DRAFT

REPORT TO CONGRESS:

Strengthening the Scientific Understanding of Climate Change Impacts on Freshwater Resources of the United States

March 2011

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Executive Summary

The Omnibus Public Lands Act (Section 9506 of Public Law 111–11; Appendix A) calls for a report to Congress that describes the current scientific understanding of each impact of global climate change on freshwater resources of the United States.

This draft report identifies key actions to improve the Nation's capacity to detect and predict changes in freshwater resources that are likely to result from a changing climate. In addition, a series of next steps for Federal agencies is provided. The ultimate goal is to help decision-makers and water resource managers by facilitating improvements in observational, data acquisition, and modeling capabilities.

Freshwater resources are vulnerable to a number of stressors, of which a changing climate is but one of the more recently recognized. Some key impacts of climate change on water resources that have been identified to-date include[1]:

- increasing air and water temperatures;
- declining rainfall amounts in some areas and increasing amounts in other areas while the proportion of precipitation that falls as snow decreases;
- changes in the timing of snowmelt runoff;
- decline in the mass of water stored in glaciers;
- more intense rainfall and storm events;
- rising sea levels; and
- changing quality of coastal and ocean waters.

The Nation invests considerable resources in monitoring, mapping, evaluating, assessing, modeling, and managing water resources. Many of the existing observational water data networks, models, and hydro-statistical methods were developed for specific users and pre-date recent advances in climate change science. As a result, these systems (networks, methods, and models) were not designed to address climate-induced stressors, to account for non-stationary hydroclimatic processes, or to evaluate the effectiveness of climate change mitigation and adaptation strategies. Today, there is a need and an opportunity to modernize data networks and climate-relevant data collection, data management, mapping, modeling, and information dissemination. Of particular importance is maintenance and strengthening of long-term *in situ* and remote observational capabilities to detect change.

This draft report provides a general overview of the challenges that a changing climate poses for water resource managers in the context of other water-resources stressors. In particular, the report considers water resources measurement and modeling systems that are relevant to climate change adaptation, as required by Section 9506. Recommendations are focused on strengthening these systems to inform water management decisions at the Federal, State, and

[1] http://www.globalchange.gov/what-we-do/assessment

local levels. This report draws from and builds on a number of recent climate and water documents that have been produced across the Federal, State, local, Tribal, and private water sectors.

Observational data, the networks that provide these data, the systems that make these data available, and the models that enable projections of future climate conditions are critical for decision-making. Investments in hydrologic data, science, and technology need to be leveraged to promote the ready interoperability of data and models, and ultimately provide decision-makers with more effective information, tools, and services.

Findings

The key findings for each of the six "review elements" included in the statute (i.e.: Section 9506 of PL 111-11) are summarized below.

1. **Assess adequacy of current hydro-climatological observation networks**

   Finding 1: The observational networks assessed in this process provide necessary and useful data for a range of water-resources management decisions, including but not limited to climate-related decisions.

   Finding 2: Most hydro-climatic networks exhibit deficiencies, whether in inconsistent methodologies used to collect data of a given type; inadequate spatial coverage; temporal data gaps or insufficiently long records; failure to seamlessly present data from different networks operating at different scales; insufficient models to project conditions in space and time; incomplete use of new or emerging technology; or delivery of data through a variety of redundant or incompatible portals. The USGS streamgage network is uniquely valuable for assessing both long-term water availability and for providing day-to-day operational guidance, but continues to experience cuts, particularly in long-term gages that provide the most climate-relevant data.

2. **Identify Data gaps in current water monitoring networks**

   Finding 3: Numerous documents and reports by agency, interagency, non-governmental and trade organizations provide excellent detailed information on monitoring network gaps and specify ways to close those gaps. These documents and reports are produced by the groups who operate the networks and utilize the data, and thus are most familiar with the needs.

   Finding 4: Water-use information (withdrawals and return flows) are not collected consistently from state to state, if at all, and data are difficult to obtain in a timely manner.

Finding 5: Lake-level and reservoir content information is collected in some locations, but a true network of lake level data does not exist.

Finding 6: Wetlands are a key indicator of climate change and water-resources stress. Wetland monitoring needs to be strengthened both in terms of frequency of monitoring and types of data available.

Finding 7: Indirect effects of climate change, such as changes in the Nation's energy portfolio (increased use of biofuels; new hydrocarbon energy extraction methods) and increased use of carbon sequestration, will have an effect on water resources. Monitoring networks do not exist to address these issues.

Finding 8: Monitoring networks are inadequate to detect changes in waterborne disease as a function of climate change.

Finding 9: Research can play a key role in the design of monitoring networks and in filling gaps. Research on new measurement technologies and on models for extending data should be strengthened. Research on the linkages among water use, climate drivers, and water availability also is inadequate. Adoption of common open standards among data systems would increase the utility and lower the cost associated with information integration.

3. Improve data management to increase efficiency of data acquisition and reporting

Finding 10: While existing observational data systems address the essential physical and chemical dimensions of freshwater resources, improved coordination among the data systems is needed. Particular attention should be focused on improving the capability to monitor waterborne disease.

Finding 11: Access to the full range of hydro-climatic data collected by multiple government agencies (Federal, State, local, Tribal), and other interests (academic organizations, non-governmental organizations, and others), is inadequate. Data are collected using a range of protocols, which are not always documented, and are archived in a variety of ways, from modern relational databases to paper copies in files. There is much to be gained from use of consistent documentation standards and improvements in interoperability of data systems.

Finding 12: Data are insufficiently integrated to support important management decisions. For example, most water-quality data are not integrated with water quantity data. Likewise, groundwater and streamflow data generally are not integrated, thereby limiting, for example, understanding the effects of groundwater pumping on streamflow.

Finding 13: Data that are critical to climate impact assessment in a multi-stress context are often missing entirely. For example, both the data and the information systems that would be needed are very limited. As an example, the capacity does not exist to link information about vulnerable human populations with data about implications of changes in the hydro-climatic cycle (i.e., frequency and magnitude of floods and droughts).

Finding 14: Current efforts to design a Hydrologic Information System, funded by the National Science Foundation are important investments that are leading to more tools to support interoperability of data sets. It is unlikely, however, that this effort will be sufficient to integrate data at the state, regional, and local levels, where most water management decisions are made.

4. Establish a data portal to enhance access to water resource data across agencies

Finding 15: There is a well-established need for an interagency data portal to provide access to climate related data, including hydrologic data. The U.S. Global Change Research Program is an appropriate entity to develop a strategic plan for implementation of such a portal.

5. Facilitate the development of hydrologic and other models to integrate data that reflects groundwater and surface water interactions

Finding 16: Existing groundwater models are adequate for some hydrogeologic settings, but not all (e.g., fractured rock environments).

Finding 17: Fully coupled groundwater – surface-water models are relatively recent innovations and have been applied in a limited number of locations. In addition, there is a great need for development of integrated groundwater-surface water models that incorporate water quality components.

Finding 18: Models that are capable of assimilating real-time spatial, *in situ*, and remotely-sensed data do not exist. Such models could become integral to more effective water-resources management.

Finding 19: Models for estimating hydro-climatic statistics are inadequate. The effects of climate and management changes (i.e., changes in trends in temperature and precipitation, land use, water management, land management practices, etc.) currently are not considered when estimating the probability of future hydro-climatic events, such as large storms, floods (and associated groundwater impacts), droughts, etc.

Finding 20: Guidance for using output from global and regional climate model output as input to hydrologic models is needed. A particular need is the ability to translate uncertainties in climate models to uncertainties in water-resources forecasts.

Finding 21: In many cases, existing hydro-climatic records have been inadequately explored to fully determine regional and national trends in hydro-climatic conditions or to satisfactorily explain the relation of some changes to causative factors.

6. **Apply hydrologic information to resolve water resource problems including improvement of ecological resiliency**

   Finding 22: Significant ecological and social benefits are expected from enhanced coordination of water related data collection and integration activities across the federal government. Better use of models, tools and information currently available through improvements in data management and interoperability, as well as continued investments in new understanding of hydroclimatic changes, will make significant contributions to human and ecological resiliency.

   Finding 23: Even though there have been improvements in the ability to use hydrologic data and models to resolve water management problems, there is a significant need for enhanced federal coordination of water management efforts as well as monitoring and research.

Next Steps

Implementing the findings of this report will require a coordinated effort. Key action items are:

1. **Strengthen observational data systems for freshwater resources and climate change**

   - Implement recommendations from existing reports describing needed enhancements to the observational network, giving priority to information that is critical from a health, safety and welfare perspective, as well as considering the data needs of land, water and environmental resource managers. Give consideration to monitoring effects on water resources of energy extraction and production and to geologic carbon sequestration.

2. **Prioritize observations that fill important gaps in understanding of water supply reliability**

   - Enhance collection of water use information, including provision of timely information on withdrawals and return flows (quantity and quality) from surface and groundwater resources and information on withdrawals by sector.
   - Implement a national lake/reservoir level and contents data network.
   - Enhance interagency efforts to monitor wetland areas and habitat quality on a seasonal basis.
   - Implement a waterborne disease tracking network, including all appropriate ancillary data.
   - Conduct research on new monitoring technologies, including sensors, data transmission, automated quality assurance, and remote-sensing technologies.

3. **Strengthen links between water observational data systems and climate models; improve data management, acquisition and reporting**

    - Link monitoring, observational systems, climate model outputs and other data systems, to support high-priority water management decisions (particularly related to water supply reliability and quality).
    - Establish and encourage the use of consistent data standards across agencies and with non-governmental partners and other ways to integrate existing data into more comprehensive water information systems.

4. **Support the establishment of an interagency climate data portal and provide access to high priority water-related datasets**

    - Promote interagency coordination to assess climate impacts on freshwater resources in national and regional climate assessments.
    - Develop guidance for water managers on appropriate use of probabilistic projections and model outputs.

5. **Make strengthening water data a key priority in the national freshwater climate action plan now under development, including a focus on a better understanding of groundwater-surface water interactions and modeling needs**

6. **Strengthen federal agency coordination to improve the quality and accessibility of freshwater data systems including technical outreach and support to stakeholders and decision-makers**

    - Federal agency actions towards improving data integration should continue and the Subcommittee on Water Availability and Quality (SWAQ) should promote cross-agency communication and additional coordination opportunities as appropriate.
    - SWAQ should monitor progress on implementing the findings and recommendations of this report and provide periodic updates to the USGCRP and the Interagency Climate Change Adaptation Task Force.
    - Promote interagency coordination and cooperation to implement the National Water Census.[2]
    - Encourage the Advisory Committee on Water Information, an existing Federal Advisory Committee, to establish a new subcommittee or other appropriate mechanism, to solicit and consider input from the public and stakeholders on matters related to freshwater resources and a changing climate and relay these views to Federal water data program managers and the SWAQ.

[2] http://water.usgs.gov/wsi

Introduction

Freshwater, one of the Nation's most valuable and fragile natural resources, is experiencing dramatic effects from changes in climate. Water supplies and their supporting infrastructure are critical to the health and well-being of society and central to a vibrant economy, food production, energy reliability, and national security. The quantity and quality of freshwater affects the viability of aquatic habitats, wetlands, and critical ecosystems that support fisheries, wildlife, and recreational activities. The consequences of a changing climate on freshwater already being observed include:

> "We don't yet have the observation networks and capacities that we ought to have to keep track of what's happening on and to the Earth. . . That priority on maintaining and expanding the data sets, the observations, the monitoring, is absolutely key. If you don't do that, you can never make up for it, in the sense that we will never know what the Earth was doing in places and time when we weren't monitoring it."
>
> *John Holdren: Science Advisor to the President*

- Changing precipitation patterns (frequency, storm intensity, timing, etc.) that lead to flooding or drought conditions, pollutant runoff from land surfaces into freshwater resources, and disruption of aquatic habitats (e.g., Christensen et al., 2007; IPCC, 2007a and 2008);

- Altered snowpack characteristics (depth, density, storage capacity or water equivalent, temperature, melt rate, etc.), that affect timing and volume of snowmelt runoff and the capacity to store water (e.g., McCabe and Wolock, 2002);

- Changing sea levels that affect coastal and near-coastal environments, increase impacts of coastal storms, cause saltwater intrusion into groundwater resources, disrupt water-resources infrastructure, and impair the health of coastal wetlands (e.g., Karl et al., 2009); and

- Perturbation of aquatic ecosystems due to changing patterns of air and water temperature, precipitation, water quality, land use, and water allocation (e.g., Christensen et al., 2007; IPCC, 2007a and 2008; Karl et al., 2009).

