collected.

The frequency of when the water-level recorder should be visited should be based on the stability of the transducer, the storage limitations of the recording device, and knowledge of the expected hydrograph of the aquifer. Generally, a routinely scheduled field visit of 6–8 weeks should be sufficient. Regardless of the measurement device, measurements should be made often enough that the recording devices onsite will not run out of paper/memory and so that the accuracy of the measurements is not compromised through excessive drift or range of water level. A large annual drawdown/recharge cycle would necessitate additional visits and perhaps require resetting the float or transducer during different parts of the hydrograph cycle. Real-time (or near-real-time) telemetry can also be added to the well; a stable well displaying real-time data may be visited much less frequently than other wells.

Instrument drift corrections, calibration corrections, and datum corrections all can affect the accuracy of measurements and should be applied after downloading the data. In addition, tidal effects, effects from pumping wells, effects of changes in barometric pressure, effects from earthquakes, and other effects can also affect continuous or near-continuous water-level measurements and should be considered when the data are analyzed.

5-5.1.3 Data Handling and Management

Thorough documentation of field and office procedures is of paramount importance and should be emphasized in order to ensure that the quality of the data is not compromised. This section covers some specific data handling and management procedures. Much of this section is derived from Sauer (2002), which was developed for surface-water electronic data entry and analysis; however, many of the concepts are completely analogous to ground-water data.

5-5.1.3.1 Electronic Entry of Data

The first step in processing water-level data is entry of unit value data (measured or computed values associated with a specific instantaneous date and time), field data, and related information into an electronic database and (or) processing system. Field data may include water-level measurements (with associated time and date), elevation of measurement point, site conditions and other remarks, or notes from the site (Sauer, 2002).

5-5.1.3.2 Verification and Editing of Unit Values

Unit values must be checked carefully and verified against field measurements before being used in further analysis. Erroneous or suspicious values may require editing and identifying individual values that might be incorrect, relative to field measurements or to known extremes of record. Prior to editing, original unit values should be archived; a copy of the original data file should be edited, and this copy should also be archived upon completion of editing (Sauer, 2002).

Various issues can arise in the collection of unit value data, including errors with times and dates and instrument drift or datum errors. Sauer (2002) provides methods for corrections for time, date, instrument, and datum errors that are analogous to ground-water unit value data. One major difference between ground-water data and surface-water data that should be pointed out is treatment of missing values: in surface-water analysis, missing values are sometimes estimated relative to an established rating curve; in ground-water, missing values typically are not estimated because of the heterogeneous nature of most ground-water systems.

5-5.1.3.3 Verification and Analysis of Field-Measurement Data

Field-measurement data includes discrete water-level measurements, well-construction data, and miscellaneous field notes. Field-measurement and related data typically are entered into the electronic system in the office, although some data can be entered by PDAs or portable field computers. Various computations and comparisons should be made to ensure accuracy of the data and consistency of the information (Sauer, 2002).

Arithmetic errors (such as a conversion from water-level depth below measurement point to water-level depth below land surface), transcription errors, and logic errors (such as depth of well less than water level), should all be checked and corrected before final entry into the database. All data should be entered into the database with the same precision and significant figures as recorded in the field. Calculated values should be rounded to the significant figures recorded in the field notes. Significant figures for water-level measurements typically are the same as for water-surface gage height and elevation for surface-water data (Sauer, 2002, table 2). Measurement-point elevations (analogous to gage datum analysis in Sauer (2002)) should be a permanent datum maintained as accurately as possible throughout the lifetime of the station. Surveying or leveling should be performed periodically to ensure that corrections can be made to adjust for movement of the datum.

It cannot be stressed enough that original paper records should not be modified, deleted or erased, or returned to the field because this increases the chance they will get damaged or lost. Archival of these paper notes should be done so that all editing of errors, instrument or time drift corrections, and such can be recreated if necessary.

5-5.2 Field Practices for Ground-Water Quality

5-5.2.1 Minimum Field Standards

The implementation of minimum standards for collecting water-quality samples is critical to the value of the data derived from an analysis of the samples. Proper attention to pre-sampling site review and sampling preparation, onsite preparation, collection procedures, sample preservation and handling, and use of appropriate data recording will ensure that information obtained can be integrated into a national monitoring network data-collection system and will be comparable to other sample data in both space and time.

5-5.2.1.1 Pre-Collection Site Review and Preparation

Planning and preparing for a ground-water sampling event is an important step in the sampling process. Each sampling site has inherent data elements that need to be verified prior to sampling. For example, the name, location, sampling source, sampling depth, and aquifer name should be known. The sampler should check this information prior to conducting sampling to ensure that it is accurate and up to date. Corrections and updates to the information should be made prior to sampling. Preparation for sampling includes the gathering of equipment and supplies. Creating a checklist of the equipment and supplies needed for each sampling will help the sampler avoid delays and prevent the collection of invalid samples. For example, a checklist should include all equipment such as pumps, bailers, probes, analysis kits, meters, and coolers and all supplies such as batteries, bottles, preservatives, cooling media, forms, labels, filter media, tape, and gloves. Additionally, equipment that will be used to collect and (or) conduct a field analysis of samples should be decontaminated and calibrated in accordance with the manufacturers' instructions. Calibration solutions should only be used if they are within the shelf life recommended by the manufacturer. Decontamination and calibration should be conducted as near in time as practicable to field sampling. A record of decontamination and calibration should be maintained for all equipment.

Prior knowledge of sampling site conditions is essential to the successful collection of samples. For example, knowing that a sampling point is located in a gully that is prone to flooding could prevent unnecessary time being spent attempting to sample during wet conditions and could affect the methods used to clean the sampling point prior to sampling. Other factors, such as knowing whether or not the sampling point has a functional pump or is secured with a lock, can help the sampler avoid foreseeable problems.

The sampler should determine sampling container needs for each field-sampling event and either obtain pre-treated or prepared sample containers from the laboratory that will conduct the analyses or prepare containers themselves using appropriate pre-treatment or decontamination procedures.

5-5.2.1.2 Minimum Data Elements

Each water-quality measurement site has inherent data elements that need to be verified and recorded either prior to or during the sampling event. The person making the water-quality measurement should check to ensure minimum data elements are available prior to conducting the sampling to ensure that the data are accurate and up to date when in the field. Corrections and updates to the information should be made prior to making a measurement.

The following is a list of the minimum data elements that should be recorded as part of a sampling event; some of these are the same or similar to the minimum data elements required for a water-level measurement:

Site/well information:

- Site name: A unique identifier for the well, such as a well number or State registration number.
- Grid reference: The coordinates of the well in either latitude/longitude or Universal Transverse Mercator (UTM) coordinates. (Note: If UTM coordinates are used, the datum also should be recorded.)
- Section, Township, and Range and footages from at least two lines for States that use the rectangular survey system.
- Contact information: Name, address, and telephone number of the person on whose property the well resides (if available).
- Operating interval: The depth to the top and bottom of the screened, slotted, or open-hole interval.
- Total depth: The total depth of the wellbore.
- Fluid level: Depth to top of fluid prior to purging.
- Pump depth (if known).
- Pump status: Pump on or off upon arrival.
- Pump status time: Time pump was started prior to arrival, if known.
- Well construction.
- Measuring point: The identification of the point on the wellhead from which the depth to top of fluid was measured.
- Measuring-point elevation: The elevation of the measuring point typically given in feet above or below a specified datum.
- Special instructions: Any instruction specific to the sampling site that will facilitate future sampling, such as pump configuration, wellhead locking or capping, and fluid depth.

Sampling information:

- Sampling procedure: The identification of the sampling procedure used.
- Date and time of sampling.

- Weather: The conditions present during sampling, such as air temperature, humidity, and precipitation.
- Name of sampler.
- Affiliation of sampler: Name of the sampler's organization or company.
- Purge method: The method used to purge the well, such as pumping, bailing, etc.
- Purge volume: The calculated volume of fluid to be purged from the well.
- Sample appearance: The color, turbidity or cloudiness, and odor (e.g., strong or weak, metallic or sulphuric, etc.) of the sample.
- Preservation: The precise preservation and handling techniques used on each sample (e.g., filtered, preserved using an X-percent nitric acid solution to a pH of less than 2 and cooled to less than 4 degrees Celsius (°C)).
- Analyses: A list of the analyses to be conducted on the sample.
- Method: The specific analytical method to be used to test the sample (e.g., EPA Method 300.1).
- Transfer date: The date on which the custody of the sample was transferred to the laboratory.

5-5.2.1.3 Onsite Preparation

Preparing the site for sampling should include the following elements:

- Site verification. This can be accomplished in several ways, including having made a previous visit to the site, comparing the site to a known grid reference using GPS equipment, comparing photographs of the listed site to the actual site, and identifying the site by a physical label on the wellhead or on an identifying sign.
- Cleaning the sampling point. Depending on the analysis to be conducted, the cleaning of the sampling point may be as simple as washing the wellhead or spigot or as complex as sterilization. Prior knowledge of the sampling parameters will determine which cleaning methods are appropriate for the sampling point.
- Equipment decontamination. Equipment must be decontaminated between sample collections.
- Pre-purging measurement of depth to top of fluid. Fluid measurement should be taken using an appropriate physical process such as a steel tape or electronic probe. Taking a Barometric pressure reading can also assist the sampler in the proper interpretation of the water level.
- Purge calculation. The amount of fluid that must be purged from a well prior to sample capture can be calculated using several methods, including prior knowledge of purge volumes for the site or the use of a formula that takes into account the depth of the well, radius of the casing, and depth to top of fluid to estimate the total volume of fluid contained within the casing. Regardless of the method used, wells should be purged of no less than three casing volumes.
- Pump installation (if needed).
- Fluid level measurement. Determining the fluid level is important because fluid levels can have an effect on analytical results. Consequently, the fluid level becomes one of the parameters that must be considered when normalizing the data obtained from sampling. Note: It is recommended that the tape or probe used to measure fluid level be decontaminated prior to use.
- Site condition notations. These include the date and time of day, weather conditions, sample point condition, e.g., damage, deterioration, etc., and any other factors that could affect the results of a sample analysis.

5-5.2.1.4 Sample Collection

Sample-collection techniques play an important role in sample viability. The use of appropriate sample containers and collection techniques are critical elements of proper sample collection. Additionally, the proper purging of the wellbore is essential to the collection of a representative sample of formation fluids. Viable sample collection specifications should include the following elements:

Purging of at least three casing volumes of fluid is necessary. During purging, the sampler should monitor the temperature, conductivity, and pH to assess the adequacy of the purging operation and record the results at least once for each casing volume of fluid purged. If possible, continuous water-level measurements in the well during purging should be made to ensure that drawdown of more than 1 ft, if the pump inlet is above a screened interval, or 6 inches, if the pump inlet is within the screened interval, does not occur. Whenever possible, purging should be conducted using low-flow purging techniques.

- Purging efficacy check. The purging operation is complete if
  - A total of three casing volumes of fluid has passed through the tubing connecting the pump to the container, and
  - The difference between the last two field measurements of temperature, conductivity, and pH falls within the following change allowance:
    - Temperature ± 0.2°C
    - Conductivity ± 3 percent
    - pH ± 0.1 pH unit.
- Sampler preparation. Depending on the parameters to be analyzed, the sampler may need to put on clean or, if possible, sterile powder-free latex gloves before sampling.
- Sample-container preparation. Sample containers should be labeled prior to use and should be appropriate for the sample being collected. For example, at some laboratories samples collected to measure chlorofluorocarbons require a glass bottle with a capacity of at least 125 milliliters (mL), whereas an acid-preserved sample should be collected in a new or acid-washed plastic, polyethylene, or polypropylene bottle. A list of appropriate sampling containers, seals, and volumes can be found in the laboratory's Quality Assurance Management Plan.
- Filling method. Samples should be collected under laminar-flow conditions. Thus, the pumping rate for sample collection should be low enough to prevent turbulent flow or aeration of the sample. Further, the collection tube should be placed at the bottom of the sampling container, and the container should be filled slowly and evenly until the container is overflowing to prevent the introduction of air into the sample. This is a typical sample-collection method; however, the specific method used to fill containers should reflect the type of analyses to be performed.

5-5.2.1.5 Sample Preservation, Handling, and Transport

After collection of the sample, it may be necessary to preserve or chill the sample to prevent degradation. A list of appropriate sample preservation techniques can be found in the laboratory Quality Assurance Management Plan. The need for sample preservation or chilling is based on the analyses to be conducted. For example, samples collected for the analysis of cations or metals must be preserved using nitric acid to a pH of less than 2 and such samples may be, but need not be, chilled, provided they do not freeze. Also, many samples have a holding time restriction. For example, samples collected for total dissolved solids have a holding time of no more than 28 days from date of collection. A list of appropriate sample holding times can be found in the laboratory Quality Assurance Management Plan. Samples should be transported in appropriate clean coolers or containers that are designed to keep the contents at a constant or even temperature, prevent the spillage of samples, and prevent damage to sample containers from reasonable impacts.