The United States Global Change Research Program (USGCRP) is actively engaged in evaluating the effects of climate change on human and natural systems in the U.S., including freshwater resources. The recent USGCRP national assessment, released in 2009[3], highlights the importance of providing decision-makers with appropriate data, tools, and models for climate change adaptation. The next National Climate Assessment, due in 2013, provides an opportunity for enhanced water related data collection in partnership with regions and sectors as well as improved mechanisms for data interoperability.

In addition, in its 2010 *Progress Report* (CEQ, 2010), the Interagency Climate Change Adaptation Task Force[4] (ICCATF) called for "improving water resource management in the context of a changing climate." The Task Force identified several key actions, one of which was to "strengthen data and information systems for understanding climate change impacts on water." The Task Force also called for an interagency effort to develop a national action plan supporting adaptation of water resources management to a changing climate

Congress recognized the importance of supporting water resources decisions when it enacted Section 9506 of the Omnibus Public Lands Act (Public Law 111–11) in March of 2009 (Appendix A). Section 9506 calls for a report to Congress describing the current scientific understanding of impacts of global climate change on the freshwater resources of the United States.

This draft report was developed in response to the requirements of Section 9506 by an interagency team of water data program managers. The interagency team cooperated with the Subcommittee on Water Availability and Quality (SWAQ), an interagency subcommittee of the National Science and Technology Council (NSTC) Committee on Environment Natural Resources, and Sustainability (CENRS)[5] and the Interagency Climate Change Adaptation Task Force[6,7] and it's Water Resources Workgroup. The interagency team also collaborated with a range of interested parties including the Advisory Committee on Water Information (ACWI)[8].

This draft report was prepared for public review and comment and is available on the internet at www.acwi.climate/waterreport along with a link for providing comments. The interagency team will consider public comments, make needed changes, and forward a revised draft report to the Interagency Climate Change Adaptation Task Force. The Task Force will review the public comments and the revised draft report and make any further changes prior to providing a final report to the Secretary of the Interior for transmittal to Congress as required by Section 9506.

[3] Global Climate Change Impacts in the United States. http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts

[4] CEQ, 2010. The Task Force was established in 2009 to provide overall direction and guidance to Federal agencies in matters relating to adaptation to climate change. http://www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation

[5] CENRS 2010. http://www.whitehouse.gov/administration/eop/ostp/nstc/committees/cenrs

[6] The Interagency Climate Change Adaptation Task Force is co-chaired by the Council of Environmental Quality, the Office of Science and Technology Policy, and the National Oceanic and Atmospheric Administration.

[7] http://www1.eere.energy.gov/femp/regulations/eo13423.html

[8] ACWI 2010. http://acwi.gov

Climate-relevant Water Resource Challenges

Every day, all across the Nation, decisions are being made that affect the quantity, quality, and sustainability of water resources (IPCC, 2007a and 2008; USCRP, 2009). These decisions can have significant economic, health, social, and environmental implications. Some decisions directly affect local water availability such as water withdrawals and infrastructure development to support drinking water systems, irrigation, energy production, or industrial activities. Other decisions that affect the quality and availability of water include urban development and land use changes, energy development, runoff and discharges associated with transportation, municipal, industrial, and agricultural practices.

Concerns about environmental quality and climate change impacts on water have highlighted the importance of protecting our citizens and infrastructure from the consequences of impaired water quality (contaminants, salts, nutrients, etc.), too much water (flooding), or too little water (droughts). Given today's knowledge about climate change, it is clear that decision-makers need ready access to reliable data, effective data management, and up-to-date analyses and scientific tools.

In addition to direct climate impacts on water availability (e.g., changes in amounts and timing of precipitation) and quality, decisions made to mitigate or adapt to climate change also affect water resources. For example, shifts in our national energy portfolio such as increased use of alternative energy sources (e.g., biofuels, solar, wind), increased energy efficiencies, or alternative approaches for resource extraction (e.g., the use of hydraulic fracturing) can affect local or regional water availability and quality (EPRI, 2002; Mielke et al., 2010). Similarly, the use of carbon capture and sequestration to control greenhouse gas emissions can impact water systems (Dooley et al., 2006; IPCC, 2005). It is, therefore, important to maintain or develop adequate data collection systems that focus on the water related implications of a wide range of decisions and track the net effect on future water availability and quality.

High priority water resources challenges that are affected by climate can be categorized into four interrelated areas:

- Assuring an adequate water supply;
- Protecting human life, health, and property;
- Protecting the quality of freshwater resources and the ecosystems they support; and
- Protecting coastal and ocean resources and the ecosystems they support.

Climate-relevant aspects of each of these challenges are highlighted below. Water managers and decision-makers need access to robust and reliable data, modeling capabilities, and information exchange systems to predict, respond, and adapt to a changing climate.

Assuring an Adequate Water Supply

Federal, State, and local governments, utilities, farmers, energy companies, industry, and private citizens all make decisions that affect and are impacted by the availability, reliability, and quality of water supplies. Critical freshwater needs include:

- municipal, domestic, and private drinking water supplies;
- agriculture;
- energy development, production, and generation;
- industrial cooling and process water;
- navigation, recreation, and tourism; and
- healthy aquatic ecosystems.

Water managers and decision-makers need to ensure that water is managed in a safe manner and that enough water of the appropriate quantity and quality is available at the necessary time and place to support ecosystems as well as human needs. In addition to climate change, improvements in water-use efficiency, advances in technologies (e.g., irrigation, energy, and industry), changes in land-use and development patterns, and changes in the economics of delivering water to end-users need to be considered in water supply decisions. For example, the Council of Environmental Quality is leading an effort to update the Principles and Standards for water project planning with the goal of improving project planning and decision-making.

To assure an adequate water supply now and into the future, water managers and decision-makers need the capacity to predict and anticipate:

- How aquatic ecosystems respond to the short- and long-term changes in freshwater quantity, quality, and availability;
- Historical patterns and projected trends in annual and seasonal variability in streamflows, groundwater levels, and snowpack characteristics to improve water use planning and provisioning;
- How future climate, water management decisions, and land-use scenarios will impact water uptake for agriculture, energy, water and wastewater treatment requirements, health risks, and aquatic ecosystem biodiversity;
- How water quality will change in response to the types and quantities of chemical and microbial contaminants, warmer and more variable water temperatures, different flow patterns, and alternative water resource management practices; and
- Impacts of climate, land-use, and water management practices in conjunction with streamflows, precipitation patterns, and groundwater recharge on saltwater intrusion into freshwater aquifers and estuaries and salinity in water supplies.

Robust observational data are needed to determine the extent to which changes are occurring, the rate of changes in trends as well as extremes, and the likelihood of crossing thresholds in ecological and hydrological systems. Collecting, documenting, and publishing observational data in a systematic, reliable, and defensible way is critical. Data and information form the basis for predictive tools and models to estimate and evaluate factors that affect the amount and quality of water resources likely to be available in the future, as climate, land-use, economics, and sociological factors change. Integrated data networks, mapping, and modeling tools provide a basis for simulating potential impacts of climate change at local, regional, and national scales. Equally important are effective protocols and policies for sharing and updating the data and tools. Examples of the information needs that underpin water supply decisions are given in Table 1.

Table 1. Examples of Water Resource Decisions Related to Climate Change and Types of Information Needs

Type of decision or activity	Types of Information needs
Allocating water resources for specific end-uses • Upgrade existing water supplies and develop new ones to support communities, industry, energy, and agriculture • Design and operate irrigated and rain-fed agricultural facilities; decide which crops to plant and the extent to which irrigation is needed • Ensure water availability for reliable power production (hydroelectric, thermoelectric, solar), resource extraction, and other industrial uses (manufacturing, food processing, electronics, biotechnology, etc.) ***Water and other affected infrastructure*** • Ensure the security of our Nation's water infrastructure • Protect human safety, transportation and infrastructure from potential increases in flooding • Design and operate water storage for agricultural, municipal, and industrial purposes with a focus on treatment, delivery, reclamation, and reuse facilities • Design, operate, upgrade, or rehabilitate water infrastructure (dams, reservoirs, canals, navigational systems, pipelines, storage facilities, drinking water supplies, wastewater and stormwater management and reuse systems, etc.) • Size and site facilities to manage, process, and convey drinking water, wastewater, return flows, and stormwater • Design and operate groundwater recharge systems	***Water availability measures:*** • Statistical estimates of precipitation frequency, intensity, and duration • Flood and drought frequency, magnitude, and duration • Streamflow statistics • Groundwater storage capacities and recharge rates • Snowpack characteristics • Glacier characteristics (area, volume, rate-of-change, etc.) • Nonstationarity, variability, and long-term impacts of climate change on streamflows and groundwater systems ***Water allocation and use patterns:*** • Estimates of amount and timing of water withdrawals, demand, and return flows (by communities, municipalities, agriculture, industry, and energy production systems) • Uptake and water use requirements for crop production to optimize irrigation scheduling • Minimum requirements for environmental flows and levels to support ecosystem structure and function. • Water rights, interstate agreements, compacts, and court decrees • Congressionally authorized reservoir regulation • Groundwater pumping rates • Cooling water, water use, and wastewater generation rates for thermoelectric power plants and industry (incorporating water footprint of greenhouse gas mitigation strategies and advances in water-use efficiency), as demands for cooling increase

Protecting Human Life, Health, and Property

Decisions that are made on a daily basis by Federal, state, and local governments, property owners, and insurance industries collectively influence the means by which human life, health, and property are protected and safeguarded from water-related hazards. Key challenges that are relevant to climate change include potential risks associated with:

- Increased potential for loss of life due to changes in the frequency and intensity of precipitation and related flooding;
- Increased incidence of waterborne and vector-borne disease because of changes in water characteristics that affect survival and proliferation of pathogens and vectors;
- Increased cost and energy requirements for producing safe drinking water due to changes in water quality and increased salinity;
- Increased potential for drought in some areas leading to altered water quality or quantity;
- Disruptions of power, water, sewer, and emergency services, and failure of flood control and water storage structures, as a result of more extreme rainfall and storm events;
- More intensive wildfires in some areas; and
- Reduced "ecosystem services" within watersheds (e.g., ability of the natural system to support outcomes that are valued: flood control, erosion control, improvements in water quality that come from filtering by natural systems).

High priority issues for water managers and decision-makers that have been identified in a variety of fora and publications include:

- Connecting land use and water supply decisions in the context of changing climatic conditions, including implications for ecological impacts;
- Developing early warning systems to prevent and respond to waterborne disease outbreaks;
- Preventing major disruptions to energy supply and water and sewage services (e.g., large water main breaks requiring community-wide boil water advisories);
- Identifying areas prone to water inundation to develop appropriate warning, response, and control systems;
- Protecting human safety and economic development through flood mitigation; and
- Assuring adequacy of cooling water for thermoelectric / nuclear power plants.