5-5.2.2 Automated Water-Quality Measurements

The use of real-time/automated water-quality measurements in routine ground-water quality monitoring programs is atypical for most parameters. Inasmuch as the well must be purged prior to sampling in order to obtain representative samples, in most ground-water systems the use of such automated sampling without well purging would not be expected to yield data that represent formation conditions. Consequently, it is recommended that unless a system is designed to purge the well prior to automated sampling, water-quality samples be obtained during a field-sampling event by using the procedures described in section 5-5.2.1.4 above.

5-5.2.3 Data Handling and Management

Thorough documentation of field and office procedures is of paramount importance and should be emphasized in order to ensure that the quality of the data is not compromised. This section covers specific data handling and management procedures.

The information in this section is primarily drawn from "A National Protocol for State of the Environment Groundwater Sampling in New Zealand" (Ministry for the Environment, 2006).

5-5.2.3.1 Data Recording

Because the collection of data from the analysis of ground-water samples is the principal purpose of sampling, the onsite recording of data is essential to the comparability of the data being collected. The methods used to collect field data range from pen and paper on forms to direct electronic data entry into a database. Although the methods used to collect data in the field vary, the final goal is the electronic entry of data into a database. A critical factor in collecting field data is having a structured method of collection so that critical elements are not left out. For example, simply entering the data elements into a field notebook without benefit of a form that contains a list of the elements is more likely to result in the omission of important information. Electronic field-data collection is preferable for many reasons. For example, the use of an existing database can eliminate errors such as misidentification of wells or entering data that fall outside an established set of data-parameter limits. Further, the use of electronic data entry can save time and prevent transcription errors because there would be no need to conduct separate data entry after the fact.

Appendix 6. Data Systems and Data Standards

6-6.1 National Data Systems

6-6.1.1 American Society for Testing and Materials (ASTM) Standards D 5254, D 5408, D 5409, D 5410

The American Society for Testing and Materials (ASTM) has established four standards (D 5254, D 5408, D5409, and D 5410) that collectively contain data elements that enable data users to identify monitoring locations and the data collected for a very broad range of data needs. These standards contain the most comprehensive list of data elements of all the standards examined. These ASTM standards differ from other standards in that more informative descriptions, practical examples, and notes that give better insight into the meaning of a data element are provided, and exhaustive references are given to other organizations' standards and data systems that can be used to describe data elements. The main disadvantage of the ASTM standards is that they were not designed strictly for a computerized database, rather for input of the data into any permanent file and, therefore, lack data elements of a computer database-oriented standard, such as eXtensible Markup Language (XML) tags and data formats. Many of the suggested components and representative codes for coded data elements are those established by the U.S. Geological Survey (USGS) and used in the National Water Information System (NWIS) computerized database.

6-6.1.2 U.S. Geological Survey (USGS) National Water Information System (NWIS) Data Dictionary

The USGS NWIS contains 850,000 records of wells, springs, test holes, tunnels, drains, and excavations in the United States. The data elements of this database are widely used by State geological surveys in the United States and allow a measure of comparability and shareability among these datasets by those agencies that use similar naming conventions and formats. Thus, the NWIS elements could be considered a data model for wide use among external users in other agencies. Real-time data are available for a limited number of sites. In describing the data available for these sites, the complete NWIS data dictionary contains data elements for ground-water level and quality data organized in 75 tables, including data elements for well construction, sampling location and time, elevation, sample results, and quality control.

An abbreviated set of data from NWIS is available online from NWISWeb at *http://waterdata.usgs.gov/nwis,* and the data elements that are accessible for datasets in NWIS are listed in table 6-6.1.2.1.

Table 6-6.1.2.1 U.S. Geological Survey National Water Information System Web Data Elements for Data Accessibility Online.

Data Elements	
Agency Code	Hydrologic-event code
USGS site number	Message from lab
Begin date	Parameter code
Begin time	Remark code
End date	Parameter value
End time	Result value qualifier codes
Time datum	Method code
Time datum reliability code	Data-quality indicator code
Agency collecting sample code	Reporting level
Sample medium code	Reporting-level type code
Project identifier	Lab standard deviation
Geologic unit code	Preparation set identifier
Taxonomic unit code	Result preparation date
Body-part code	Analysis set number
Analysis-source code	Result analysis date
Hydrologic-condition code	Lab result comment
Sample-type code	Analyzing entity code

6-6.1.3 U.S. Environmental Protection Agency (USEPA) Water-Quality Data Exchange (WQX)

During the 1960s, the USEPA established a database to allow the water-quality monitoring community to store data in a central place. This database is the Storage and Retrieval System (STORET). Since 2000, USEPA has been engaged in changing the approach and format of this system and, as of 2007, has established a Water-Quality Data Exchange (WQX) to allow water-quality data to be exchanged in a standard format. The water-level and quality data categories available through the USEPA WQX are listed in table 6-6.1.3.1. Reporting the data elements that can be mapped to the schema presented in table 6-6.1.3.1 allows users of WQX to share water data. The WQX relies on the National Environmental Information Exchange Network (NEIEN) for electronic data exchange among data users.

Table 6-6.1.3.1 U.S. Environmental Protection Agency Water-Quality Data Exchange data elements. Water data tables and data categories accessible through the USEPA WQX (abstracted from *http://www.epa.gov/STORET/archive/WQX_factsheet.pdf*).

Organization
ORG Description
ORG Electronic Address
ORG Phone
ORG Address
Activity Group
Activity Group Name
Activity Group Type
Activity IDs
Project
Project Description
Project Binary Object
Monitoring Location
Monitoring Location Identity
Monitoring Location Geospatial
Monitoring Location Binary Object
Monitoring Activity
Activity Description
Activity Location
Sample Description
Sample Prep
Subsample Description
Activity Binary Object
Result
Result Description
Result Binary Object
Result Analytical Method
Result Lab Info
Result Detection
Quantitation Level
Lab Sample Prep

6-6.1.4 Environmental Data Standards Council (EDSC) Environmental Sampling and Analysis Results (ESAR) Standards

In 2006, the EDSC (*http://www.exchangenetwork.net/*) developed a suite of standards designed to improve environmental reporting when exchanging information over the NEIEN. The EDSC describes data elements and data groupings that are used to exchange information over the Internet. The advantage of the EDSC standards as compared to the ASTM standards is that they are specifically designed for electronic database development and contain all of the requisite elements needed for that task: data groupings and data elements, definitions, XML tags, notes, example lists of values, and format for each level (table 6-6.1.4.1). EDSC data standards include sampling, analysis, results, field activity, and well information.

The table below is a portion of the description of data elements from the EDSC approved data standards for Environmental Sampling, Analysis and Results: Analysis and Results (Standard No. EX000005.1, January 6, 2006 (Environmental Data Standards Council, 2006a)). The first entry in the table includes the name of the data table, its definition, and its XML tag. The XML tag is a plain language data format that allows data to be more easily understood. XML is the electronic data language widely used among businesses and governments. The second entry, which is within the “Laboratory Identification” data table is the data element name, “Laboratory Identifier,” including its definition, notes explaining important data relations, format (in this case, “A” stands for “alphabetical”), and XML tag.

The EDSC standards include detailed Environmental Sampling, Analysis and Results Data Standards (Standard No. EX000001.1, January 6, 2006, (Environmental Data Standards Council, 2006b)) applicable to ground water, which follow the business processes used to collect, analyze and report environmental data. The standards include the following components:

(a) Analysis and Results: This standard includes the data groupings and elements required for describing the information resulting from the analyses that are performed on environmental samples and the results that are determined from the analyses.
(b) Field Activity Data Standard: This standard provides a group of data elements that are used to exchange information about field activities.
(c) Monitoring Location: This standard identifies and describes the elements required for describing monitoring location information. Additionally, the Well Information Data Standard includes information about well ownership, location, use, and construction.
(d) Project: This standard describes data groupings that are used to exchange data related to environmental projects.

The proposed minimum data elements for ground-water monitoring of levels and quality are listed in the table 6.1.1.1 in the main text of the report.

Table 6-6.1.4.1 Environmental Data Standards Council data description example.

Data Table Name	Data Table Definition			Data Table XML Tag
1.0 Laboratory Identification	Identifying information of the entity or person responsible for the analysis.			LaboratoryIdentification
Data Element Name	**Data Element Definitions**	**Notes**	**Format**	**XML Tags**
1.1 Laboratory Identifier	A designator used to uniquely identify the laboratory doing the analysis.	Note: Based on the business need, additional meta-data may be required to sufficiently describe an identifier.	A	LaboratoryIdentifier

6-6.2 International Geospatial Data Standards

6-6.2.1 International Organization for Standardization (ISO)

The ISO technical committee TC211 develops standards relating to geographic information. ISO standard 19115, *Geographic Information—Metadata,* was designed for international use and to satisfy the requirements of all well-known metadata standards. ISO 19115 is a content standard that defines the schema required for describing geographic information and services, and provides information about the identification, the extent, quality, spatial and temporal schema, spatial reference, and distribution of digital geographic data. ISO standard 19139, *Geographic Information—Metadata—Implementation Specification,* provides a schema in XML format that indicates how ISO 19115 metadata should be stored in XML format. ISO 19139 provides an encoding schema for describing, validating, and exchanging metadata about geographic datasets, dataset series, individual geographic features, feature data elements, feature types, feature properties, etc.

6-6.2.2 National Efforts

The Federal Geographic Data Committee (FGDC; *http://www.fgdc.gov/*) has developed standards for geographic databases, data, and metadata that are to be shared among Federal agencies and among geographic information system (GIS) researchers, most commonly datasets to be used in GIS applications. The standards define information and XML tags describing the identification, extent, quality, spatial and temporal schema, spatial reference, and distribution of digital geographic data. With respect to the Subcommittee on Ground Water (SOGW) and ground-water monitoring, FGDC standards apply to several aspects of locational attributes of monitoring stations and monitoring networks and the metadata used to describe those attributes.

The FGDC standards for geographic metadata, however, are far more comprehensive than what would typically be used for ground-water monitoring stations largely because many of the metadata elements in the standards are not useful to the design of ground-water monitoring networks or the interpretation of ground-water data. As a result, FGDC metadata formats and standards are not widely used in ground-water science. For example, although ground-water monitoring stations have geographic attributes (x, y, and z coordinates), and many State and Federal databases include geographic metadata, such as coordinate datum, coordinate units, method used for determining location, accuracy of the location, date of measurement, and the organization responsible for determining the location, these metadata are not stored or readily transferrable in a format compliant with applicable metadata standards. The challenge is to provide translation tools to convert the geographic metadata applicable to ground-water monitoring into a format compliant with national standards.

The Advisory Committee on Water Information (ACWI) Subcommittee on Spatial Water Data (SOSWD; *http://acwi.gov/spatial/index.html*) is jointly sponsored by the FGDC. The purpose of the Subcommittee is to coordinate spatial water data and information activities among all levels of government and the private sector. The efforts of this group have been largely focused on development of data, data models, data standards, and tools for evaluating land-surface and surface-water features (Hydrologic Unit code (HUC), National Hydrography Dataset (NHD), National Elevation Dataset (NED)).

6-6.2.3 Open Geospatial Consortium (OGC)

The Open Geospatial Consortium (OGC; *http://www.opengeospatial.org/*) comprises more than 400 companies, government agencies, and universities internationally that collaborate to develop open standards for discovery, integration, and dissemination of geospatially related datasets. OGC standards define both the structure of data, which is often domain dependent, and the mechanisms by which to exchange data.

OGC spans 10 different domains, one of which is “Geosciences and the Environment.” Within this group, the Hydrology Domain Working Group was formed in 2009 to develop, test, and evolve OGC standards with a special emphasis on hydrologic data. This group is responsible for the development of the Water Markup Language (WaterML) standard, currently in its second version, which defines the structure or format of hydrological observations data with a specific focus on time series structures and the Ground Water Markup Language (GWML; Boisvert and Brodaric, 2011b), a ground-water specific data-model extension to the OGC Geography Markup Language (GML; Portele, 2007) and the GeoSciML standard (Sen and Duffy, 2005). WaterML2.0 is implemented as an application schema of the GML, making use of the OGC Observations & Measurements standards (Taylor, 2012). WaterML2.0 is designed as an extensible schema to allow encoding of data to be used in a variety of exchange scenarios. Examples of possible application of the standard are as follows: Exchange of data for operational hydrological monitoring programs; supporting the operation of infrastructure (e.g., dams, supply systems); cross-border exchange of observational data; release of data for public dissemination; enhancing disaster management through data exchange; and exchange in support of national reporting. This standard provides the framework under which time series can be exchanged with appropriate metadata to allow correct machine interpretation and thus correct use for further analysis.

The Hydrology Domain Working Group has also sponsored several interoperability experiments specific to the exchange of groundwater data. The first Ground Water Interoperability Experiment (Brodaric and Booth, 2010) was initiated among international participants from government, academia, and the private sector to focus on ground-water data exchange across the U.S./Canadian border. GWML was investigated as a model to describe well characteristics via the OGC Web Feature Service (WFS; Vretanos, 2005) and WaterML2.0 was tested for encoding water-level measurements in an OGC Sensor Observation Services (SOS; Na, 2007). A second Ground Water Interoperability Experiment was initiated in 2012 and is currently underway (OGC, 2013). Its purpose is to develop an international ground water data model by harmonizing and extending existing models such as GWML and the E.U. INSPIRE Groundwater Model.

6-6.3 State Data Systems

States have evolved their own databases and have set their own standards or used established standards of other organizations. Naming conventions for data elements are not consistent among States or even agencies within States. The case study appearing below highlights issues with data collected and reported that impede data sharing and exchange among States or between States and agencies with which they share data.

6-6.3.1 Case Study – Montana, Florida, and Washington: Comparison of State Databases

For this case study, the SOGW reviewed information about the following three databases:

- Ground-Water Information Center (GWIC), Montana
- Watershed Monitoring Program, Florida
- Washington Department of Ecology online database, Washington

Each of the three databases appears to be storing and delivering (in general) either the same or a very similar set of fields. This makes a fair amount of sense because a well has the same characteristics regardless of whether it was drilled in Montana or Florida.

Identification

Each of the States reviewed had some form of unique identifier for their wells. Some used a character field and others used an integer field. Ideally an identifier, or primary key, should be an auto-generated numeric value with absolutely no relation to the data.

Locations

All three States appear to be storing at least one form of locating the well on the ground surface using some sort of coordinate system.

Florida is storing

- latitude and longitude (as a floating point)
- county

Montana is storing

- township, range, and section (along with determined quarter sections)
- latitude, longitude (as decimal), method, and datum
- well address
- subdivision, lot, block
- geocode (cadastral)
- county

Washington is storing

- township, range, and section
- well address
- UTM or latitude and longitude
- county

Latitude and longitude values are stored differently among the three States. Florida is storing their values in a floating point field, which only stores an approximate value. Montana is storing their values in a numeric field with up to 6-decimal precision.

The retrieval interface for Florida makes it seem like most of the identifying fields are controlled by validation lists. Montana is also controlling the majority of fields for location to only allow values that make sense for the State.

Construction and Completion

Both Montana and Florida store the details of the construction of the well, including casing and perforated/screened intervals. The most common and intuitive information includes storing the start of the interval, end of the interval, and description of material used.

Water-Level History

The data structures provided indicate that Florida tracks water-level histories, where monitored, but it was not immediately obvious that the data were stored in the tables provided.

Montana stores both the static water level reported by the driller at the time of completion and long-term water levels measured by field technicians. Montana maintains a statewide network of 900 wells that are measured at frequencies ranging from hourly to quarterly. Data from other projects at the Montana Bureau of Mines and Geology (MBMG) and other agencies across the State increasingly are being stored in the GWIC database.

Both States appear to be tracking water-level measuring-point changes over time.

Hydrogeology

The Florida database includes whether or not lithologic details are available.

The Montana database stores all available intervals and descriptions as provided by the driller/contractor who constructed the well/borehole. Montana also stores geologic source/aquifer codes on wells where they have been determined by a qualified professional.

Land Use

Neither the Florida nor the Montana database currently tracks a marker for LAND USE. Montana is considering how to implement this.

Conclusion

This comparison demonstrates that States that regularly monitor ground water may collect similar data stored under different names and also that data stored about ground water are variable from State to State.

6-6.4 Data Exchange Systems

Data exchange is defined as “the storing, accessing, and transmitting of data” (CERN Engineering Data Management Service, 2001). When considering the significance of data sharing through voluntary exchange, the ACWI National Water Quality Monitoring Council (NWQMC) noted that: “When common data elements are used by data generator organizations, the information collected and reported increases its value to other agencies, to the public, and even to the agency that originally collected the data because the data continues to be understood. Such data can then be used in subsequent studies and shared with others, potentially increasing the geographic or temporal coverage of water quality characterizations and providing better information upon which to base management decisions" (National Water Quality Monitoring Council, 2006).

The Federal government has participated in or led several efforts to establish agreements to facilitate data exchange nationally. These efforts include:

1. The USGS NWIS Web data dictionary available online at *http://waterdata.usgs.gov/nwis/help/?codes_help*
2. The USEPA WQX accessible online at *http://www.exchangenetwork.net/schema/WQX/1/WQX_DET_v1.0.xls*
3. The USEPA NEIEN accessible online at *http://www.exchangenetwork.net/*
4. U.S. National Science Foundation funded HIS developed through the CUAHSI accessible online at *http://his.cuahsi.org/system.html*

There are two general models for exchange and distribution of water data at the national and regional levels. The first model encompasses legacy sites that contain massive datasets with a national spatial context and a long period of record. Data users can retrieve data by way of the Internet from the various data sources through data-exchange nodes, which host the datasets outside the respective agency's firewall and provide public access to the data. The first model is exemplified by both the USGS-NWIS and USEPA-STORET database systems, which have been in operation since before the advent of the Internet and each contain results from millions of water measurements for levels and quality. These systems also now have multifeatured Web sites for search and retrieval of information. A key difference between the systems is that many State, Tribal, and local agencies provide data for USEPA-STORET while the USGS-NWIS data are predominately generated by USGS personnel, including some comparable State data.

At this time only the USGS-NWIS database contains level and quality data with a national spatial context and long-term time context. The USEPA-STORET databases (legacy and modern) contain vast quantities of surface-water data but relatively limited ground-water quality data. Ground-water data holdings in STORET-Legacy Data Center (LDC) vary State by State and primarily consist of water-quality data. Water-level data appear to be restricted to those measurements associated with water-quality samples. Metadata on wells in STORET-LDC are very limited and in many cases do not meet the minimum set of data elements recommended for sampling stations.

The current NWIS data dictionary used by the USGS is based on the Ground Water Site Inventory (GWSI) database. The GWSI dictionary appears to contain data elements needed for almost all purposes. However, the list of searchable fields available to NWIS-Web users is very limited, requiring many users needing to search or retrieve data from those fields to contact the USGS. A revision to this dictionary that will allow Internet users to search on additional terms has been proposed.

The second model for exchange and distribution of water data encompasses systems that are service-heavy portal-type sites that have capabilities for users to search distributed datasets to bring all of the data to the user, through the systems of the CUAHSI and the USEPA WQX. Web services or other Web-based programming tools are the means by which users enter text or map-based search terms. A variation of this approach includes the USEPA Region 5 electronic data delivery (EDD) and electronic data preparation (EDP) and STORET data entry and reporting module applications that use Web-based or stand-alone programs to help laboratories, States, and consultants prepare, quality assure/quality control (QA/QC), and submit data to regional exchange-node databases and (or) to STORET. These applications ensure standardized metadata entries and vocabularies.

Recent developments in technology, especially in GIS, are blurring the boundaries between the two general models and resulting in systems with both types of functions. For example, there are indications that the USGS is moving toward developing data services for users to access NWIS more easily. The USEPA-STORET Web site now contains a map interface to help users refine spatial search parameters.

In addition to map-based search and analytical tools, the HIS, developed by CUAHSI, has implemented a robust data model and XML scheme that will permit and encourage development of a large central database as well as a network of distributed databases that encompass data from the entire country. To test this concept, HIS participants have built, tested, and published Web-service tools that allow users to retrieve and analyze data from USEPA-STORET and USGS-NWIS.

Similar systems in various levels of development exist within the States, regional water management agencies, and local water authorities such as the Montana system that is described in a preceding section. Many of these systems include data-rich, well-documented databases to serve their stakeholders. In addition to traditional point-and-click lists and text-based and drop-down box functions, some systems have sophisticated GIS applications for Web-based data search and retrieval along with Internet-accessible, customized data services for GIS users. Presentations have been made on several of these systems at the National Ground Water Association (NGWA) Annual Expos over the past 5 years. What is lacking is a publicly accessible data exchange or service mechanism that will pull data from these multiple sources.

At the other end of the spectrum, there are many agencies holding water data that have no Internet-accessible or even computerized data resources. Data access requires visiting, writing, or phoning the office to obtain hard-copy data sheets or reports. In some cases, a written request for information is needed. Internet access to these data would be a valuable service for consultants, regulators, and researchers. These agencies will require resources to make their data Internet accessible.

In all cases, data-storage and exchange systems that make use of clearly defined metadata standards and standard vocabularies are a necessity for the long-term viability of any national or regional database or data service. EDSC and ASTM provide standard frameworks for State and local entities to make their data accessible to data services such as CUAHSI-HIS.

6-6.4.1 U.S. Geological Survey (USGS) National Water Information System (NWIS) and NWISWeb

The USGS NWISWeb application is a publicly accessible Web-browser data-distribution system for the USGS NWIS database. The USGS released several Web-browser-based data-distribution applications in 2007. These applications have packaged existing NWISWeb data-distribution applications in a portal with simple map interfaces. The Ground-Water Watch portal (*http://groundwaterwatch.usgs.gov/*) provides access to data from the Active Water-Level, Climate Response, and Real-Time Ground-Water Level Networks. "Water-resources data for the United States" (*http://wdr.water.usgs.gov*) is another such portal.

The movement of data from State and local agencies to the USGS and into NWIS is controlled by USGS policies that require that data generators, whether Federal or State, use the same data-element names to enter data into the system. Typically, these data generators are USGS Water Science Centers and State cooperators, such as Natural Resource Departments, State Engineers, and Geological Surveys. A significant percentage of the wells with water-level data in NWIS each year are provided by cooperators.

6-6.4.2 U.S. Environmental Protection Agency (USEPA) National Environmental Information Exchange Network (NEIEN)

The Exchange Network is a secure Internet- and standards-based approach for exchanging environmental data and improving environmental decisions. The USEPA, State environmental departments, and Tribes and territories are partnering to build the Exchange Network to increase access to environmental data and make the exchange of data more efficient.

A Network Node is a Web server that facilitates the interface between database systems and the network. It is an entity's "point of presence" on the Exchange Network. Using standards-based Web services and XML schema, Nodes securely initiate and respond to requests for information. With properly configured Nodes, network trading partners can seamlessly exchange data regardless of hardware, operating system, or programming environment.

Nodes are defined by their specific function, rather than what they are in a physical hardware sense. Network participants may use several different hardware and software approaches and combinations to establish a Node. For example, a network participant could implement a Node with (1) specialized Node software on a dedicated server, (2) one or more types of software on more than one server, or (3) existing enterprise software on an existing server. Network partners are free to choose their own approach to Node establishment—what is important is that the Node performs its functions as outlined in the Network Node Functional Specification, which has principles, assumptions, constraints, and requirements outlined below in the "Exchange Network."

The Exchange Network relies on data exchangers to have resolved differences in data-element naming conventions to allow data sharing in meaningful ways. These data exchangers typically are State environmental agencies and the USEPA, although other Federal agencies are also using the Exchange Network. One approach to resolving data-element names is to use the data standards of the EDSC.

Exchange Network

The USEPA NEIEN Principles, Assumptions, Constraints, and Requirements V1.0 for facilitating data exchange among States and the USEPA include

1. The specification is expected to have a life of 18–24 months. During this time, actual network usage information will be used to develop V2.0.
2. The specification will be kept as simple as possible. This is to ensure interoperability without unreasonable network participation criteria.
3. Immediate development of the specification is required because
    - Network participants need the specification to assist their Node implementations.
    - The network Implementation Plan calls for 10 Nodes implemented by 2003. However, a few dozen State agencies began establishing Nodes in 2002.

- Even if the initial specification is imperfect and incomplete, the network will work more efficiently and effectively with network standardized expectations, functional performance standards, and “rules.”
- Given the flexibility of network technologies, implementers will be looking for all practical guidance available.

4. The specification must be consistent with the Network Exchange Protocol V1.0.
5. The specification must be consistent with the Network Security Guidelines provided in a separate document.
6. The specification must be consistent with the Network Registry Guidelines and operation.

Requirements describe what will be delivered as part of the Network Node Functional Specification Version 1.0. The Network Node Functional Specification V1.0 is designed to

1. Support all critical requirements for dataflows, including the ability to “package” the relevant data using XML schemas developed by exchange partners and network participants.
2. Use Hypertext Transfer Protocol (HTTP), Web Services Description Language (WSDL), and Simple Object Access Protocol (SOAP). Emerging industry standards will be used as consistently as possible in the application of these protocols.
3. Implement and be compliant with security procedures identified in the Network Exchange Protocol V1.0. If the Network Security Guidelines become available during the shelf life of the protocol, they will supersede security measures outlined herein.
4. Be implemented using the most common toolsets in use by Node implementers. A high degree of customization will be avoided.