The types of monitoring and modeling systems needed to ensure water supply reliability are similar to the information needs highlighted in Table 1. However, specific attention should be focused on the incidence of waterborne disease and the proliferation of invasive species in a changing climate. Additional modeling and predictive tools that are needed include:

- Predictions of relationships between climate, human activities, and the occurrence and prevalence of waterborne disease vectors and other contaminants in water supplies;
- Health risks due to invasive species and microbial pathogens that can survive under changing climate conditions; and
- The ability to identify and safeguard human and ecological populations that are vulnerable to water-related hazards and health-risks.

Protecting the Quality of Freshwater Resources

Protecting the quantity and quality of freshwater resources and aquatic ecosystems will become increasingly challenging due to the changing patterns of precipitation (intensity, frequency, and type); land use and land-cover change; and changing water management practices. Increasing temperatures will also pose direct challenges, including higher evapotranspiration rates leading to increased demand for water for all external water uses, energy generation, etc. Regulatory agencies, local, State and regional governments, utilities, non-governmental organizations, and industries make decisions that can affect freshwater quality in various ways including:

- Altering local hydrodynamics (through infrastructure projects, water withdrawals, return flows, runoff, or discharges), resulting in changes in runoff patterns, contaminant levels, in-stream flows and lake and groundwater levels;
- Implementing policy tools (e.g., National Pollutant Discharge Elimination System (NPDES) permits, Effluent Limitation Guideline (ELGs), Water Quality Criteria and Standards (WQS), Designated Uses, Total Maximum Daily Loads (TMDLs)) for managing impaired waters in accordance with the Clean Water Act;
- Developing and implementing Best Management Practices (BMPs) for managing agricultural and natural resources;
- Restore/maintain riparian buffers and floodplain bottomland hardwood forests to mitigate downstream flooding and sediment pollution during storm/flood events;
- Balancing competing water resource needs, including Congressionally authorized reservoir releases, flood risk reduction, and controlling downstream water quality (temperatures and other physical, chemical, or biological water quality parameters);
- Changing and more variable temperatures, microbial ecology, biogeochemistry, or salinity (due to increased evaporation, discharges of salt-laden constituents, or release of nutrients or other contaminants associated with water use for domestic, industrial, or agricultural purposes);
- Managing water quality changes associated with the water-energy nexus (thermoelectric and nuclear power plant cooling), the development of alternative fuel sources (biofuels, shale-gas, tar sands, hydrogen, coalbed methane), and carbon capture and sequestration;
- Salt water intrusion into aquifers that are being depleted by groundwater pumping;

- Mobilization of contaminant plumes in groundwater supplies due to increased pumping;
- Coastal inundation in places where the natural vegetative buffers are ineffective or no longer exist; and
- Addressing sediment loading into reservoirs and developing mitigation and prevention measures to control runoff from intense storms, landscape scale fires, and reservoir operations.

In many cases, water quality concerns are expected to be exacerbated by the impacts of a changing climate on the amount and timing of flows (e.g., Larsen, 2010). These changes affect nutrient (nitrogen and phosphorus) loading and associated impacts on vulnerable aquatic ecosystems. The extent to which waterborne contaminants (arsenic, fluoride, radionuclides, organics, gases, and microorganisms) are mobilized from aquifer material may also vary in response to changes in groundwater levels related to natural and engineered recharge and withdrawal patterns. In addition, new and different health risks may be associated with localized microbial and ecological responses to different temperature and water quality conditions that impact the population dynamics and survival of invasive species, pathogens, and algae.

While considerable progress has been made in reducing pollution within watersheds, the number of impaired water bodies continues to increase[9]. Governmental agencies (Federal, State, interstate, Tribal, county, and municipal) and private entities (universities, watershed associations, environmental groups, permitted dischargers, and local citizens) are actively engaged in tracking the occurrence, quantity, quality, distribution, and movement of surface and underground waters[10]. Significant efforts are being coordinated among the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service (USFWS), U.S. Forest Service, coastal states, and the National Estuary Programs (NEP) to evaluate ecological and water quality conditions. For example, the National Water Quality Assessment Program (NAWQA)[11] integrates monitoring data with geographic information on hydrological characteristics, land use, and other landscape features. Examples of other efforts include the National Water Information System (NWIS)[12] and the Wadeable Streams Assessment[13] (WSA).

Changes in water quantity (streamflows, groundwater recharge) are considered to be a primary contributor to degraded river ecosystems and loss of native species[14]. Historical trends in streamflows are compared in Figure 1. It is important to note that the snowpack dominated

[9] EPA 2011. National Summary of State Information. http://iaspub.epa.gov/waters10/attains_nation_cy.control#total_assessed_waters
[10] EPA 2009. An Introduction to Water Quality Monitoring. http://water.epa.gov/type/watersheds/monitoring/monintr.cfm
[11] USGS 2011. NAWQA, http://water.usgs.gov/nawqa
[12] USGS 2011. NWIS: Web Interface, http://waterdata.usgs.gov/nwis
[13] EPA 2006. Wadeable Streams Assessment. http://water.epa.gov/type/rsl/monitoring/streamsurvey/index.cfm
[14] Carlisle et al. 2010. http://water.usgs.gov/nawqa/pubs/Carlisleetal_FLowAlterationUS.pdf

regions in the west are experiencing clear downward trends while the northern and eastern regions are more variable. The absence of trend data for some regions in part reflects variations in the distribution of monitoring stations and the length of the historical record.

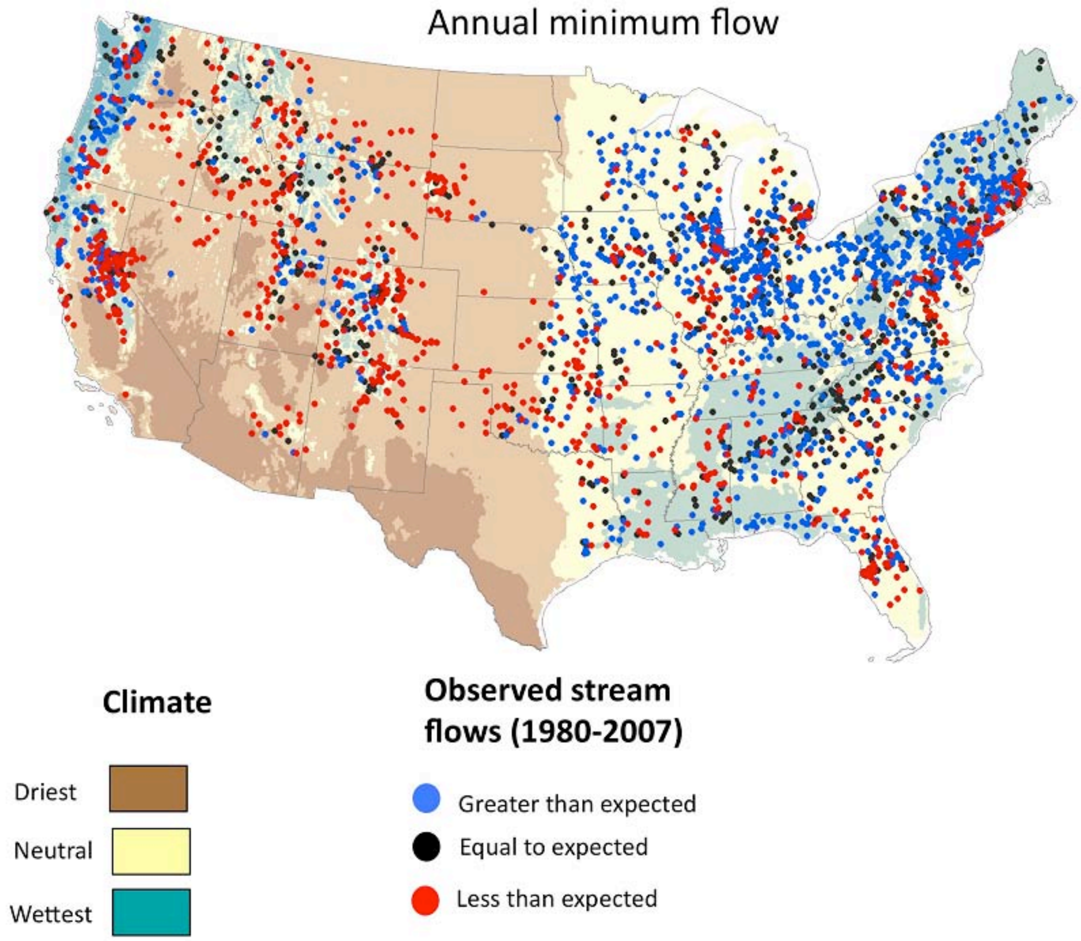

Figure 1. Comparison of expected and observed streamflows between 1980 and 2007. Nearly 90 percent of the monitored systems reflect altered streamflows as compared to historic data.[15]

Protecting Coastal and Ocean Resources

Coastal areas include some of the most densely populated areas in the nation. These areas play an integral role in the economy through supporting commerce (ports), transportation, energy (oil, natural gas, refineries, wind, tidal and wave energy, solar), fisheries, tourism, and recreation. Coastal waters are valued for their ecological richness and encompass many unique habitats (estuaries, coastal wetlands, seagrass meadows, coral reefs, mangrove and kelp forests, and upwelling areas). These sensitive environments yield highly productive fisheries

[15]NAWQA. Altered flows lead to ecological degradation in streams across the US. http://water.usgs.gov/nawqa/home_maps/stream_flow.html

and provide breeding habitat for 85 percent of U.S. waterfowl and other migratory birds[16]. Coastal and ocean resources and coastal communities face unique challenges associated with a changing and changed climate. Maintenance of healthy coastal resources is directly dependent on the freshwater systems that sustain coastal environments. For example, many species are sensitive to temperature and salinity, which are directly influenced by weather patterns and freshwater inputs. Temperature and salinity can also influence the frequency and tenacity of algal blooms (red tides, cyanobacterial blooms, pfiesteria, etc.).

Key issues that are likely to be impacted by climate change include:

- **Emergency Response Infrastructure:** Changes in hazards to life, property, and infrastructure due to disruptions of energy production and distribution, water, sewer, transportation, communication, and emergency services as hurricanes and other storms increase in intensity;
- **Drinking water quality:** Changes in the condition of coastal fresh water aquifers and drinking water supplies that are vulnerable to risks as sea levels rise or salt water intrusion increases;
- **Sea level changes:** Rising sea levels and changes in storm frequency, intensity, and duration that affect the design, operation, and management of water infrastructure (drinking water systems, water storage, wastewater and stormwater management and reuse) (e.g., IPCC, 2007b);
- **Coastal habitats:** Alterations in estuarine and coastal habitats and loss of water-resources infrastructure in coastal areas at risk of inundation as sea levels rise (IPCC 2001);
- **Hypoxia:** The extent of hypoxia (lowered oxygen levels) and "dead zones" in the Gulf of Mexico, Chesapeake Bay, and other water bodies; and
- **Acidification:** The quality of coastal and ocean fisheries and habitat, such as coral reefs, at risk due to warmer waters and ocean acidification.

The National Assessment of Coastal Vulnerability to Sea Level Rise[17] has classified US coastal environments to develop a comparative index of the potential for physical shoreline changes in response to sea level rise (Figure 2).