6-6.4.3 Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), Hydrologic Information System (HIS)

The HIS takes a different approach to data exchange than the two previous systems. The CUAHSI approach leaves the data-element naming convention unresolved, allowing organizations to continue with their current data-element names. Rather than building and maintaining a single massive database, automated data retrieval services access data from diverse, distributed databases through “mapping” of the data elements with common definitions (e.g., “constituent” and “substance”) of the various systems. At the time (2009) of the first release of the Framework Report, HIS had the capability to access, manage, and distribute data from NWIS, STORET, and several of the CUAHSI observatories. The CUAHSI observatories also include datasets from State and regional programs.

HIS members have developed a variety of automated data retrieval services and data analysis tools. Some of the services and tools are Web based and others can be installed with GIS and spreadsheet applications. The Data Access System for Hydrology (DASH) and HydroSeek are Web-browser-based tools developed by HIS that aggregate, report, and deliver these data to the end user in a seamless tabular or map display. Data search tools enable analysts to query databases for similar data using keywords or other search criteria.

6-6.4.4 U.S. Water Quality Portal and Web Services

The Water Quality Portal (*http://www.waterqualitydata.us/*) is the result of a joint data exchange effort between the U.S. EPA and USGS sponsored by the National Water Quality Monitoring Council (NWQMC) to allow access to water-quality data stored in both the U.S. EPA STORET system and USGS NWIS from a single Web-accessible end point in a common data model. The system currently contains more than 180 million public water-quality data records. Data collected by the USGS and by States and Tribes (submitted to STORET) conform to a common nomenclature known as the Water Quality eXchange (WQX) for biological and physical elements, chemical substances, chemical groups, sites, types, and sampling media developed through the Council. The Water Quality Portal utilizes this common nomenclature between NWIS and STORET to yield a merged dataset from both sources. A variety of filters, including geographic and sample parameters, are available in the portal to narrow down the retrieval dataset to sites and samples of interest. Output formats available through the portal include comma-separated, tab-separated, MS Excel, Keyhole Markup Language (KML), and Extensible Markup Language (XML). A Web service API is also available for incorporation of the Water Quality Portal data into other data systems or Web applications.

Appendix 7. Options for the National Ground-Water Monitoring Network (NGWMN) Management Structure and Funding Models

The Subcommittee on Ground Water discussed several options for management of the NGWMN. Chapter 7 of the report presents the consensus recommendations on the management structure and funding of the NGWMN. Other management options were considered and are included in this appendix. This appendix also includes additional information about the possible funding mechanisms for the NGWMN.

7-7.1 Management Options

More than 100 stakeholders likely will be involved with this program. To provide a voice for the stakeholders and at the same time provide efficient program direction, some compromise will be required on the part of every stakeholder. To accomplish this, a three-section structure is recommended that consists of (1) an advisory panel at the Federal level to provide guidance and be a voice for the network, (2) a two-tiered group of program boards (PBs) made up of stakeholders, and (3) a management and operations group (MO group) to conduct the day-to-day network operation functions, including the managing of data.

The advisory panel would be best served by the Advisory Committee on Water Information-Subcommittee on Ground Water (ACWI-SOGW), and the MO group would be best served by the U.S. Geological Survey (USGS). The stakeholder boards would include about 10 regional program boards and a national program board serving as the regional board's voice with ACWI-SOGW and the USGS MO group. The key issue for success of the NGWMN is developing a structure that is truly cooperative and inclusive between the stakeholders who operate the State and regional well networks and the USGS at the level of data collection, sample analysis, and data dissemination.

Three alternative proposals are described that fit the structure listed above. The main differences are in regard to management and oversight of the program. There are two options for the ACWI-SOGW role, either strictly advisory, as their current role is, or modifying their role to have direct decision making authority as part of this program. There are also two options for the role of the program boards. The program boards can either be advisory or they could have direct decision making authority as part of this program. In all three options, the USGS MO group would have joint decision making authority in regard to the NGWMN. Table 7-7.1.1 provides a summary of the options.

Option A would have National Program Board's role as advisory to the ACWI-SOGW and the USGS MO group. The ACWI-SOGW and the USGS MO group would have joint authority to make decisions and give direction to the NGWMN program.

Option B would have ACWI-SOGW's role as advisory to both the USGS MO group and the National Program Board. The National Program board and the USGS MO group would have joint authority to make decisions and give direction to the NGWMN program.

Option C would have ACWI-SOGW and the National Program Board serving the USGS MO group in an advisory capacity. The USGS would take recommendations and advice from the other two groups but would have direct authority over the NGWMN program.

Table 7-7.1.1 Summary of the Management Options.

Group/Option	A	B	C
ACWI-SOGW	Joint authority	Advisory role	Advisory role
National PB	Advisory role	Joint authority	Advisory role
Regional PB	Advisory role	Advisory role	Advisory role
USGS MO Group	Joint Authority	Joint Authority	Direct Authority

Table 7-7.1.2 provides a summary of key characteristics of the options. Option A and B may require Federal legislation. Of the three options, Option B, which has the National Program Board having joint authority to make decisions and help provide direction to the program, is believed to provide the greatest opportunity for State participation and overall program success. State buy-in for this program, which will include many wells already in service for monitoring at the State level, is considered the most critical issue facing the NGWMN.

The recommendation of the SOGW is Option B, with ACWI-SOGW remaining in an advisory role, and the formation of a new National Program Board and Regional Program Boards through legislation to work with the USGS to implement the NGWMN. This option provides ACWI-SOGW the opportunity to influence the direction of the NGWMN, as they currently do with other Federal programs, as well as providing the NGWMN a Federal voice. Option B is the most cooperative approach. It allows the USGS and stakeholders in the program to work together, make decisions together, and guide the program together. State participation is the most critical component of the program and the key to its success. The stakeholders will have more incentive to participate, which will lead to a more comprehensive network, and allow the USGS to better meet the needs of the Nation.

Table 7-7.1.2. Key Characteristics of the Three Management Options

Characteristic\Option	A	B	C
Funding Appropriation Required	√	√	√
No Legislation Required			√
State Participation More Likely		√	

7-7.2 Advisory Panel

The ACWI-SOGW understands the importance of the NGWMN and has members with diverse backgrounds and the experience to provide sound advice on the needs of the Nation. ACWI-SOGW members work directly with Federal agencies and will be sensitive to individual Federal agency priorities and issues when recommending/providing direction to the National Program Board and (or) the USGS MO group.

ACWI-SOGW can respond to new, emerging Federal issues. When directives related to emerging issues are given to the individual Federal agencies, ACWI-SOGW can provide guidance to address those issues with an overarching understanding of how the NGWMN priorities should shift, if necessary.

ACWI-SOGW is an established and proven advisor at the Federal level. Their recommendations carry significance nationally and having their guidance will influence how the NGWMN is viewed and, therefore, how resources are allocated in support of the NGWMN.

In Option A, ACWI-SOGW would govern and direct the NGWMN program jointly with the USGS MO group. The ACWI-SOGW and the USGS MO group would solicit advice and opinions on the direction of the NGWMN from the National Program Board, but they would make final recommendations and decisions on priorities and distribution of funding for the network. The National Program Board would be advisory and make recommendations on stakeholder issues to the ACWI-SOGW for their consideration. The ACWI-SOGW would have the following roles (many in conjunction with the USGS MO group*):

- Approve changes in scope and program.
- Approve grant solicitations based on agreed priorities.
- Evaluate proposals for funding from stakeholders and (or) make final determinations on funding issues.
- Determine priorities for the program.
- Coordinate, consult, and reach consensus with the USGS MO group.
- Evaluate success of the program, making necessary changes.
- Ensure that the NGWMN Level I questions (required questions) are appropriately addressed.
- Appoint working groups to work on specific issues (proposal evaluation, etc.).
- Provide the stakeholders with information and advice related to national issues and funding opportunities.
- Provide feedback to stakeholders on decisions made for the NGWMN (why, what was considered, etc.).
- Assist in startup of the program, soliciting participation, set up of the boards, etc.

* It is likely that some of the roles listed above would be completed by the USGS MO group and then reviewed and approved by ACWI-SOGW.

In Options B and C, ACWI-SOGW would strictly maintain an advisory role. Their specific roles would be to

- Provide advice to the USGS MO group and the National program board on Federal issues and suggest directions and priorities for the NGWMN based on their national experience and contacts within the Federal government.
- Provide the stakeholders with information and advice related to national issues and funding opportunities.
- Evaluate the success of the program and provide feedback.
- Assist in startup of the program, soliciting participation, set up of the boards, etc.

7-7.3 Program Boards (PBs)

The program boards would serve as the voice of the stakeholders that make up the networks that are part of the NGWMN. Because of the large number of stakeholders involved nationally, a two-tiered approach is necessary to adequately represent interests at every level. There would be one national program board (National PB) and a series of regional program boards (Regional PB) under and reporting to the National PB. The Regional PBs would consist of stakeholders from a specific region of the country, the USEPA regions (10) being recommended here, but some redistribution of the States in the EPA regions to better fit the location of principle aquifers will be necessary where obvious disconnects occur. Having 10 Regional PBs strikes a balance between the sizes of the membership of the Regional PBs themselves and the size of the National PB, keeping both manageable.

The makeup of the National PB will be one member from each of the 10 Regional PBs and a member each from the USGS and USEPA (plus ACWI-SOGW in Option B). The 10 Regional PB members of the National PB would have rotating 2-year terms, so that each stakeholder with a local, regional, or State monitoring network would have a chance to serve and be the voice for their specific region. The terms would be staggered among regions to maintain consistency in the board to carry over institutional knowledge and promote consistent interaction between the SOGW, the USGS, and the NPB. This approach will create consensus among regional stakeholders and create an environment that promotes national and regional needs first, and individual network needs second.

The Regional PBs will function as advisory groups to the National PB. The Regional PBs mission is to bring together regional interests to develop consensus on how to best work cooperatively with the USGS MO group, other regions, and other stakeholders for the betterment of both the NGWMN and their individual networks. The Regional PBs will send forward to the National PB needs, suggestions, recommendations, and reviews that will provide local and regional insight on every aspect of the program, from what is working and not working, to where resources should be focused, to how to improve success of the program.

In Option A and C, the National PB would serve in an advisory role to ACWI-SOGW, providing a voice for the Regional PBs. The National PB would make recommendations to ACWI-SOGW, based on the needs identified by the regions. In Option A, ACWI-SOGW would have the authority to determine how to use/prioritize those recommendations. In Option C, ACWI-SOGW would consider those recommendations when making their recommendations to the USGS MO group. The PB roles in Option A and C would be

Regional PB

- Ensure regional success and accomplishment of goals.
- Set priorities to be brought forward to the National PB for their region.
- Identify areas of regional cooperation around aquifers or with shared resources.
- Recommend issues that the NGWMN should answer within their region.

National PB

- Prioritize regional issues to forward to ACWI-SOGW.
- Make recommendations to ACWI-SOGW (priorities, funding, proposal review, etc.).
- Cooperate with ACWI-SOGW; participate in ACWI-SOGW calls and meetings.
- Provide feedback to the Regional PBs.

In Option B, the National PB would be an equal partner with the USGS MO group in making decisions regarding the NGWMN. The National PB would be directly involved with the USGS MO group in setting priorities related to funds distribution, program logistics, member cooperation, and determining program direction, based on the advice/direction of ACWI-SOGW. The National PB will work with the USGS MO group to cooperatively develop solutions, keeping in mind the constraints and directives the USGS has to work under. The National PB will review the information coming from the Regional PBs and consider those suggestions and needs when making decisions. The National PB will respond to the Regional PBs as to why specific decisions are being made in relation to their suggestions, to promote feedback and communication.

In addition to serving on the National PB periodically, the Regional PB members could be asked to serve on subcommittees under the National PB that would be charged with specific tasks. These tasks include reviewing proposals seeking additional resources for individual well networks, developing priorities/needs as seen by the stakeholders, performing an evaluation of the program or aspect of the program, and making recommendations for funding or improvements in the network where needed, among others. Each Regional PB would appoint their subcommittee member to ensure that conflicts of interest were eliminated. (For example, the subcommittee member would need to not have submitted a proposal if the subcommittee were charged with scoring proposals for the National PB). Option B would likely require that the National PB have at least one staff member/secretary to organize meetings and information, mail materials, etc.

The roles associated with the Regional PBs and the National PB in Option B are:

Regional PB

- Ensure regional success and accomplishment of goals.
- Set priorities to be brought forward to the National PB for their region.
- Identify areas of regional cooperation around aquifers or with shared resources.
- Determine issues that the NGWMN should answer within their region.

National PB (jointly with and taking advice from the USGS MO group)

- Approve changes in scope and program.
- Approve grant solicitations based on agreed priorities.
- Evaluate proposals for funding from stakeholders and (or) make final determinations on funding issues.
- Determine priorities for the program.
- Coordinate, consult, and reach consensus with the USGS MO group as a team.
- Evaluate success of the program, making necessary changes.
- Appoint working groups to work on specific issues (proposal evaluation, etc.).
- Provide the stakeholders with information and advice related to national issues and funding opportunities.
- Provide feedback to stakeholders on decisions made for the NGWMN (why, what was considered, etc.).

7-7.4 Management and Operations (MO) Group

The MO group is envisioned as a new unit at the USGS devoted to conducting the day-to-day tasks needed to operate the network at the national level as well as provide guidance to well network operators that are part of the NGWMN. The USGS has the experience and expertise and their mission is directly related to the goals of the network.

Initially, before the Regional and National PBs are set up, the USGS MO group will be charged with making the contacts with the owners of the networks and States to gather details about their programs and information on their wells, methods, data capabilities, and willingness to participate. This will be a very large and difficult undertaking. The USGS MO group will require assistance from ACWI-SOGW members to develop and cultivate this information. Regardless of the final structure, the MO group will have to oversee the gathering of well and well network data, as well as soliciting the members to the regional boards of stakeholders, with assistance from ACWI-SOGW.

Below are the tasks associated with the USGS MO group:

- Implement startup of the program, including developing a solicitation for participation and organizing stakeholders to get involved and forming the Regional PBs (using volunteer organizations (such as the National Ground Water Association (NGWA), State geologists) and State/regional SOGW members to help).
- Coordinate, consult, and reach consensus with the National PB (Option B).
- Coordinate, consult, and reach consensus with ACWI-SOGW (Option A).
- Recommend funding priorities.
- Create and manage the data portal.
- Evaluate and recommend new technologies.
- Provide program guidance/technical advice to stakeholders.
- Oversee/manage grants program.
- Disseminate technical information to stakeholders on methods, national needs, data standards, etc. (to maintain the day-to-day, two-way flow between the USGS and network managers).
- Assist/advise on committees and subcommittees.
- Disseminate data and interpretive reports as needed in an open and flexible system.
- Assist in developing report findings, answering basic questions, promoting the program with relevant and timely technical results.
- Develop interpretative methods.
- Conduct training as needed.
- Assist stakeholders in obtaining ancillary data as needed.

7-7.5 Issues Identified with the Options

The options presented identify specific issues that potentially have a bearing on the acceptability and success of the program. These issues are:

1. Legislative action may be required to create a new body with authority in managing resources or directing the program. The effort could be a stumbling block in getting that legislative action done.
2. A strong opinion exists that in order to gain cooperation of many stakeholders/well owners/States in volunteering to become a part of the NGWMN, the stakeholders will have to be involved in decisions and allocation of resources in order to see the program as truly cooperative where they are using data from their individual networks for the betterment of the Nation.

Issue 1. Legislative Action

Option A, ACWI-SOGW Authority: Based on OMB-92-01 and information on the Federal Advisory Committee Act (FACA) Web site, it appears that ACWI is advisory only. Therefore, in order to have ACWI accept the roles outlined in Option A, legislative action will be required to give them that authority.

Option B, National PB Authority: The National PB would be a new organization and, therefore, legislative action will be required to give authority to the National PB and Regional PBs to accept the roles outlined in Option B. (The role of the Regional PBs is only in the sense that one member from each Region makes up the National PB. The Regional PBs would have no other direct authority over the program, though individual members may be asked to serve on National PB committees.)

Issue 2. Stakeholder Participation

Options A and C, Stakeholders as Advisors: The stakeholders would have a voice in providing input, recommendations, and feedback to ACWI-SOGW regarding the NGWMN, but would be relying on ACWI-SOGW to decide which actions to take (Option A) or which to pass forward to the USGS MO group (Option C). The positive is ACWI-SOGW is made up of a diverse group of State, regional, and national members that would act in the best interests of the program. The disadvantage is that some States may feel the program is not truly cooperative and inclusive if they have no authority over decisions that could affect their networks and the prospect of obtaining additional funding to build and (or) better their networks.

Option B, Stakeholders as Decision Makers: The stakeholders would be directly involved in the implementation of resources and priorities related to the network. The advantage is that this will likely create the buy-in necessary to get the network started, maintain stakeholder cooperation, and help in securing the overall success of the network. It will also promote Federal-State cooperation and potentially build bridges between those entities where no current joint efforts are occurring. The disadvantage is that more decision makers are involved, and the potential exists for consensus to be more difficult to achieve.

7-7.6 Funding Options for NGWMN – Management and Operations (MO) Funding/Data Gathering Models

Funding included in the USGS budget would be allocated to support the NWGMN Management and Operations (MO) group, activities of the NGWMN National Board, NGWMN data management, and NWGMN cooperator costs. Because NGWMN is largely cooperator based, the USGS has data-collection agreements with a variety of non-Federal entities including

- Water management districts that may operate on a relatively local scale,
- Tribal governments that may operate at multicounty scales,
- State governments that operate on statewide scales,
- Multistate groups that may operate on regional scales similar to that of the High Plains aquifer in the western high plains, and
- Federal agencies including the USGS that have existing long-term ground-water monitoring networks, have water-management responsibilities, manage large amounts of Federal land, or control military installations.

Because the number of potential cooperators is large, the scales at which the cooperators operate differ, and the cooperators themselves have widely varying capabilities, several funding/data gathering models are necessary. The NGWMN National Board and USGS MO group work together to develop the best data-collection agreements between NGWMN and its cooperators.

All NGWMN funding/data gathering models address the topics listed below:

- Monitored sites and measurement frequencies.
- Standard operating procedures.
- **Data collection, storage, and transfer.**
- Data gaps, replacement monitoring sites, and new data-collection needs.
- Infrastructure improvement.
- **Work assignment, and funding flow and cooperator support.**
- Failure to perform and (or) inability to sustain long-term monitoring.
- Duplication of effort.

Two other elements critical to funding/data gathering agreements but not necessarily directly addressed within agreements are:

- **A focus on long-term, not issue-driven monitoring,** and
- **Overall applicability of a model to NGWMN.**

The bolded topics are critical to the success of the NGWMN and determine how well a funding/data gathering model fits the program, and the cooperator’s goals. Applicability also depends on the sites being considered, the cooperating agencies, and their capabilities.

NGWMN uses four funding/data gathering models to collect data:

1. **Federal Programs and Federal-to-Federal collaboration.** Various Federal Programs and Federal-to-Federal collaboration can provide for direct Federal monitoring of backbone network sites, such as those in the USGS Climate Response Network or National Water-Quality Assessment (NAWQA) Program water-quality monitoring, or for monitoring sites at locations with restricted access, such as in national parks or military installations.

2. **The USGS Cooperative Water Program (CWP) model.** USGS Cooperative Water Program agreements are appropriate for cooperators that have funding for long-term monitoring but lack the technical expertise or personnel to collect the data.

3. **A modified STATEMAP/NGWMN model.** A modified STATEMAP/NGWMN funding option is appropriate for cooperators who have an existing long-term ground-water monitoring network; a need to enhance their infrastructure, instrumentation, or frequency of data collection; the technical expertise and personnel to successfully collect the data; long-term ground-water monitoring funding; and a mission closely aligned with that of the NGWMN.

4. **U.S. Environmental Protection Agency (USEPA) funding.** USEPA funding for NGWMN has great potential to add data-collection sites, enhance infrastructure, and provide for more frequent measurement and instrumentation. However, USEPA and USGS must coordinate closely at the agency level so that duplication of effort is minimized.

Federal Programs and Federal-to-Federal collaboration

Federal agencies cooperate to generate NGWMN data, particularly where site access by non-Federal entities is difficult and (or) the non-USGS Federal agency has its own capabilities. Federal programs provide funding for USGS “backbone” networks such as the Climate Response Network (*http://groundwaterwatch.usgs.gov*). Federal-to-Federal agreements between the USGS and the U.S. Forest Service, National Park Service, Department of Defense, Bureau of Land Management, and the Bureau of Reclamation ensure that data from areas managed by these agencies are included.

USGS Cooperative Water Program (CWP) model

The USGS enters into agreements with States, Tribes, and local agencies through its Cooperative Water Program (CWP) and provides hydrologic data collection and interpretative services for projects meeting local and national goals. About half the program funds are used for interpretive studies, and half are used for data-collection activities. The data-collection program is active in all 50 States and focuses on streamgaging, ground-water levels, and surface and ground-water quality. Cooperators and the USGS plan data-collection efforts that meet Federal and cooperator objectives, and depending on the agreement, the USGS either does the work, or work is done jointly with the cooperator.

Modified STATEMAP/NGWMN model:

Under the STATEMAP program, State geological surveys write proposals to create geologic maps consistent with national and State geologic mapping goals. The State survey receives benefit of detailed geologic mapping and the National Cooperative Geological Mapping Program receives mapping consistent with its goals. STATEMAP cooperators provide 50 percent of the funding. The STATEMAP program strongly links the USGS National Cooperative Mapping Program’s mission and the missions of its cooperators; both are focused on producing geologic maps and developing unified broad-based geologic mapping support during the executive and congressional budget process.

NGWMN’s modified STATEMAP structure also links NGWMN’s mission with the missions of its cooperators. Because more agencies have expertise to monitor ground water than to create geologic maps, the model can include a broad range of partners. STATEMAP/NGWMN agreements are with local, State, and regional entities that have ground-water monitoring expertise, current management of a long-term ground-water monitoring network, and a non-Federally funded long-term ground-water monitoring mission. NGWMN’s need to collect data from the same sites year after year requires competitive and non-competitive elements:

- A non-competitive element under which the USGS MO group and the National Board solicit proposals from cooperators to collect data from monitoring sites and either make the data available to NGWMN or store them in databases for access. Contracts to gather data are renewed upon satisfactory cooperator performance and data quality.

- A competitive element where cooperators propose enhancements to NGWMN infrastructure. Examples include installation of new wells to reduce the number of nondedicated network wells and (or) to fill data gaps. The USGS MO group and the National Board annually reviews proposals and, based on national-network need, awards grants to accomplish all or part of the proposed work.

Because many cooperators are States that already have long-term monitoring programs, the cooperative agreements not only provide data for NGWMN but also allow cooperators to cover NGWMN-imposed costs related to modified field procedures, internal data management, and other operational factors. Wells within cooperator networks that are included in NGWMN provide data for non-Federal as well as NGWMN purposes and because there is State interest in the data, cooperators provide 50 percent of the support, often through in-kind services. Federal funding for long-term ground-water monitoring, similar to the Federal funding for State geologic mapping, creates broad, unified, State-level support during executive and congressional review.

USEPA funding:

Historically, the U.S. Environmental Protection Agency (USEPA) has not actively funded long-term aquifer-based ground-water level and quality networks similar to the NGWMN, but has focused on sites where impacts to ground water must be defined and (or) the effectiveness of cleanup evaluated. Potential USEPA involvement in NGWMN-like networks may depend on future need to evaluate the availability of potable ground-water supplies in response to climate variability and (or) change.

USEPA has historically funded State or other non-Federal agencies either through direct grant programs or through "pass-through" funding. State agencies often use "pass-through" funds to accomplish Federally mandated tasks, but may also further distribute the funds through State-level grant programs. An example of "pass-through" funds used to support a State-level grant program is the "319 Non-Point Source" program through which non-point source contamination issues are addressed. Because the groups that ultimately receive the funding have local interest in the work, matching funds are required. For example in Montana, "319 Non-Point Source" cooperators must match 40 percent of each project.

If USEPA determines that it must characterize how water supplies respond to climate variability, it may fund States to provide the data through direct grants or "pass-through" programs. If future USEPA long-term monitoring programs could be linked with NGWMN, the additional funding would be beneficial because additional locations could be monitored, measurement frequencies increased, more instrumentation employed, and network infrastructure enhanced.

Appendix 8. Examples of the Use of Statistics in Addressing National Ground-Water Monitoring Network Questions

8-8.1 Introduction

Table 3.1.5.1 of the main body of the report lists 20 major questions that the National Ground-Water Monitoring Network (NGWMN) will either address or assist in addressing. Many of them can be reduced to the following fundamental questions.

A. How are baseline ground-water quantity and quality conditions determined?

B. What is the uncertainty associated with the obtained answers?

C. How many ground-water levels or samples are needed in order to answer the question of interest?

D. How are changes in the conditions of ground-water resources determined?

Questions B and C above are directly related to each other. In addition, a knowledge of A, B, and C are needed in order to fully appreciate D, which is probably the most important issue of the NGWMN. The purpose of this chapter is to inform the reader how statistics can be used to answer the major NGWMN questions. There are many statistical procedures that can be used to address the questions. Only a few are presented here and the use of equations is purposely kept to a minimum. The equations presented are relatively easy to understand and should assist the reader in understanding the concepts needed to fully appreciate how A–D can be addressed. This chapter is not intended to be an introduction to statistical processes. If readers are interested in the processes pertaining to environmental monitoring, an excellent overview is given by Gilbert (1987).