Key variables include:

- Tidal range, which contributes to inundation hazards;
- Wave height, which is linked to inundation hazards;
- Coastal slope (steepness or flatness of the coastal region), which is linked to the susceptibility of a coast to inundation by flooding and to the rapidity of shoreline retreat;
- Shoreline erosion rates, which indicate how fast a section of shoreline has been eroding;

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[16] EPA 2011. Report on the Environment. "Coastal Water" http://cfpub.epa.gov/eroe/index.cfm?fuseaction=list.listBySubTopic&ch=47&s=274

[17] http://woodshole.er.usgs.gov/project-pages/cvi/

- Geomorphology, which indicates the relative erodibility of a section of shoreline; and
- Historical rates of relative sea -level rise, which correspond to how the global (eustatic) sea -level rise and local tectonic processes (land motion such as uplift or subsidence) have affected a section of shoreline.

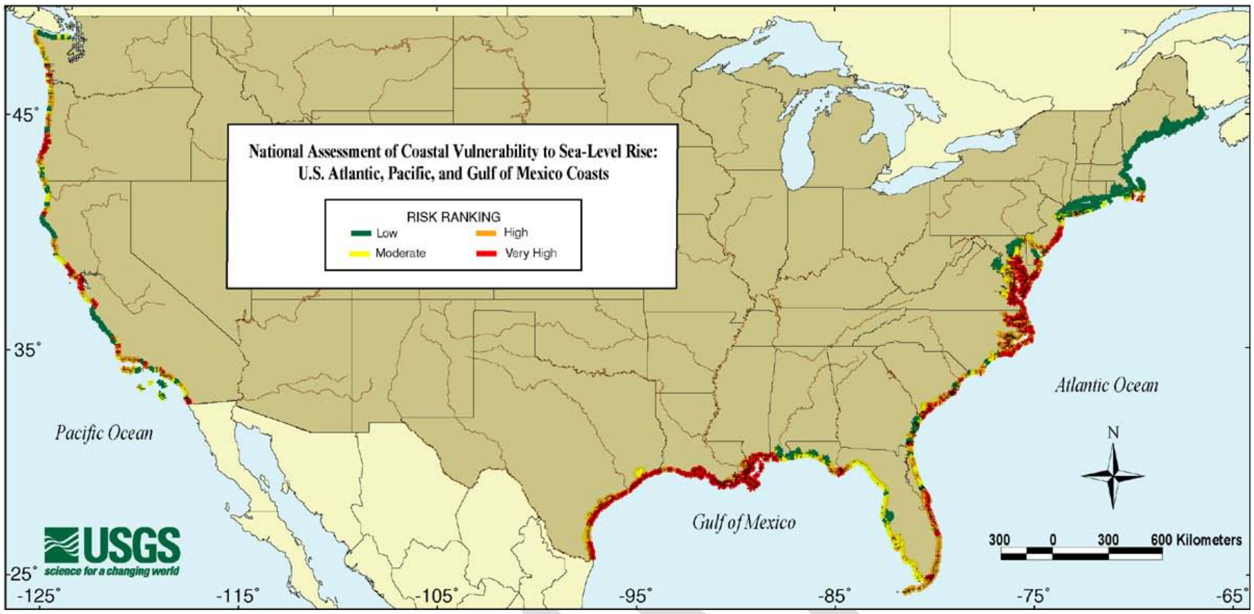

Figure 2. Relative vulnerability of coastal areas to sea level rise.[18] The comparative index objectively determines the potential for physical shoreline changes in response to future sea level rise.

The recent National Coastal Commission Report (NCCR) (coordinated through the EPA, NOAA, USGS, USFWS, coastal states, and the NEPs) rated the overall condition of coastal environments as fair[19]. From a water quality standpoint, the National Coastal Commission develops a net score based on five indices of ecological condition[20]:

- Water quality index (including dissolved oxygen, chlorophyll a, nitrogen, phosphorus, and water clarity);
- Sediment quality index (including sediment toxicity, sediment contaminants, and sediment total organic carbon [TOC]);
- Benthic index;
- Coastal habitat index; and
- A fish tissue contaminants index.

An overview of the national coastal condition scorecard is shown in Figure 3. As of the 2008 report, 18 percent of estuarine waters are considered to be impaired for fishing, based on the

[18] http://woodshole.er.usgs.gov/project-pages/cvi
[19] EPA 2008. National Coastal Condition Reports. http://water.epa.gov/type/oceb/assessmonitor/nccr/index.cfm
[20] Ibid

prevalence of fish tissue contaminants[21]. The effects of climate change on these resources are a subject of considerable concern.

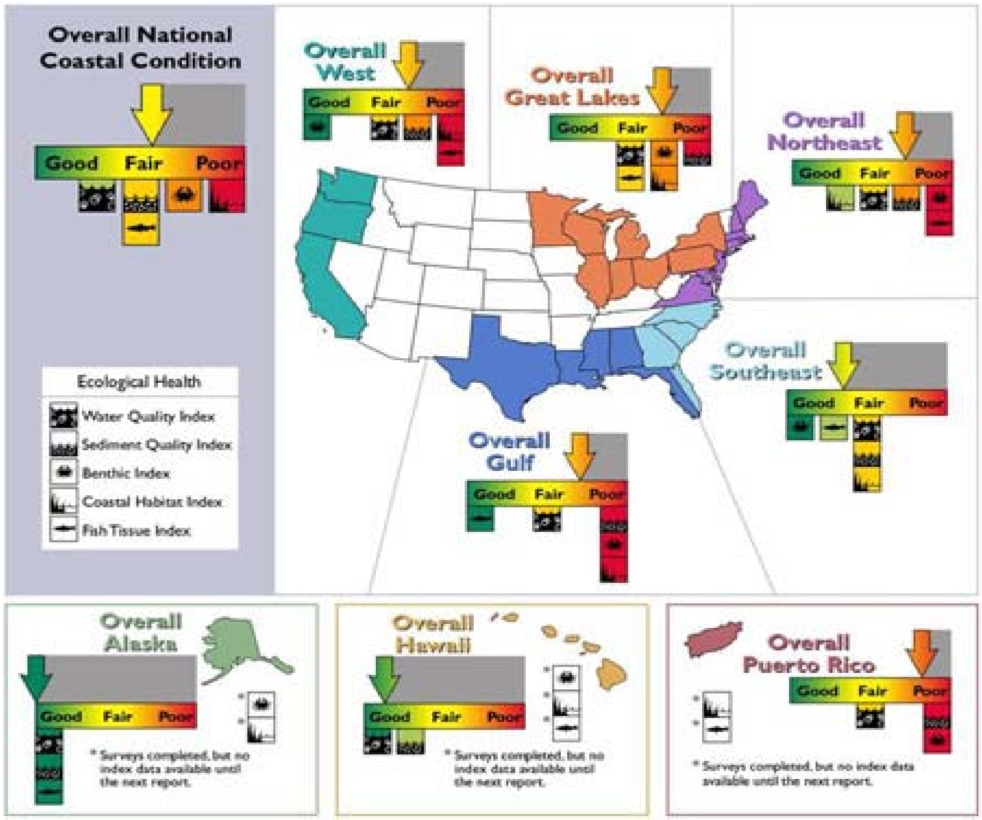

Figure 3. Overview of coastal condition scorecard. The recent National Coastal Commission Report rated the overall condition of coastal environments as fair. [22]

Examples of up-to-date climate-relevant information, data, maps, and models that are needed to make decisions about the management of coastal and ocean resources and the ecosystems they support include:

- Estimates of relative sea level change and storm-surge hazards to determine how tidal fluctuations and sea level rise will impact coastal communities and their water infrastructure;
- Geospatial data on the locations and characteristics of wetlands and their resiliency to sea level rise to predict the effects on coastal wetlands and adjacent coastal resources;

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[21] EPA 2008. National Coastal Condition Report III. http://water.epa.gov/type/oceb/assessmonitor/upload/nccr3_entire.pdf

[22] EPA 2010. National Coastal Condition Report- NCCR Factsheet. http://water.epa.gov/type/oceb/assessmonitor/nccr3_factsheet.cfm

- An understanding of coastal response to changing upland hydrology, flood frequencies, and water quality conditions; and
- Hydrodynamic models to predict the likely extent and consequences of saltwater intrusion under various conditions and water management practices (groundwater recharge, water allocations, ocean outfalls, deep well injection).

Review Elements

Section 9506 identifies six interrelated review elements (Appendix A):

- Assess Adequacy of Current Hydro-climatological Observation Networks;
- Identify Data Gaps in Current Water Monitoring Networks;
- Improve Data Management to Increase Utility of Information that is Collected and Efficiency of Data Acquisition and Reporting;
- Establish a Data Portal to Enhance Access to Water Resource Data Across Agencies;
- Facilitate the Development of Hydrologic and Other Models to Integrate Data that Reflects Groundwater and Surface Water Interactions; and
- Apply Hydrologic Models to Resolve Water Resource Problems Including Improvement of Ecological Resiliency.

This report provides an overview of each review element in terms of the capacity of available data systems and analytical tools to address climate change issues. Information was contributed by the agencies that produce or manage the specific data elements, networks, models, and tools.

Each of these review elements is addressed using several key criteria including:

- **Robust data-collection programs:** Are programs / funding in place to ensure continuity of critical data collection? Can we improve accuracy or lower costs by adopting new data collection technologies? What investments could help ensure that data accuracy and usefulness increase in the future?
- **Up-to-date information and approaches:** Are the types of analyses available to decision makers up-to-date? What can be done relatively quickly to keep our analyses and tools up-to-date?
- **Capacity to incorporate climate relevant knowledge:** Are the methods of analysis used appropriate in light of likely future changes? How do they handle climate, land use/land cover, population, water use, groundwater depletion or other types of change? What can be done to make better use of new data and models?
- **Processes for ensuring continuity:** Are programs in place to assure that new data, scientific understanding, and critical analyses will be incorporated, updated, and disseminated in the future?

There is substantial complexity in monitoring and observing systems and the way data from these systems are combined to increase understanding of past, current, and future climate conditions and trends. Some of the interconnections among the review elements are illustrated in Figure 4. As shown, networks are used to organize and map individual data elements. Integrated networks can be compiled and shared through data portals. Models require data for calibration, validation, and application. Mapping and modeling tools build upon historical data to evaluate changes over time to project the range of outcomes of future climate scenarios on water resources and the human and aquatic systems they support. The extent to which the physical hydrologic system, as well as observations, data, modeling, mapping, and decision-making are interconnected highlights the importance of coordination, collaboration, and communication. Some of these integrated efforts are underway through the USGCRP and other groups that are actively engaged in climate issues. It is also important to recognize that each of the six review elements encompass significant ongoing activity both inside and outside of the Federal government.