8-8.2 How are Baseline Ground-Water Quantity and Quality Conditions Determined?

One way to establish baseline (starting point) conditions is to statistically describe the distribution of the network's indicators (analytes or determinants) during a baseline period. Chapter 1 of the main body of the report states that baseline represents historic data or data from an initial monitoring period for up to 5 years. One can think of the definition of baseline as a type of control. Once baseline is described, then future datasets can be compared to the initial control dataset in order to determine if changes have occurred. If so, they can be quantified.

For the baseline period, all ground water within one or more aquifers is characterized. The ground water in all wells tapping an aquifer can be thought of as the population of interest. If the ground water in all wells is sampled, population characteristics such as the mean (μ) or the standard deviation (σ) of an indicator (e.g., concentrations of a chemical or the ground-water levels in the aquifer) for the population can be calculated. This is an example of a census. Unfortunately, obtaining a census typically is unrealistic and is usually too expensive to undertake. Instead, the status of ground water is obtained from a *subset* of all wells in the aquifer (a statistical sample) and the sample statistics, such as the mean ($\overline{X}$) and standard deviation (s) (descriptions are listed below), are computed. Once sample statistics are determined, representative estimates of their corresponding population characteristics are inferred, and within a level of confidence, the error associated with the *sample* estimates can be calculated. Through examples, some of the processes are presented below.

For the NGWMN, defining baseline generally consists of using data obtained from one or more synoptic sampling events of an aquifer, along with available data from trend monitoring sites (sites that are sampled at a relatively high frequency). In addition to $\overline{X}$ and s, investigators often describe other sample characteristics such as the median, the minimum and maximum values, and the first, second, and third quartiles (Q1, Q2, and Q3). For a mathematical description of each sample statistic, see almost any introductory statistical text book (e.g., Triola, 1997). A description of the sample characteristics mentioned above is listed below.

Distribution: Indicator data are ordered from lowest to highest value along the x-axis and the frequency of each occurrence is displayed on the y-axis (e.g., figure 8-8.2.1).

Mean ($\overline{X}$): The sum of a set of values divided by the number of values. The mean is the arithmetical average. For a normal (bell-shaped or Gausian) distribution (figure 8-8.2.1), the mean is a measure of the central tendency of the distribution of the data.

Median: The middle of a set of numbers arranged in order of magnitude (smallest to largest). The median is also a measure of the central tendency of a distribution. If the distribution is normal, then the mean equals the median (figure 8-8.2.1, left).

Unfortunately, many indicator distributions in ground-water data are not normally distributed. Many distributions of ground-water indicators are skewed to the right (figure 8-8.2.1, middle). That is, there are a relatively few number of observations that have very large values. The large values are often called outliers. The mean is sensitive to outliers and the outliers affect the value of the mean more easily than the median. When this occurs, the mean has a larger value than the median (figure 8-8.2.1, middle). Since the median is less sensitive to the effects of outliers, the median is a better representative of the central tendency than the mean. If there are a few observations that have extremely small values (also referred to as outliers), the distribution becomes skewed left (figure 8-8.2.1, right). Skewed left distributions are relatively rare for ground-water indicators. When they occur, however, the median again is the better of the central tendency measures.

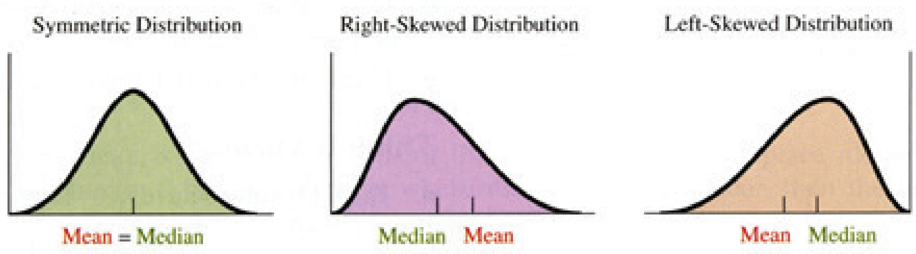


Figure 8-8.2.1. Comparison of a normal and a skewed (right) distribution (from Agresti and Franklin, 2009).

Q1, Q2, and Q3: The quartiles represent values of x that divide ordered data into four groups with 25 percent of the values in each group. Q1 equals P_{25} (the 25th percentile). Twenty-five percent of the observations are equal to or less than the value of Q1. Q2 equals P_{50} (the 50th percentile) and also equals the median. Fifty percent of the observations are equal to or less than Q2. Q3 equals P_{75} (the 75th percentile). Seventy-five percent of the observations are equal to or less than Q3.

Standard Deviation (*s*): Standard deviation is the measure of the variation or spread of the distribution. It is also a measure of how indicator data vary from the mean.

Minimum and Maximum: For the sample, minimum and maximum are the smallest and the largest values of the distribution.

8-8.3 What is the Uncertainty and How Many Samples are Needed?

Section 4.4.2 of the main body of the report discussed several methods that can be used to determine the number of monitoring points needed for NGWMN monitoring activities. If samples are obtained in a random fashion, that is, each well has an equal chance of being sampled, then the following methods can be used to estimate (1) μ, (2) the certainty of the estimate, and (or) (3) the number of samples needed to make the estimate. The methods described below are most often used for ground-water quality sampling. Because ground-water levels are often obtained in order to generate a potentiometric surface, wells used to obtain water levels are not typically selected in a random manner, and the methods described below do not apply. However, if the wells are obtained randomly, the methods are valid.

8-8.3.1 Uncertainty and Level of Confidence

When a statistical sample relative to a census is obtained, the cost is reduced, but unfortunately, only estimates of the descriptive characteristics desired are obtained. In doing so, uncertainty is created. Fortunately, statistical methods can be used to quantify the uncertainty (level of confidence). The methods are dependent upon the number of observations making up the sample and require that certain assumptions be met. Regarding a synoptic sampling event, ground-water samples must be randomly obtained and each well must be independent of others. That is, the value (outcome) of x between any two samples is assumed to be far enough away (in both distance and in time) that the outcome from one observation is not correlated with the other.

In a simplified hypothetical example, suppose the mean value of total dissolved solids (TDS) in the ground water from wells within an aquifer is of interest. In a synoptic sampling event, suppose samples are obtained from 100 surveillance wells and that the wells are located independently from each other. Suppose also that TDS is normally distributed. In milligrams per liter (mg/L) it can be determined that the $\bar{x}$ equals 452 and that s equals 300. Because a census was not obtained, the value 452 only represents an estimate of the population mean. What is a reasonable range of values of TDS that likely encompasses the true population mean? Begin by setting a confidence level (CL). How much confidence should be placed in the answer?

Confidence levels are given either in percentages or in decimals. In decimals, the possible values range from 0.00 to 1.00. Levels are typically set at 0.90, 0.95, or 0.99, but 0.95 (95 percent) is the value most often used. As it turns out, if the number of ground-water samples (n) is greater than 30, the large sample approximation allows analyzers of the data to take advantage of the Central Limit Theorem (Triola, 1997). If $n > 30$, it can be assumed that the distribution of all possible sample means has a normal distribution. In practice, the requirement is eased slightly to $n \geq 30$. Thus, if there are as few as 30 samples, a variety of statistical tools can be used that are not available if the data are highly skewed (figure 8-8.2.1) or if the sample size is small. Referring back to the example with a 95 percent CL, the following two equations can be used to determine the confidence interval (CI) of the mean and the margin of error (MOE).

$$\mathrm{CI} = (\overline{\mathrm{x}}) \pm \mathrm{MOE}, \tag{1}$$

where the MOE is the margin of error and is defined as

$$\mathrm{MOE} = \mathrm{t} \times [\mathrm{s/sqrt(n)}]. \tag{2}$$

The value for t is obtained from a statistical table for t-distributions (Triola, 1997). It is dependent on the CL and on the value n – 1 (referred to as the degrees of freedom (DF)). Thus, a separate t exists for each DF. In the example above, if DF = 99 and CL = 95 percent, the value t = 1.99. Equation 2 can be used to determine that the MOE equals 60. Then, by using equation 1, the 95 percent CI of TDS becomes 452 ± 60. The lower bound is 392 (i.e., 452 – 60) and the upper bound is 512 (i.e., 452 + 60). Even though the true population mean is not known, there is a 95 percent certainty that the value lies within the range of values 392 – 512.

Now suppose that instead of 100 samples, because of cost considerations, only 30 samples have been obtained. Also, for this example, suppose that $\overline{\mathrm{x}}$ and *s* are again 452 and 300 mg/L, respectively. Using equation 2, the MOE increases to 112, and using equation 1, the 95 percent CI is expanded to 452 ± 112 or (340, 564). The lower bound is 340 and the upper bound is 564. Since a small rather than a large MOE is generally preferred, 100 ground-water samples are better than 30; however, because of cost consideration, the smaller number of samples and a larger MOE would be used.

8-8.3.2 Number of Samples

How can the number of samples that are needed for a pre-set level of confidence be determined? The most important issue to remember is that the number of ground-water samples is inversely related to the MOE. Cost, in terms of time and funding, limits most studies. The risk is that, owing to limited resources, the number of samples collected will not be sufficient to allow a low MOE to be generated. If the population mean is to be estimated, with an estimated value of σ (e.g., s) and a 95 percent CI, Peck and others (2009) state that the following equation can be used to determine n:

$$\mathrm{n} = [(1.96 \times s)/\mathrm{MOE}]^2, \tag{3}$$

where the value 1.96 is the large sample approximation of t.

Suppose the amount of TDS is still of interest, but from an aquifer that only has a limited number of wells to sample. Suppose, based on a very small sample size, a previous investigator stated that *s* was equal to 250 mg/L. Suppose the estimate of the population mean is to be within 40 mg/L of the true mean. Since the preliminary, and only, estimate of *s* is 250, and the desired MOE is 40, the results is

$$\mathrm{n} = [(1.96 \times s)/\mathrm{MOE}]^2 = [(1.96 \times 250)/40]^2 = 150.06. \tag{4}$$

Typically, n is rounded up, not rounded off. Thus, n = 151 samples. Since cost usually forces a decrease in the desired sample size, a MOE of 90 instead of 40 is used. Using equation 4, the new computed value of n = 29.64, or by rounding up, n = 30. By increasing the MOE, there can be a 95 percent certainty that with 30 samples, the estimate of the mean will be within 90 mg/L of the true population mean.

8-8.4 How are Changes in the Conditions of Ground-Water Resources Determined?

Probably the most important issue facing the NGWMN is determining whether changes in ground-water resources occur and, if so, by how much? Using examples, several selected statistical methods for objectively making those determinations are briefly discussed. The methods for detecting change fall into two broad categories: (1) methods for use at one sampling site and (2) methods for detecting changes over time and area using multiple sites; generally referred to as Before–After–Control–Impact (BACI) designs. Note that scale of area can vary and the latter methods can easily be adapted over space. In order to make these determinations, hypothesis testing is often used. All examples below are very simplistic. Again, if the reader is interested in the statistical details, Gilbert (1987) is an excellent source of information.

8-8.4.1 Trend Detection at One Sampling Location

A trend exists when the data change systematically (often analyzed for a linear change), usually over time. Statistically, it is referred to as trend analysis. The example below describes how water levels in a well vary over time. A brief overview of selected statistical procedures used to detect trends at one site is then presented.

Figure 8-8.4.1.1 depicts monthly ground-water levels, obtained between 1991 and 2010 from a trend or (backbone) well of the NGWMN. The well (W1931) taps the Upper Floridan aquifer in north-central Florida. Figure 8-8.4.1.1A covers the years 1991–2010, figure 8-8.4.1.1B displays the years 1991–2002, and figure 8-8.4.1.1C depicts the years 2002–2010. Note that the time scales differ on each graph. The straight lines, angling from the horizontal, are indicative of the overall slope of the time series. In addition, note that cycles are present, which is typical of environmental time-series data. The cycles can, and do, affect the results of trend analyses. Short-term changes can be detected by monitoring activities and, unfortunately, there is often bias when the time frame of monitoring is considered. For example, if only the time period beginning in 1991 and ending at the first maximum peak (late 1998) is of concern, water levels are increasing. However, for the period, late 1998 through the minimum value (mid 2002), water levels are decreasing. In reality, long-term changes that extend beyond the period of monitoring likely go undetected. Therefore, when one conducts statistical analysis in an effort to determine the presence of a *trend*, it *only applies to the time frame of the analysis*.

From a Florida water management perspective, the mid 1990s represented a time of surplus rainfall and the water levels in the well increased. Beginning in late 1998 and continuing through 2002, Florida suffered a severe drought (Verdi and others, 2006). During the drought, water levels decreased considerably over all of Florida, and there was a downward slope between the beginning and the end of the drought. For a variety of reasons, in addition to the affects of the drought, water managers were interested in whether there was a trend between 1991 and 2002. Hydrographs, along with a brief description of regression analysis and hypothesis testing, can assist in understanding trend analysis.

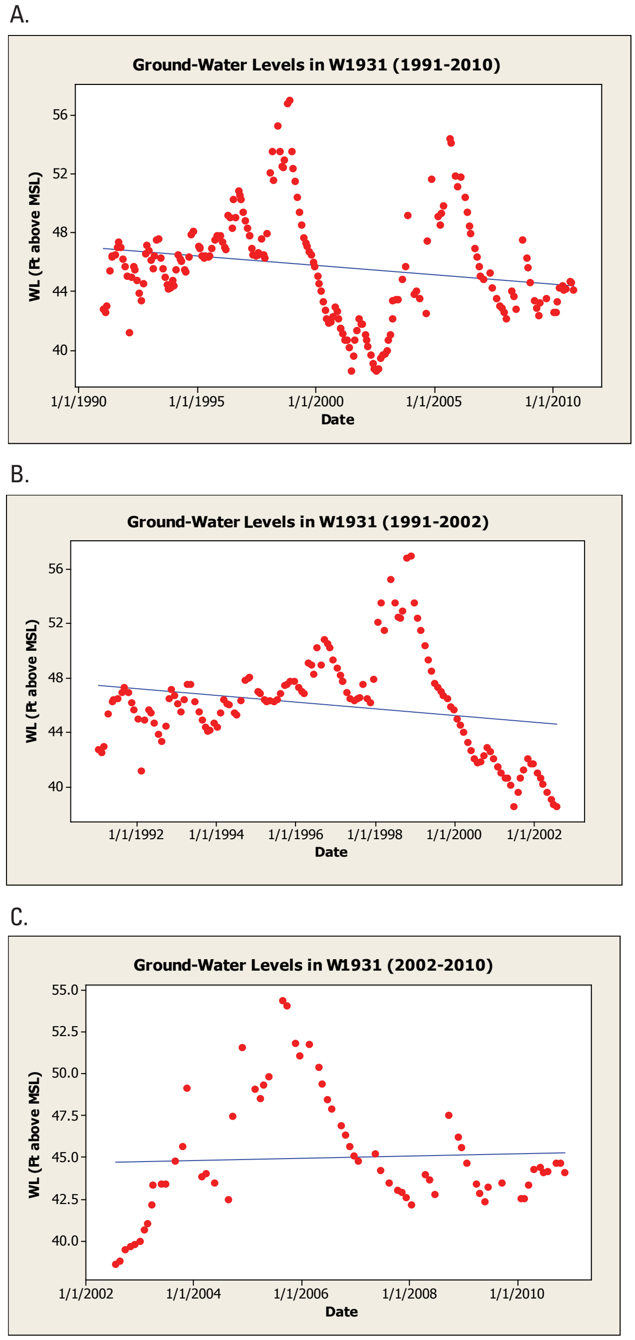


Figure 8-8.4.1.1 Ground-water levels in Well-1931 for (A) 1991–2010, (B) 1991–2002, and (C) 2002–2010, in feet above the North America Datum (NAD) of 1983.

8-8.4.2 Linear Regression

In linear regression analysis, a straight line is generated for the entire time series (solid lines in figure 8-8.4.1.1). Triola (1997) indicated that the straight line is called the regression line because some of the early investigators studied the phenomenon of heredity and showed that when tall or short couples have children, the heights of those children tend to regress or revert to more typical heights. The least-square regression linear equation is

$$Y = b_0(\mathrm{x}) + b_1, \tag{5}$$

where b_o equals the slope of the equation, and b_1 represents the y-intercept. Triola (1997) explains that formulas are available to generate b_o and b_1 from the sample data. The regression equation 5 has a special property—it represents the line with the best fit. That is, if (a) errors are generated by subtracting each sampled (observed) value from the corresponding predicted values of Y, (b) each error is squared, and (c) the total amount of error is summed, equation 5 represents the line with the least amount of squared-errors (hence, the name “least-square” regression equation). In time series, the x-axis represents time. Thus, the regression slope represents the best estimate as to the change in y (e.g., water levels) over time (x).

8-8.4.3 Hypothesis Testing

In hypothesis testing, one tests a claim or statement about a property of the population. Triola (1997) covers the subject in detail. The null hypothesis (H_0) is a statement about the value of population parameter, such as the slope. The alternative hypothesis (H_A) is a statement that must be true if there are sufficient data to reject H_0. Regarding slope, there are three possibilities:

$$\begin{array}{lll} H_0\text{: slope} = \text{zero} & H_0\text{: slope} \le \text{zero} & H_0\text{: slope} \ge \text{zero} \\ H_A\text{: slope} \ne \text{zero} & H_A\text{: slope} > \text{zero} & H_A\text{: slope} < \text{zero} \end{array} \tag{6}$$

Note that the H_0 always has an equal sign. The first example represents a two-sided test. In rejecting H_0, evidence of either an upward or a downward slope or trend is concluded. In the second example, if H_0 is rejected, an upward trend is concluded. Finally, in the third model, in rejecting H_0, evidence of a downward trend is concluded. In hypothesis testing, unless there is very strong evidence that H_A is true, H_0 should not be rejected. In terms of the legal system and a trial, H_0 is assumed to be true unless there is evidence beyond “reasonable doubt.”

Another important issue in hypothesis testing is that uncertainty is a recognized fact. Thus, the concept of the confidence level is again considered. How confident do we want the answer to be? Suppose a 95 percent CL is satisfactory. In trend analysis two t-values (t_0 and t_C) must be considered. The first (t_0) is calculated using the time-series data themselves. However, before t_0 can be calculated, a value referred to as the standard error (SE) must first be calculated. The SE is related to the standard deviation (s). SE, t_C and t_0 are each dependent upon the sample size (n). Using the time-series sample data, the value of t_0 is found by dividing the slope (b_1) by SE. Once computed, t_0 is compared to critical t value (t_C), found in almost any statistical text book. If the magnitude of t_0 is greater than t_C, there are sufficient data to reject H_0 and conclude the presence of a trend.

Consider figure 8-8.4.1.1 again. For simplicity, suppose the question is whether there are sufficient data to support the presence of a trend, regardless of whether the slope of the trend is upward or downward. First consider figure 8-8.4.1.1A. As stated previously, the straight line is indicative of slope and represents the regression line. Even though the data represent monthly samples, for the 20 years, samples were not always obtained. Of the 240 months in the time sequence, only 215 were sampled. The slope was based on these sample measurements and was calculated to be –0.0122 (approximately feet per month). Is the value significant?

For the example, H_0: slope = zero and H_A: slope ≠ zero. In the two-sided test, start by assuming that the time series has no slope (depicted by a horizontal line). For a thought exercise, data could have been collected at different times of the day and during different weeks of the month. Assuming adequate resources were available, in theory numerous time series from this well could have been generated over the course of the 20 years. Again, if the true slope is zero, then most of the time series calculated slopes would be expected to be very close to zero. However, some would display a weak positive slope, some would display a weak negative slope, and occasionally one of the slopes might equal exactly zero. In addition, a few slopes would probably be very strong, either positive or negative. Assuming H_0 is true, if an average of all possible slopes is considered, the mean would be zero.

Reality indicates that there is only one time-series dataset and only this dataset can be analyzed to make an inference about the true population slope. Because of the uncertainty, if the notion of no slope is rejected, strong evidence is needed. Two other statistical characteristics of interest are the P-value (or simply P-val) and alpha (α). First, address P-vals, which are measures of probability and, for this reason, range in value from 0.00 to 1.00. Recall that the sample dataset represents only one of numerous possible datasets that could have been generated. If H_0 is true, what is the probability that the randomly generated dataset will generate a value of t_0 equal to the one generated? If the slope associated with the one dataset is close to zero, t_0 will be small and the resulting P-val will be relatively close to 1.00. Conversely, if H_A is true, then t_0 will be relatively large, and the resulting P-val associated will be close to 0.00. In the example, the results have a 95 percent confidence. If the population slope is actually zero and if hundreds of time series were obtained from W1931 of the 20 years of interest, it is expected that on the average, a slope would not be correctly detected 95 percent of the time.

Second, address α, which represents the error of incorrectly detecting a slope if one does not exist and is related to the CL by: α = 1.00 – CL. Thus if CL = 0.95, then alpha α = 0.05. If the CL is set to 0.95, then if the P-val is less than or equal to 0.05, H_0 is rejected and HA is assumed to be true. The value of α represents a standard. If the CL = 0.95, then for any hypothesis test, the strength of the P-val can be compared to α = 0.05. For any P-val less than or equal to 0.05, H_0 is rejected. If the resulting P-val is determined to be 0.02, then H_0 should be rejected. If P-val = 0.01, then there is stronger evidence that H_0 should be rejcted than if the P-val was 0.02. P-vals can be obtained using statistical tables and almost all statistical packages will produce P-vals automatically.

In figure 8-8.4.1.1, is there enough evidence to reject H_0 and conclude that there is a trend in ground-water levels in W1931? Suppose a statistical package was used to perform a regression analysis for the 1991–2010 time period (figure 8-8.4.1.1A) and, regarding the slope, the resulting P-val is 0.004. Since the P-val is less than α (0.05), it is concluded that a trend exists for the 20-year period. The slope indicates that the trend is downward. Suppose for the 1991–2002 time frame (figure 8-8.4.1.1B), the calculated P-val is 0.013 and for the 2002–2010 time frame (figure 8-8.4.1.1C), the P-val is 0.674. It can be concluded that a downward trend exists for the 1991–2002 time frame. A plausible reason for the downward trend is the drought that existed from late 1998 through 2002. Between 2002 and 2010, visually it appears that water levels are recovering; however, doubts remain because the corresponding P-val is 0.674. Therefore, the presence of a statistically significant trend cannot be concluded.

8-8.4.4 The Seasonal Kendall Test

If the indicator distribution is normally distributed and seasonality is not an issue, the regression techniques work fine. Unfortunately, most distributions pertaining to ground water are skewed to the right (figure 8-8.4.1.1B) and seasonality may be an obstacle. Seasonality can be thought of as periodic fluctuations or cycles. Cycles are not restricted to calendar years and can occur over virtually any length of time. As previously mentioned, the cycles can potentially have an adverse effect on the trend analysis.

For these reasons, alternate trend detection procedures have been developed. Today, probably the most popular procedure for ground-water trend detection is the Seasonal-Kendall (SK) test. The SK test is a nonparametric procedure. Conover (1999) gives an excellent overview of the test. Because it is a nonparametric test, it makes no assumptions about the underlying distribution. In addition, the SK test takes into account the issue of seasonality. For these reasons it is generally preferred over the regression procedure for ground-water trend analysis. As with all hypothesis tests, the resulting P-val is compared to α in order to determine the presence of a significant statistical trend. Note that other procedures are available and many are discussed by Conover (1999) and Gilbert (1987). Each method has its pros and cons. Thus, a thorough evaluation of each method should be conducted prior to statistical analysis.

8-8.5 Methods for Detecting Changes over Time, Area, and Space

8-8.5.1 Wilcoxon Rank Sum Test

An introduction to one more hypothesis tests is needed before detecting change over time, area, and space, using multiple sampling locations. There are several tests that potentially can be used. Fortunately, knowledge of just one, along with an understanding of the SK test can serve the reader well. The Wilcoxon Rank Sum (WRS) test (Triola, 1997) is a nonparametric test. Note that the WRS test generates the same results (e.g., P-vals) as a similar test (the Mann-Whitney test (Conover, 1999)). Both tests are often used in ground-water studies. This discussion will be limited to the WRS test. For the test,

H_0: the two samples come from the same distribution

H_A: the two samples are different in some way.

The test is often used to compare the central tendency of two independent populations that have 10 or more observations each. Since ground-water data are not typically normally distributed, the WRS is used to test the equality of the central tendency, such as the median; however, it can also be used to compare the means. For our discussions, think of comparing the median values of the two corresponding independent populations that are separated in space or in time. For example, the TDS of two independent regions of an aquifer could be compared. Or, the median values of say, the first 5 and the last 5 years of the water levels from a well with a 20-year record could be compared.

Triola (1997) states that for the WRS test the investigator combines data from the two sets. He or she ranks the data of the combined samples, from lowest to largest, and for each observation, keeps track of which population the corresponding observation came from. The lowest ranked value is given a rank of “1,” the second is given a rank of “2,” and so on. Triola gives a procedure for keeping track of ties in the ranked scores. The investigator then sums the ranks of either of the two samples. Based on the sum of the ranks, a Z value (calculated Z (Z_0)) is determined. The Z-distribution is a “cousin” of the t-distribution. Z-tables are available in almost all statistical text books, and statistical software programs can readily calculate the corresponding Z value. Triola (1997) gives an excellent presentation of Z.