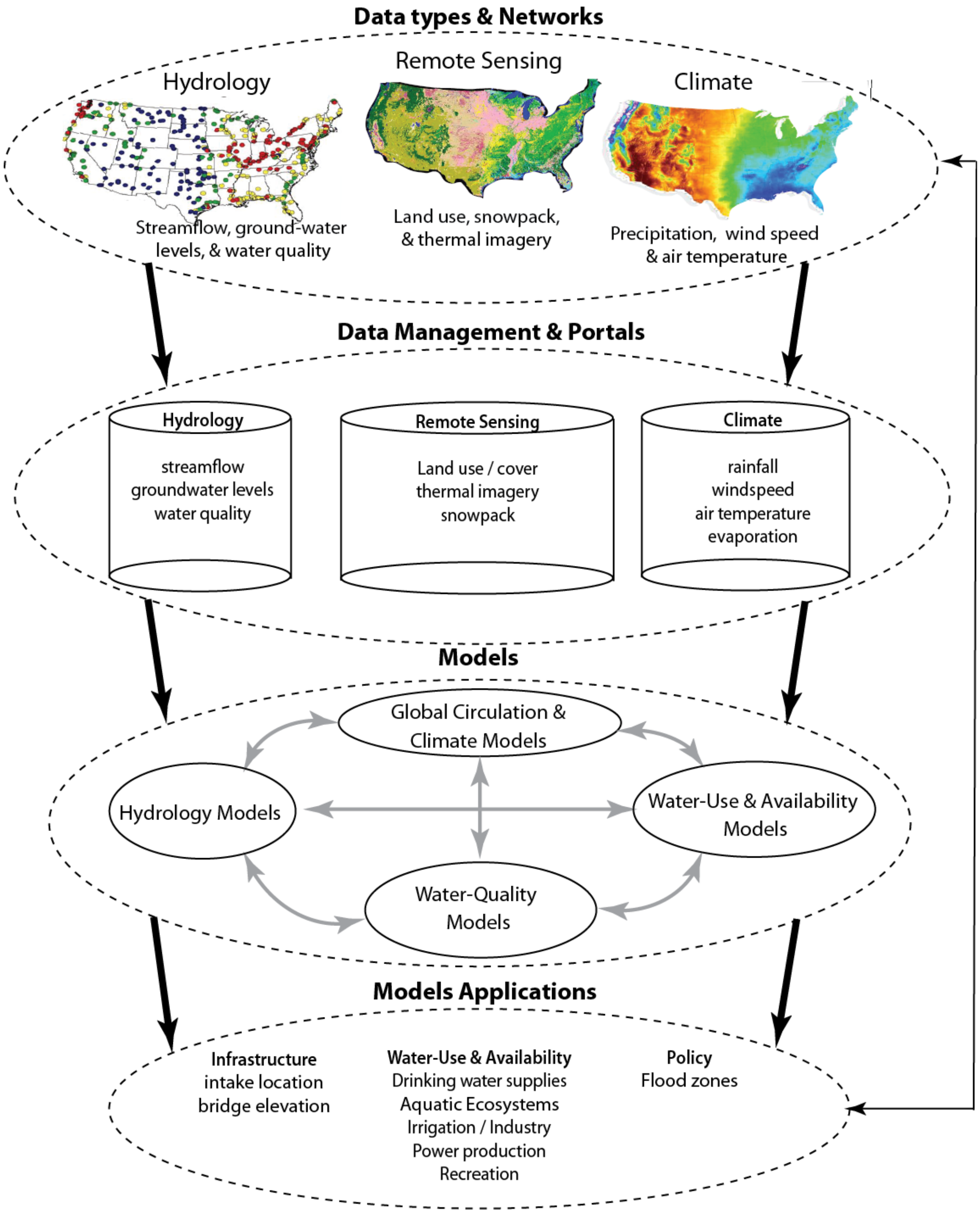

Figure 4. Examples of interconnections between data, models, and model applications for decision-makers.

Review Element 1: Assess Current Hydro-climatological Observation Networks

Review Element from Section 9506:

"to assess the extent to which the conduct of measures of streamflow, groundwater levels, soil moisture, evapotranspiration rates, evaporation rates, snowpack levels, precipitation amounts, and glacier mass is necessary to improve the understanding of the Federal Government and the States with respect to each impact of global climate change on water resources…"

Finding 1: The observational networks assessed in this process provide necessary and useful data for a range of water-resources management decisions, including but not limited to climate-related decisions.

Finding 2: Most hydro-climatic networks exhibit deficiencies, whether in inconsistent methodologies used to collect data of a given type; inadequate spatial coverage; temporal data gaps or insufficiently long records; failure to seamlessly present data from different networks operating at different scales; insufficient models to project conditions in space and time; incomplete use of new or emerging technology; or delivery of data through a variety of redundant or incompatible portals. The USGS streamgage network is uniquely valuable for assessing both long-term water availability and for providing day-to-day operational guidance, but continues to experience cuts, particularly in long-term gages that provide the most climate-relevant data.

Review Element 1 is subdivided into five sub-elements:

- Streamflow
- Groundwater levels
- Soil moisture, evapotranspiration, and related weather data
- Snowpack, precipitation amounts, and glacier mass
- Water quality, water use, and ecosystem conditions

Streamflow

Surface waters (streams, rivers, lakes, and reservoirs) serve as a source of drinking water to more than 170 million Americans and supply over 80 percent of the water used in the United States (Kenny et al., 2009). Much of the Nation's treated municipal, domestic, and industrial water is returned to surface waters along with irrigation return flows, rainfall, and stormwater runoff. Surface waters provide important aquatic habitats and maintain the viability of commercially valuable fisheries and aquatic ecosystems. Surface waters also generate tremendous economic benefit through supporting agricultural irrigation, tourism (fishing, canoeing, rafting, etc.), navigation, power production, and other industrial freshwater needs. However, variable flows and temperatures coupled with waterborne contamination have degraded the availability and quality of critical water resources (EPA, 2008).

Until recently, it was assumed that the future streamflow conditions (magnitude and duration of flows, floods, droughts, etc.) could be estimated from historical data using an assumption of water data from stationarity, which means that the underlying statistical properties of the records do not change with time (Milly et al., 2008). However, as natural systems respond to changing climate and other types of global change, (e.g., land-use patterns), there is increasing uncertainty about the amount and timing of water that will be available in the future. As a result new statistical methods are required to estimate the probability of future occurrences of floods and droughts and to evaluate future water availability from historical records.

In order to understand current and possible future changes in streamflow patterns

- ***Long-term streamflow observations need to be maintained and enhanced***
- ***New statistical methods are needed to estimate the likelihood of future floods, droughts, and water availability.***

The USGS operates more than 7,500 streamgages (Norris, 2009; Figure 5) in cooperation with more than 850 Federal, State, Tribal, and local partners who help provide resources to maintain the gages. In most cases, streamflow observations are made at 1-minute to 1-hour intervals and are transmitted via satellite to Federal (e.g., NWS) and local users using the Internet[23]. The immediate availability of streamflow data (often reported within 1 hour of collection) helps decision-makers respond to emergency situations and also address day-to-day management of irrigation systems, water supply and wastewater facilities, reservoirs, canals, and navigation systems. The compilation of long-term streamflow datasets[24] provides aggregated data that are used to design water systems and infrastructure, calibrate forecasting models, and evaluate streamflow response to climate change (McCabe and Wolock, 2002).

[23] USGS 2010. USGS Water Data for the Nation http://waterdata.usgs.gov
[24] http://waterdata.usgs.gov/nwis

The National Streamflow Information Program (NSIP)[25] was initiated in 2003 in response to Congressional and stakeholder concerns about (1) the decrease in the number of operating streamgages (Figure 5), including a disproportionate loss of streamgages with a long period of record; (2) the inability of the USGS to continue operating high-priority streamgages in an environment of reduced funding through partnerships; and (3) the increasing demand for streamflow information due to emerging resource-management issues and new data-delivery capabilities (Norris, 2009). There is significant concern about the level of funding for this program over time, as is evidenced by multiple reports from water managers across the country that were reviewed in this process. Understanding streamflow changes over time requires long-term records, as well as strategic placement of new gages in areas where changes in runoff patterns are anticipated. The goals of NSIP include a robust Federally supported system of 4,744 long-term streamgages, regional assessments of streamflow, 100 percent real-time data, and flood-hardening of gages. The NSIP network is envisioned as a subset of the existing USGS streamgage network. As of 2009, about 11 percent of the proposed Federal core streamgages were fully funded by NSIP and the other goals remain partially complete, with no regional assessment completed.

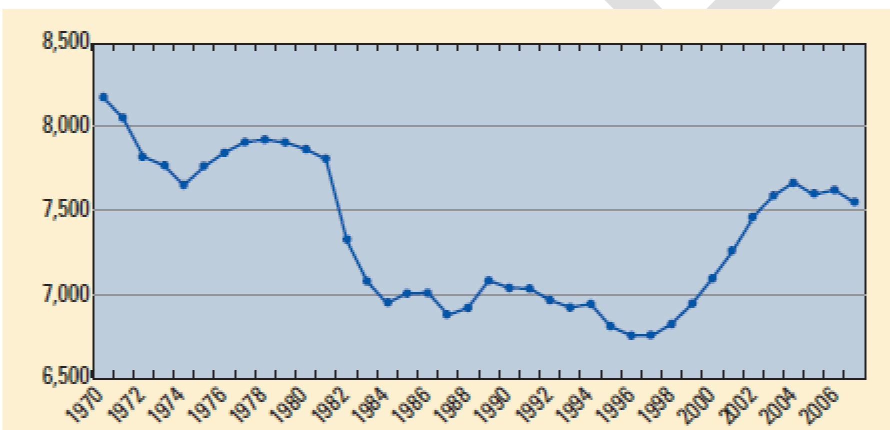

Figure 5. Number of active streamgages in USGS network, 1970 – 2007 (Norris, 2009)

As part of the WaterSMART initiative, USGS is planning to conduct comprehensive water supply and demand inventories to provide the baseline information needed by public and private water managers to manage water supply in a sustainable manner. This effort will include estimating freshwater resources, how those supplies are distributed, and how they are changing over time; evaluating factors affecting water availability including energy development, changes in agricultural practices, increases in population, and competing priorities for limited water resources; and assessing water use and distribution for human, environmental, and wildlife needs.

The amount of water stored in lakes and reservoirs also provides important data for water-resources decisions, and these data are directly linked to streamflow because of the effect of

[25] USGS 2011. USGS National Streamflow Information Program (NSIP). http://water.usgs.gov/nsip

dam releases on flows. The U.S. Army Corps of Engineers (USACE)[26], the Bureau of Reclamation (BoR)[27], and the Tennessee Valley Authority (TVA)[28] provide lake level data on most of the reservoirs which they operate, with some of the lake level measurements made by the USGS. Although Federal projects (USACE, TVA, BoR) account for the majority of water storage in the U.S., a number of river systems are managed by private or state-based entities (e.g., the Catawba – Wateree River in North and South Carolina, managed by Duke Energy, and the Alabama River, managed by Alabama Power, the Salt-Verde River System in Arizona, managed by the Salt River Project among many others). Numerous small impoundments are managed by the Natural Resources Conservation Service (NRCS), irrigation districts, and water utilities, some of which have continuous lake level information. Currently, levels at many lakes and reservoirs are collected only at monthly intervals. Improvements in efficiency of collection are needed to allow many of these data to be collected close to real-time. Limited data (few lakes, infrequent measurements) exist for many natural lakes.

The WaterSMART Initiative, through the Water Census, is being designed to describe the changing availability, quality, location, and uses of water resources. This key information needs to be readily available to water managers and the public for all of the Nation's river basins.

Water resource managers need knowledge about reservoir and lake volumes in conjunction with water-level monitoring. Sediments tend to accumulate in lakes and reservoirs, reducing the volume available for storing water. Precipitation patterns (form, intensity, frequency), fires, intense storms and droughts, along with changes in hydrology, land use, and land management affect the amount of sediment transported into reservoirs. The Reservoir Sedimentation Database (RESSED)[29], started in 2009, is a preliminary effort to develop a dynamic database of reservoir volume obtained through bathymetric surveys. NOAA provides bathymetric data on coastal waters and collaborates with the Canadian Hydrographic Service (CHS) to provide data on the Great Lakes[30], but measurements of other freshwater systems have declined substantially (Figure 6; Ackerman et al., 2009). In addition to affecting the available volume, trapped sediments in reservoirs can be an important sink for carbon and also harbor contaminants and pathogens (Stallard, 1998).

[26] U.S. Army Corps of Engineers 2011. Lake Level Data from http://www.ndc.iwr.usace.army.mil
[27] Bureau of Reclamation Water Information 2011. http://www.waterinfo.org/bureau-of-reclamation.html
[28] Tennessee River Valley Authority 2011. Lake Level Data from http://www.tva.com/river/lakeinfo.index.html
[29] USGS 2009. RESSED. http://ida.water.usgs.gov/ressed
[30] NOAA 2011. Great Lakes Bathymetry http://www.ngdc.noaa.gov/mgg/greatlakes/greatlakes.html

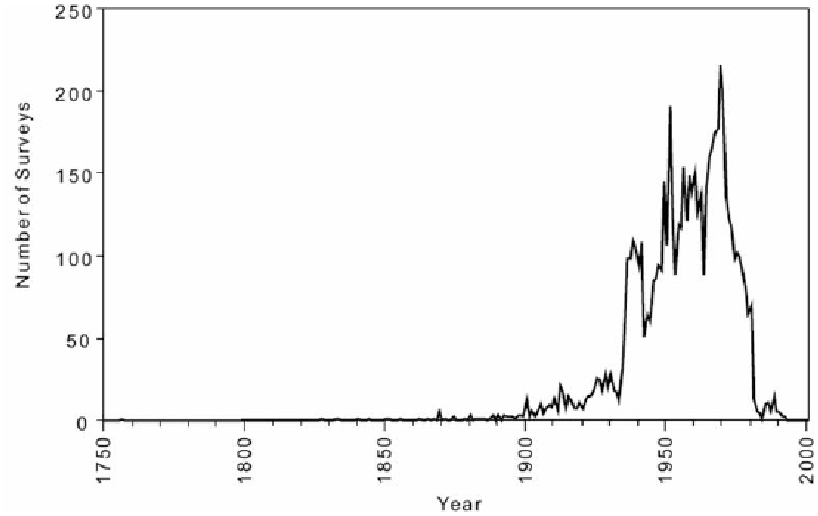

Figure 6. United States reservoir sedimentation surveys, 1750 – 2000 (Ackerman et al., 2009). Measurements of these freshwater systems have declined substantially in recent years.

A comprehensive, real-time network providing consistent information on reservoir and lake levels and volumes is needed for water-resources management.

Groundwater Levels

Groundwater is the primary source of public water supply for almost half of the Nation's population including about 97 percent of the rural population (USGS, 1995; Kenny, 2005). Approximately 30 to 40 percent of agricultural water supplies are withdrawn from groundwater. Additionally, groundwater sustains and replenishes rivers and streams during the hottest and driest parts of the year, providing critical flow to aquatic ecosystems. As locations for additional reservoirs become limited and availability of water from the Nation's streams becomes increasingly scarce, withdrawals from groundwater are likely to increase (Hutson et al., 2004). In many areas, including California and the southeastern U.S., increases in groundwater use during surface water shortages have been dramatic. These shifts have multiple implications from a water sustainability perspective.

Measurements of groundwater levels are used to determine how much water is available within specific basins, watersheds, and regions. In addition, the effects of pumping, water allocations, droughts, and intense storms on groundwater levels can be evaluated, depending on the frequency of monitoring and the extent of the monitoring network. Climate affects groundwater levels directly through impacting the availability of rainwater to recharge local aquifers. In addition, the timing and volume of streamflow is critical to aquifer recharge rates.

Data and models are needed to better understand the implications of precipitation variability on geohydrology and biogeochemical cycles.

Climate change may also introduce other impacts on groundwater systems, triggering changes in the rate and intensity of pumping to support local water needs (irrigation, frost prevention, fire-fighting, urban uses). For example, intensive short-term demands on groundwater within agricultural regions in response to freezing or drought conditions has lead to rapid lowering of instream flows and aquifer levels and generation of sinkholes, particularly in karst regions (Tihansky, 1999). Climate change can also spur development of competing water uses in a region such as biofuels, hydraulic fracturing, mineral resource extraction, industry, or agriculture.

The USGS maintains and monitors over 20,000 observation wells in cooperation with State and local agencies. Industries and municipalities also operate and maintain wells for which some data are available. In addition to data on water levels, water quality and precipitation data are collected at many sites. Observation wells also are used to evaluate underground sources of drinking water, to support the Underground Injection Control (UIC) program under the Safe Drinking Water Act (SDWA), to monitor the effects of mineral and energy resource extraction on groundwater, to develop aquifer storage and recovery or groundwater recharge programs, and for groundwater remediation projects.

A complete inventory of all active (or abandoned) wells does not exist. In fact, there is wide variability in the amount of information available, depending on how active state governments and local water districts are in managing groundwater rights and well drilling activities. In addition, limited analyses have been conducted of the interrelationships among water quality, water levels, and well pumping practices. This is of particular concern in coastal areas where overpumping is causing saltwater intrusion. Recent studies have suggested that groundwater depletion is contributing to sea level rise (Wada et al., 2010).

Over the past few years, the USGS has made concerted efforts to develop a Climate Response Network (CRN) to track the nationwide response of the groundwater system to climate variations[31]. The primary purpose of the Climate Response Network is to portray the effect of climate on groundwater levels in unconfined aquifers or near-surface confined aquifers that are minimally affected by pumping or other anthropogenic stresses. The CRN currently consists of about 500 wells, and about 60 percent of the Nation's principal aquifers (Miller, 1999) are represented in the network. A complete network would have at least one well in each of the Nation's 366 climate divisions (NOAA, 2006), but fewer than half of these divisions are covered by the network. Moreover, some climate divisions may require more than one climate-response monitoring well if the division includes more than one principal aquifer. The median measurement starting date for a well in the network is 1983, and the value of the data increases with the length of record (Cunningham et al., 2007).

As dependence on groundwater increases, the importance of a high-quality, well-positioned monitoring network will also increase, particularly in a warming climate. Questions regarding

[31] USGS Groundwater Watch http://groundwaterwatch.usgs.gov/Net/OGWNetwork.asp?ncd=crn

the effect of climatic changes on groundwater levels can best be answered with a groundwater monitoring network that represents the Nation's major aquifers and climate divisions. The ability to provide relevant and timely data on groundwater systems is critical to sustaining the quality and quantity of this resource.

The Subcommittee on Groundwater of the Advisory Committee on Water Information (ACWI) recently (2009) proposed a framework for a long-term national groundwater quantity and quality network, along with a data management structure[32]. The proposed network would be a compilation of selected wells across the Nation that leverage and enhance existing State and Federal monitoring efforts, and is focused on the Nation's most productive aquifers and aquifer systems. Data from the network would be used to assess baseline conditions and long-term trends in water levels and water quality. The overall network would be comprised of two sub-networks (Figure 7): a sub-network that focuses on monitoring unstressed, uncontaminated parts of the aquifers and a sub-network that targets areas of concern. Five pilot projects were implemented in 2010[33], but substantial efforts are needed to implement the full network and data management structure.

[32] Advisory Committee on Water Information, Technical Reports of the Subcommittee on Groundwater http://acwi.gov/sogw/pubs/tr/index.html.
[33] Ibid.

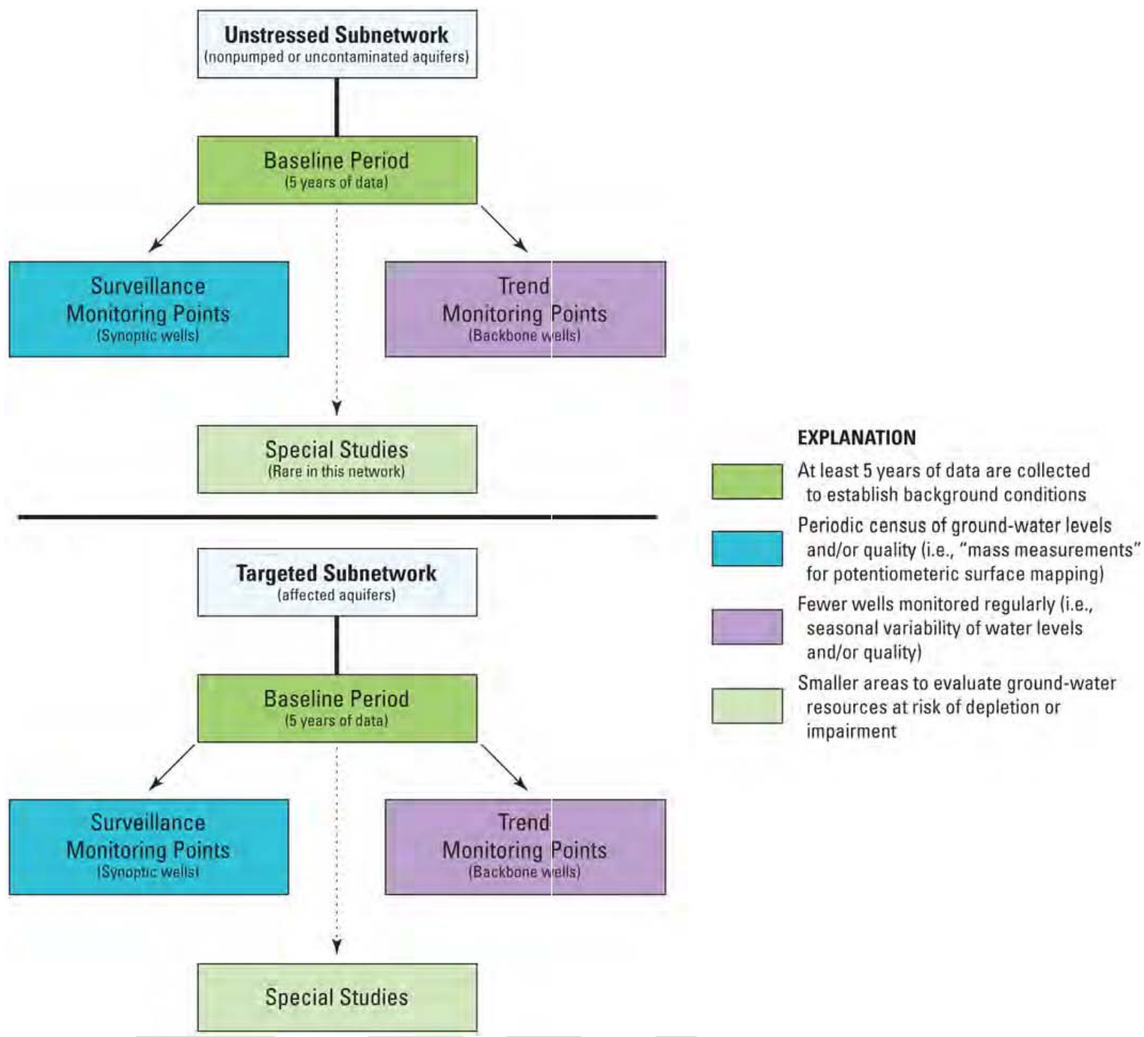

Figure 7. Proposed sub-networks and relation among networks for the proposed National Groundwater Monitoring Network (Subcommittee on Groundwater, 2009).

The recommendations of the Advisory Committee on Water Information regarding a comprehensive National Groundwater Monitoring Network and data management system should be implemented, and should include a Climate Response Network.

NASA's Gravity Recovery and Climate Experiment[34] (GRACE) uses twin satellites to measure the Earth's gravity field, which changes in response to groundwater withdrawals. As a result,

[34] National Aeronautics and Space Administration GRACE. http://www.csr.utexas.edu/grace

GRACE has the potential to identify large areas of groundwater depletion (Famiglietti et al., 2011), although the satellite cannot detect local depletion.

Soil moisture, evapotranspiration, and related weather data

Soil moisture is an important part of the hydrologic budget and critical for agricultural crop production. The amount of moisture stored in the soil is directly related to the balance between water saturation (through rainfall or irrigation) and evapotranspiration, or the amount of water released to the environment through the growth of plants, trees, and vegetation. These factors, in conjunction with land use patterns and local hydrology also influence the rate and extent of groundwater recharge and generation of runoff.