Z_0 is then compared with a critical level of Z (Z_c). If the magnitude of Z_0 is greater than Z_c, there are sufficient data to reject H_0 and conclude that the sums of the ranks of the two samples are not equal (hence Wilcoxon Rank Sum test). For the WRS test, if the values of the two medians are vastly different from each other, the corresponding P-val will be very small. If the CL = 0.95 and the resulting P-val is less than 0.05, it is concluded that the median values are significantly different.

With this rudimentary introduction to the WRS and the SK tests, plus an understanding that most ground-water related distributions are not normally distributed, the use of these two nonparametric tests can be used to evaluate changes in both ground-water quantity and quality.

8-8.5.2 Before - After - Control - Impact Designs

Practical techniques for addressing environmental changes are not new. A good synopsis is “Before - After - Control - Impact (BACI)” methods presented in “Detecting Ecological Impacts; Concepts and Applications in Coastal Habitats” by Schmitt and Osenberg (1996). The applications are not restricted to coastal habitats and can also be used in freshwater regimes including ground water. BACI designs can be broken down into three subtypes: (1) Before - After (BA), (2) Control - Impact (CI), and (3) true BACI designs. Short definitions are listed below.

Before – Samples are collected prior to the implementation of a treatment.

After – Samples are collected after the implementation of a treatment.

Control – Samples are collected from a site that is comparable to the site that receives a treatment, but the site does not receive the treatment.

Impact – Samples are collected from a site (area or space) that receives a treatment.

Triola (1997) states that a treatment is a property that allows the different populations to be distinguished from one another. In an experiment, a treatment is applied and its effects are observed. For example, a treatment could be thought of as the effect of a drought on the water levels of an aquifer. In this situation the treatment is a natural one; however, the treatment could be manmade. As another example, suppose a land-use activity causes ground-water contamination. In this scenario, the treatment can have a negative effect (e.g., area is being contaminated). In other situations, the treatment could be positive (e.g., a management plan is initiated that reduces the amount or impact of the pollutants).

8-8.5.3 Before - After (BA) Designs

Suppose in a special NGWMN study it is known that excessive pumping in a well located near the coast tapping an unconfined aquifer has caused saltwater intrusion (e.g., an increase in TDS in the well). In NGWMN jargon, the well is classified as a well with documented changes. Suppose the pumping has been relatively constant for a 6-month period and that water levels in the change well have been obtained for those 6 months. After a period of time, the local authorities decide to stop using (stop pumping) the well. For this example, refer to figure 8-8.5.3.1. Suppose that treatment (no pumping) begins in month 7. The “before” time frame is months 0 through 6. The “after” time frame continues from month 7 through 24. It is clear that throughout the period of study, the concentration of TDS has varied, but it is also clear that after initiation of the treatment, the concentration steadily decreased until it was less than 100 mg/L, beginning in month 20 and continuing through month 24. For simplicity, regarding TDS concentrations, suppose seasonality is known to not be a factor. If only one well is used, a SK test could be used to determine if, for the 24-month period of record, a significant downward trend in the concentration of TDS occurred. The only difference between this sampling method and a fixed station trend method is the division of the time sequence into "before" and "after" time frames.

This type of sampling can be easily adopted for a geographical area. Suppose that the saltwater intrusion is discovered to exist over several tens of square miles. Suppose seven production wells located throughout the area are known to be affected by intrusion. Thus the seven wells are documented change wells. Suppose all seven wells begin treatment in month 7. Now suppose the values in the graph (figure 8-8.5.3.1) represent monthly median TDS concentrations for the seven treated wells. The graph can be used to observe the effect of the treatment. Trend analysis, using the monthly median values can be used to determine the presence of a statistical trend. The presence of a downward trend can be used to infer the success of the saltwater intrusion treatment.

The **BA** design is able to account for temporal variability. Unfortunately it is unable to account for spatial variability. Without Control, the **BA** design may not be able to address the cause and effect relations. Also note that the improvement (decrease in TDS) in the example may not necessarily be due to the treatment. It may be due, or partially due, to some other cause. For example, suppose excessive rainfall occurred between months 5 and 20. The increased rainfall caused high recharge to the aquifer and was at least partially responsible for reducing the concentration of the TDS in the ground water. If this is the case, monitoring should continue past the 24-month period of the study in order to determine the affects of the treatment. This is an example of a "lurking" variable that may affect the outcome of a statistical test. When conducting statistical analyses, one must always be aware of these types of variables.

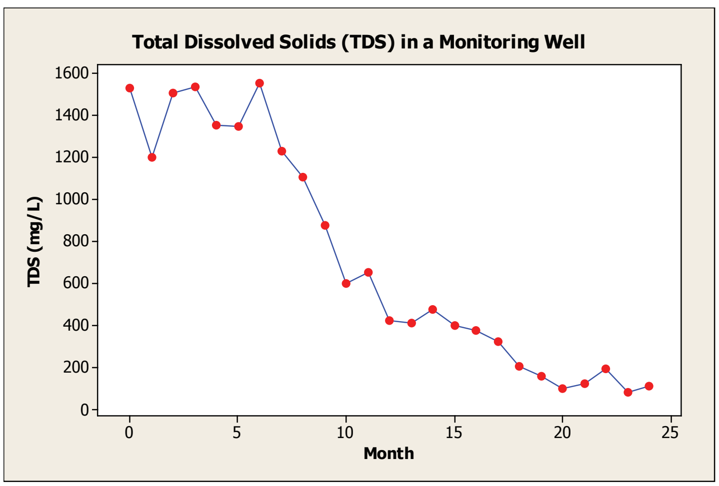


Figure 8-8.5.3.1 Example of Before - After sampling for total dissolved solids. Treatment (discontinue pumping) begins in month 7.

8-8.5.4 Control - Impact (CI) Designs

In the **CI** design, samples are collected at both the control and the impact sites, and preferably, the samples from both sites are collected simultaneously. Note that in practice, most samples come from the impact site.

In this type of design, the control site and the impact site need to be environmentally similar. Both sites should be sensitive to the treatment effect. Any change in the treatment affects the impact site, but not the control site.

Suppose that a new lawn fertilizer is being applied to a large geographical region of a county. The new fertilizer is preferred by many homeowners because it makes the lawns much greener than traditional fertilizers. Local authorities note that nitrogen, a major component of the fertilizer, exists naturally in local ground water (median = 0.05 mg/L). The authorities want to know whether the new fertilizer is finding its way into ground water, and if so, is it causing nitrate concentrations in ground water to be greater than background.

Now suppose that seven randomly selected monitoring wells are considered to be control (background) wells (wells tapping the aquifer of interest and located in portions of the county where the new fertilizer is not being applied) and that the five randomly selected wells are suspected (suspect wells) of being affected by the new fertilizer. These five wells tap the same aquifer in the region being fertilized with the new fertilizer. Suppose that both the control and suspect (impact) wells are sampled quarterly. Sampling continues for 10 quarters. After that time, a WRS test, using the median concentrations from the 70 background samples to the 50 suspect samples, can be used to determine if the suspect wells have statistically greater concentrations than background. Figure 8-8.5.4.1 displays a visual representation of the data from the two sets of wells. The box plots indicate that the suspect wells have greater nitrate concentrations than background. For verification, a WRS test can be used to compare the median concentrations of nitrate. If the CL is 95 percent, and if the resulting P-val is less than or equal to 0.05 for the one-sided test, the investigator can infer that the new fertilizer has caused nitrate concentrations to significantly increase and that the fertilizer has adversely affected the aquifer.

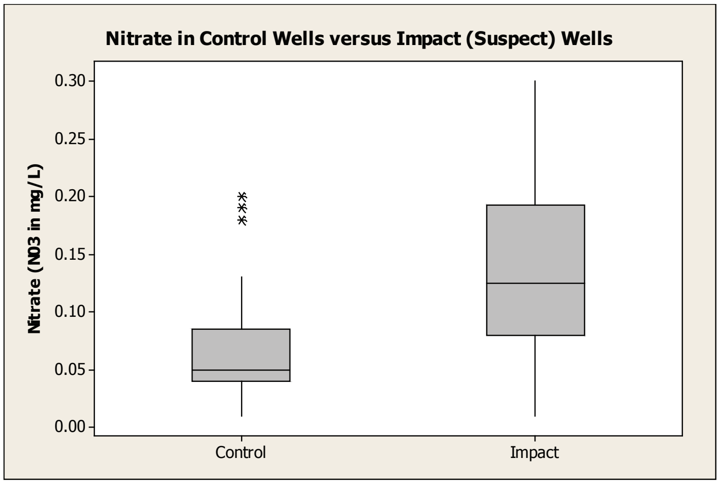


Figure 8-8.5.4.1 Example of Control - Impact sampling. Distribution of nitrate (NO_3) concentrations are compared from control wells and impact (suspect) wells.

8-8.5.5 Before - After - Control - Impact (BACI) Designs

Before - After - Control - Impact types of designs are preferred because they account for both temporal and spatial variability. Unfortunately, in many situations, the variable of interest is known, but sampling is not possible until after the treatment begins. Under this situation, a BA design is impossible.

Figure 8-8.5.5.1 can be used to demonstrate how the BACI monitoring can work. Suppose the squares represent the monthly median values of TDS in four randomly selected background wells, and the circles represent monthly median values of TDS in five randomly selected suspect wells. As shown in the figure, the median values of TDS in the suspect wells appear to have decreased over the duration of the study; however, beginning in month 20, concentrations in the suspect wells tend to taper off. The SK test can be used to test if downward trends are present. If a downward trend does exist in the suspect wells, but not in the control wells, there is strong evidence that the treatment is effective. In addition, a WRS test can be used to compare, for example, the median values in the first half to the second half of the time series for both the background and the suspect wells. If a significant decrease is found in the median concentrations of the suspect wells, but not in the background wells, there is strong evidence that the treatment is effective.

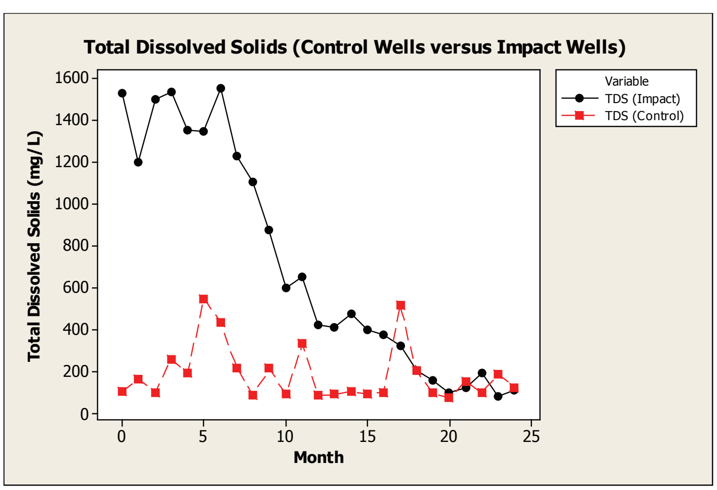


Figure 8-8.5.5.1 Example of Before - After - Control - Impact (BACI) sampling. Median concentrations of total dissolved solids in control wells are compared to impact wells over 24 months.

8-8.6 Caution with Regard to Hypothesis Testing

Caution should be used with regard to hypothesis testing. Each test requires that certain assumptions are met. If they are not, then the validity of the test results may come into question. Also, one must always consider the practical results of the test. Revisit the CI (nitrate) example, and suppose that during base-flow conditions, ground water supplies the vast majority of water to the lakes of the county. It is known that if nitrate is above a level of 0.35 mg/L, algae blooms become a common occurrence in the lakes of the region. The blooms are also known to adversely affect the ecosystems of the lakes. Local officials are determined not to have this situation occur.

Two scenarios can be considered. In the first, suppose that the median nitrate value in the background wells is 0.05 mg/L, the median value in the suspect wells is 0.07 mg/L, and the WRS test indicates that the two medians are significantly different. As such, during base flow, the elevated nitrate levels from ground-water flow into the local lakes have a minimal effect. Consider a second scenario. Now suppose that the median concentration of the background wells is again 0.05 mg/L; however, the median value in the suspect wells is 11.50 mg/L, instead of 0.07 mg/L. Suppose the WRS test indicates the medians are significantly different. In this scenario, local officials are not only concerned about the possibility of ground water adversely affecting the lake ecosystems, they are very concerned that nitrate concentrations in the ground water covering a large portion of their county is above the national drinking water standards. In both scenarios, there is a statistical significance in the difference in the median nitrate concentrations; however, considering the practical significance, the local officials are likely to restrict their concerns to the second scenario.

Being cautious about the results of hypothesis tests is wise. Nevertheless, if assumptions are met and if the samples are obtained properly and in a random fashion, hypothesis tests should produce objective results, which is their strength and why they are needed in ground-water monitoring activities of the NGWMN.

The National Ground-Water Monitoring Network Data Portal can be accessed at:

http://cida.usgs.gov/ngwmn

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A National Framework for Ground-Water Monitoring in the United States