With climate change and the concomitant changes in the length of the growing season, agricultural water-use practices will need to adapt to changes in crop requirements, available precipitation, and the rate of evapotranspiration (IPCC, 2007c). The local effects of climate change on soil moisture are complex and interdependent on multiple factors (Furniss et al., 2010). Soil characteristics influence soil moisture and are affected by climate change through changes in air temperature, humidity, cloud cover, and precipitation. The quality of irrigation water, particularly the salt and mineral content, also affects short-term and long-term soil moisture. Infiltration capacity and water-holding capacity of many soils are influenced by the frequency and intensity of freezing.

The seasonality of soil moisture is important for sustainable agriculture and often is the controlling factor in whether irrigation water needs to be applied to support crops, thereby affecting consumptive water use. For example, under some forecast climate-change scenarios for the west and Midwest (IPCC, 2007a), soils are likely to dry earlier in the year, imposing stress on existing vegetation and leading to changes in the diversity of native vegetation and insect outbreaks. In snowpack dominated areas, the runoff peaks are now occurring earlier than in the past, predicted to occur earlier, whereas there may be wetter conditions in other parts of the country. Changes in the length and timing of the frost-season affect the survival and proliferation of insect pests and the migration patterns of wildlife, all of which affect ecosystems and soil vitality.

Soil moisture is a significant input parameter for meteorological, drought, flood, and seasonal streamflow forecasts. The U.S. Climate Reference Network currently consists of 114 stations that record temperature, precipitation, solar radiation, surface skin temperature, and surface winds. Plans are to enhance data collection at these stations to track soil moisture and soil temperature at five depths (5, 10, 20, 50, and 100 cm) [35], and it is important that these plans are completed. About 30 additional stations are planned for installation over the next 5 years.

> ***Continued expansion of the Climate Reference Network is needed, including the addition of soil moisture sensors at all sites.***

[35] http://www.ncdc.noaa.gov/crn

The U.S. Bureau of Reclamation operates a 90-station weather network (AgriMet[36]) that is used to help optimize irrigation water use for a variety of crop types. Data from the AgriMet sites are used to calculate crop-specific evapotranspiration rates, and this information can be utilized by crop produces to schedule irrigation. The U.S. Forest Service coordinates a 2,200 interagency weather network (RAWS[37]) that is primarily used for a variety of purposes, but primarily for monitoring fire potential, predicting fire behavior, and monitoring fuels. The U.S. Department of Agriculture's Natural Resource and Conservation Service operates the Soil Climate Analysis Network (SCAN[38]), which includes more than 130 soil moisture and climate stations in 39 states. The network supports resource assessment and conservation activities. Numerous types of atmospheric measurements, some of which can be used to calculate evapotranspiration, are captured and archived from more than 300 instrument systems by the Department of Energy's Atmospheric Radiation Climate Research Facility[39]. Data types include aerosols, atmospheric carbon, atmospheric state, cloud properties, radiometric information, and surface properties.

Data from the *in* situ soil-moisture networks can provide calibration information for NASA's Soil Moisture Active & Passive (SMAP) mission. This mission, planned for a 2014 launch, will provide surface soil moisture and freeze/thaw state for soils at a spatial resolution of approximately 9 km, with repeat measurements every 3 days[40]. This mission will supplement existing and planned *in situ* observations. Other space missions providing weather and/or soil moisture information include (1) NASA's Aqua Mission[41], which has six instruments providing information about the Earth's water; (2) NASA's CloudSat[42], which provides information about aerosols and cloud water content; Mission European Space Agency's Meteorological Operational (MetOp[43]) satellite program, which is being operated jointly with NOAA.

Precipitation amounts, snowpack, and glacier mass

Precipitation is the primary means by which freshwater resources (e.g., rivers, aquifers, wetlands and glaciers) are replenished. Information about the quantity, distribution and frequency of precipitation (in the form of rain, snow, or ice) is relevant to a wide range of decisions with significant economic implications, including long term infrastructure

36 The Great Plains Cooperative Agricultural Weather Network. http://www.usbr.gov/gp/agrimet/index.cfm
37 Remote Automated Weather Stations. http://raws.fam.nwcg.gov
38 Natural Resources Conservations Service, National Water and Climate Center, Soil Climate Analysis Network (SCAN). http://www.wcc.nrcs.usda.gov/scan
39 U.S. Department of Energy, Atmospheric Radiation Measurement Climate Research Facility. http://www.arm.gov
40 NASA Jet Propulsion Laboratory, Soil Moisture Active & Passive (SMAP) Mission. http://smap.jpl.nasa.gov/science/dataproducts
41 National Aeronautics and Space Administration Aqua. http://www.nasa.gov/mission_pages/aqua/index.html
42 National Aeronautics and Space Administration CloudSat. http://www.nasa.gov/mission_pages/cloudsat/mission/index.html
43 European Space Agency Meteorological Missions. http://www.esa.int/esaLP/LPmetop.html

investments. Historically, water management and other resource dependent decisions have been made under the assumption that observed precipitation patterns and magnitudes will continue in the future, without accounting for the impacts of a changing climate. However, storm frequency and intensity is changing in ways that can't be predicted from evaluation of historic weather patterns. This variability affects hydrologic and water quality processes and associated flow and loadings of urban drainage systems.

Hydrologists, engineers, and water managers routinely employ rainfall-runoff models to generate flood frequency estimates to evaluate and design facilities in flood-prone areas. Data on daily rainfall and interannual variation in precipitation is important to support agricultural operations. Under a changed and changing climate, it isn't clear what intensity and duration of precipitation frequency estimates are appropriate. The NWS precipitation frequency estimates (Technical Paper 24, U.S. Weather Bureau, 1953), updated in the early 1960s, have become the *de facto* national standards by virtue of their inclusion or reference in design standards that are widely used at Federal, State, and local levels. A similar situation exists for the maximum precipitation estimates that were developed decades ago[44]. Advances in science, monitoring, and information technology provide an opportunity to revisit these estimates and incorporate newer data.

A systematic, routinely-scheduled, and consistent approach for updating precipitation frequency estimates is needed, as well as an analysis of the changes in these statistics over time.

The National Operational Hydrologic Remote Sensing Center (NOHRSC[45]) integrates airborne and satellite snow observations from all available electronic sources for the coterminous U.S. These data are used along with data from SNOTEL[46] to generate estimates of snowpack characteristics generated by a physically-based snow model to generate the National Snow Analyses (NSA)[47] on a daily basis for the coterminous US (Figure 8). Ground-based and remotely-sensed snow observations are assimilated daily into the simulated snow-model state variables including snow water equivalent, snow depth, surface and profile snowpack temperatures, snowmelt, surface and blowing snow sublimation, snow-surface energy exchanges.

Through the SNOTEL network, the NRCS has been collecting snow and climate data and producing water supply forecasts for the Western U.S. for 76 years[48]. As part of this collection system, many of the automated SNOTEL sites have been in operation since the middle 1970's and presently the network consists of 813 stations. The winter of 2010-2011 is shaping up to be

[44] http://www.nws.noaa.gov/oh/hdsc/studies/pmp.html
[45] NOHRSC 2011. http://www.nohrsc.nws.gov
[46] http://www.wcc.nrcs.usda.gov/snow/
[47] NOHRSC 2011. National Snow Analyses http://www.nohrsc.nws.gov/nsa
[48] http://www.wcc.nrcs.usda.gov/wsf/westwide.html

one of the largest snow years on record. These conditions could become challenging to water managers.

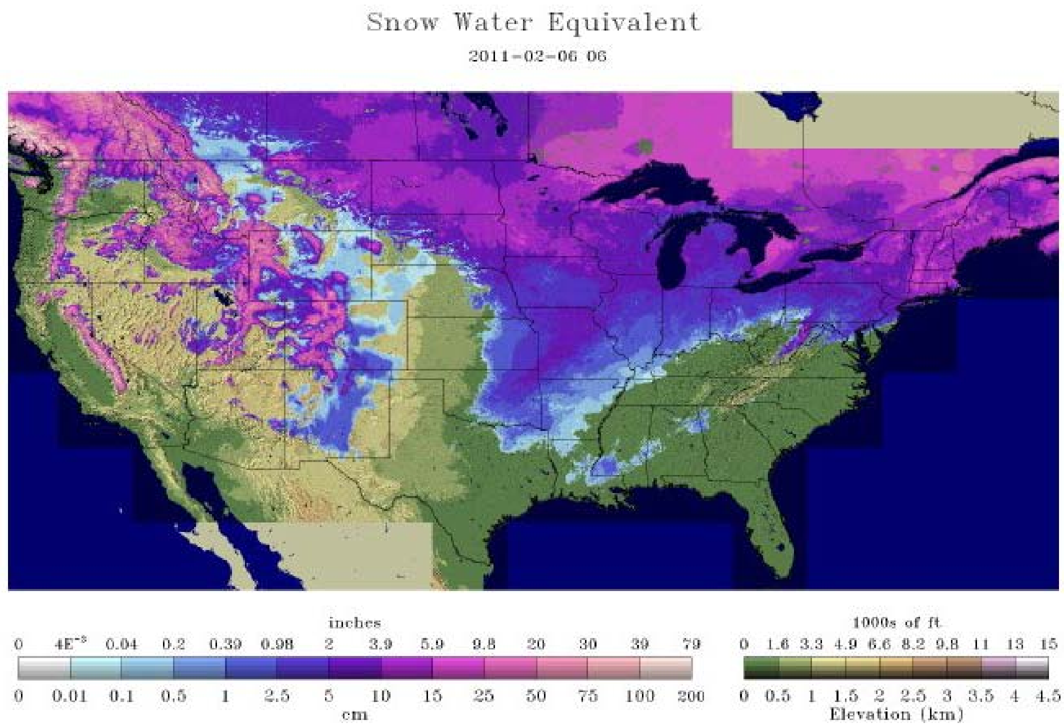

Figure 8. Example of snow-water equivalent for the conterminous U.S. during February 2011[49]. Animated maps can be produced to display daily variations in snow depth, snowpack temperatures, sublimation, and other statistics.

The SNOw Data Assimilation System (SNODAS) is a modeling and data assimilation system developed by NOHRSC to provide the best possible estimates of snow cover and associated parameters to support hydrologic modeling and analysis. The aim of SNODAS is to provide a physically consistent framework to integrate snow data from satellite, airborne platforms, and ground stations with model estimates of snow cover.

NOAA runs the Climate Reference[50] and the Regional RUSHCN[51] networks, which are designed to explore temperature and precipitation trends. Of the currently operating 11,400 Cooperative Observer Program (COOP)[52] stations, about 5,000 make up the "climate" network (the remaining stations support hydrology requirements). In general, precipitation gages tend to be more numerous in the east, south central, southeast, southwest, and northwest, often co-

[49] http://www.nohrsc.nws.gov/nsa
[50] Technical Paper 24, U.S. Weather Bureau, 1953
[51] NOAA 2011. Online Climate Data Directory. http://www.ncdc.noaa.gov/oa/climate/climatedata.html
[52] NWS 2009. Cooperative Observer Program. http://www.nws.noaa.gov/om/coop/coopmod.htm

located with stream gages or installed at or near major metropolitan airports. While airports are convenient, the continuity and accuracy of the long-term data sets can be inconsistent due to site relocations, instrument changes, and the consequences of encroaching urbanization and related heat island effects. It is important to recognize that the use of fewer observation sites to measure precipitation makes the coverage less precise; this is particularly problematic in mountainous terrain. With a few exceptions, the instruments used by NWS cooperative observers have not changed significantly over the past century.

Glacier ice contains about 70 percent of the Earth's freshwater, although most glaciers exist as large ice sheets in the polar regions. Many glaciers are shrinking as a result of warming temperatures. For example, all of the glaciers in Glacier National Park are predicted to disappear by 2030 (Hall and Fagre, 2003). Globally, glacier meltwater has contributed to sea-level rise (Leuliette and Miller, 2009), and the added freshwater into the ocean can affect ocean circulation, sea surface temperatures, and thus climate (Hillaire-Marcel et al., 2007).

The USGS and National Park Service (NPS) monitor glaciers in the U.S. The USGS[53] approach has been to establish long-term (50-year) mass balance monitoring programs at three widely spaced glacier basins in the United States that clearly sample different climate-glacier-runoff regimes (Josberger et al., 2009). The three long-term sites are South Cascade Glacier Washington and the Gulkana and Wolverine Glaciers in Alaska**.** The USGS[54] monitors changes in glaciers in Glacier National Park, as well as the hydrologic and ecological effects of those changes. USGS and other researchers have conducted a broad range of investigations of the Bering Glacier in Alaska for many using a variety of techniques (Shuchman and Josberger, 2010). The Bering Glacier is the largest glacier in North American, contains about 20 percent of the glacial ice in Alaska, is melting at the rate of about 10 m/year at its terminus, and is contributing 30 km^3 of freshwater to the Gulf of Alaska per year.

The NPS[55] monitors four glaciers in the North Cascades National Park Complex. This park contains 312 glaciers, or more than half of the glaciers in the conterminous 48 states. The NPS also monitors 2 glaciers at Mount Ranier National Park[56], and Rocky Mountain National Park[57].

Changes in glacier mass and area are an important signal in detecting climate change. As a result, and because of the effect of glaciers on streamflow, sea level, and ocean circulation, it is important that glacier monitoring continue and perhaps be enhanced using modern remote-sensing techniques.

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[53] U.S. Geological Survey, 2011. Glacier and Snow Program of Alaska and Washington Science Centers, Benchmark Glaciers http://ak.water.usgs.gov/glaciology/index.html

[54] U.S. Geological Survey, 2011. Northern Rocky Mountain Science Center Glacier Monitoring Studies http://www.nrmsc.usgs.gov/research/glaciers.htm

[55] National Park Service, 2011. North Cascades National Park Complex, Glaciers Selected for Monitoring http://www.nps.gov/noca/naturescience/glacial-mass-balance2.htm

[56] National Park Service, 2011. Mount Ranier Glacier Monitoring 2009 http://www.nps.gov/mora/naturescience/upload/Glacier%20Report%2009.pdf

[57] National Park Service, 2011. Glaciers and Glacier Change, Glacier Research http://www.glaciers.pdx.edu/Projects/LearnAboutGlaciers/ROMO/GlcResearch.html

Water quality, water use, and ecosystem condition

Water quality, water use, and ecosystem data are critical inputs to management decisions to protect public health and sustain ecosystems. In addition, water resource managers need to continually evaluate the effectiveness of existing policies and the vulnerability of water resources to various stressors, including climate change, in order to ensure the sufficient water is available at the necessary quality.

Water quality data include physical characteristics such as temperature and suspended solids; chemical characteristics such as pH, alkalinity, minerals, metals, nutrients (nitrogen and phosphorus), organics (including naturally occurring substances, pesticides, pharmaceuticals, and other anthropogenic compounds; and byproducts or degradation products such as nitrosamines or other disinfection byproducts); and microbial characteristics such as viruses, bacteria, protozoa, and algae. Many of these parameters are interrelated and have direct public health implications (Noyes et al., 2009).

> ***Water quality directly affects water availability. Water that is not of sufficient quality for its intended uses is, to some extent, unavailable.***

Climate influences water quality directly through changes in temperature and precipitation patterns. Changes in temperature also impact microbial and chemical reactions including degradation of contaminants, solubility, and pathogen survival and die-off. In addition, temperature affects evaporation rates and consequently impacts salinity, particularly in reservoirs. Intensified precipitation can accelerate runoff and sediment erosion and deposition rates, as well as atmospheric deposition into water bodies. Drought and heavy precipitation events have been correlated with increased incidence of waterborne disease and outbreaks (Nichols et al., 2009).

Some types of water quality data can be collected through using continuous monitoring technologies that may be installed at specific locations to provide real-time data or deployed intermittently. Remote sensing and satellite imagery also provide information on water quality patterns, such as the prevalence of algal blooms or changes in the nutrient or organic loading to a watershed. Other types of water quality data are derived from collecting water samples at specific locations (streams, groundwater, wastewater, drinking water systems, outfalls, intakes, etc.) and transporting the samples to laboratories for chemical or microbial analyses. The specific types of water quality data that are collected and the frequency of sampling depend on resource availability, sampling protocols, and regulatory requirements, although improvements in sensor technology could enhance the type and timeliness of data available, as well as perhaps reduce the cost of collection and distribution.

Water-quality data are collected by Federal, State, and local agencies for a variety of purposes. The USGS collects and analyzes chemical, physical, and biological characteristics of water, sediment, and tissue samples from across the Nation and compiles the data into the NWIS database[58]. Additionally, about 4,000 surface-water and groundwater sites are instrumented to continuously record physical and chemical characteristics of the water including pH, specific conductance, temperature, dissolved oxygen, and percent dissolved-oxygen saturation[59]. Supporting data such as air temperature and barometric pressure are also available at some sites. The National Science Foundation Long Term Ecological Research sites and the USDA FS Experimental Forest and Range (EFR) Network cooperate on the HydroDatabase[3] (HydroDB) provide real-time streamflow and climate measurements and are beginning to incorporate water quality measurements.

The USGS National Water Quality Assessment Program (NAWQA)[60] applies uniform methods of data collection and analysis to provide a national and regional perspective on water-quality. Monitoring data are integrated with geographic information on hydrological characteristics, land use, landscape features, and census data. Local, State, Tribal, and national stakeholders use NAWQA information to design and implement strategies for managing, protecting, and monitoring water resources in many different hydrologic and land-use settings across the Nation.

The National Monitoring Water Monitoring Council, a subcommittee of the Advisory Committee on Water Information, developed a plan for a National Monitoring Network[61]. The network was designed in response to a recommendation by the U.S. Commission on Ocean Policy in 2004. The network includes monitoring rivers, estuaries, beaches, wetlands, atmospheric deposition, groundwater, the Great Lakes, and the ocean. The rivers component (Figure 9) was designed to measure output from at least 90 percent of each Hydrologic Accounting Unit and to measure at least 90 percent of the inflow to each of the network's 149 monitored estuaries.

[58] USGS 2011. http://waterdata.usgs.gov/nwis
[59] USGS 2011. Real-time water quality data for the nation. http://nrtwq.usgs.gov
[60]USGS 2011. http://water.usgs.gov/nawqa
[61] National Water Monitoring Council, 2011, National Monitoring Network for U.S. Coastal Waters and Tributaries, http://acwi.gov/monitoring/network/index.html

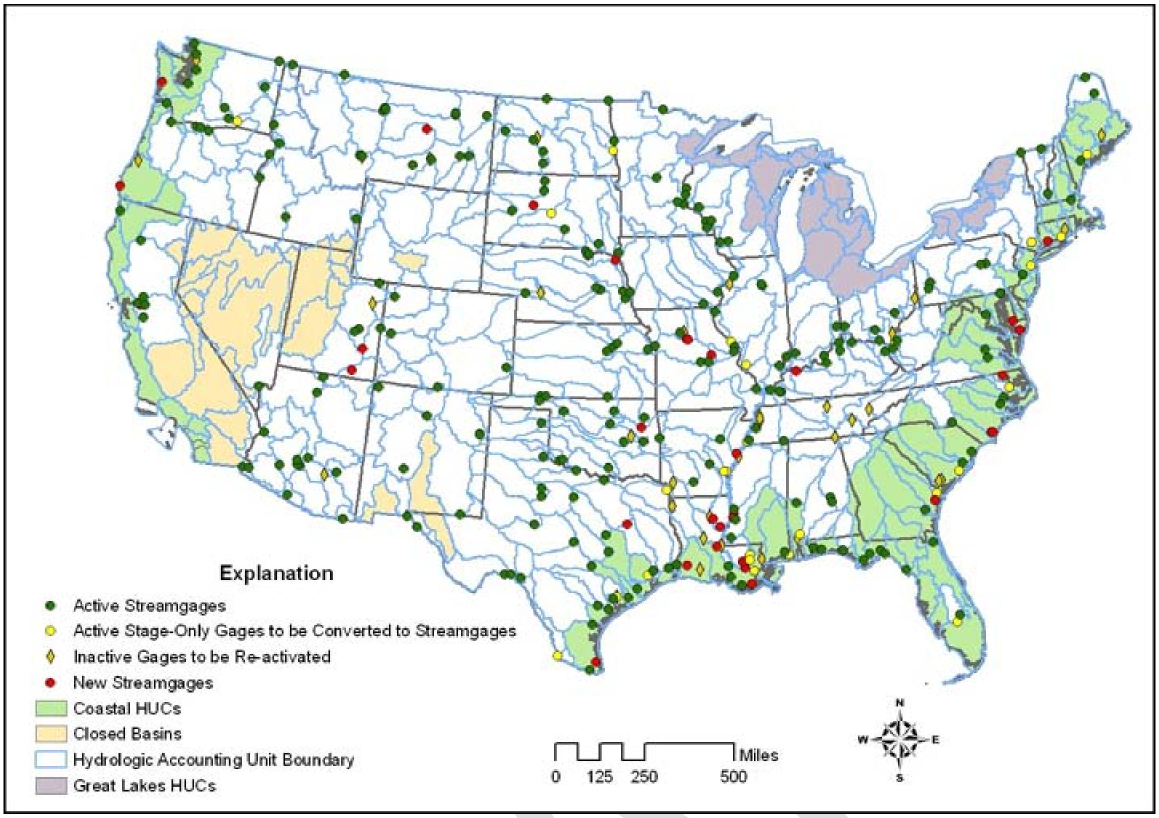

Figure 9. Map of the conterminous United States, showing Hydrologic Accounting Unit boundaries, closed basins, coastal basins, Great Lakes basins, and streamgages required to meet the design criteria for inland rivers.

The EPA maintains a water quality data warehouse called STORET[62] that catalogues water quality data by location and properties (physical, chemical, biological and habitat). STORET is updated regularly and its data record ranges from the 1970s to the present. STORET was not designed as an observation network and, therefore, the spatial coverage tends to be focused on water or wastewater treatment facilities or watersheds of concern. Because the data are derived from different entities, all inputs must document a standardized set of metadata that include: the sampling and analytical methods used; in appropriate situations, the laboratory used to analyze the samples; and the quality control checks used when sampling, handling the samples, and analyzing the data. Water quality issues associated with climate change are likely to have multiple public health implications including an increase in algal blooms and potential shifts in the microbial ecology of freshwater and coastal systems.

[62] EPA 2009. STORET/WQX http://www.epa.gov/storet

Improvements in water-quality sensor technology are needed. New in situ sensors could expand the types of data made available in real time, reduce the cost of collection, and provide more insight into physical processes through more frequent information and speed management response to undesirable conditions.

While NWIS and STORET are designed for different purposes, the systems are developing collaborative websites to provide data to users in a common format[63]. These systems have developed standardized metadata, compatible search parameters and common vocabulary that will allow for greater functionality of available data to be used for climate change analysis. This approach will allow data users to quickly access data from both databases. Efforts are underway to expand this effort to include other data systems, thus allowing for greater consistency across a wider range of water body types.

Numerous opportunities exist to improve interoperability among Federal hydro-climatic data systems. Ongoing coordination among NOAA, EPA, and USGS should continue, and interoperability efforts should be enhanced.

Water quality issues associated with climate change are likely to have multiple public health impacts due to shifts in the microbial ecology of freshwater and coastal systems, new and different pathogens and chemical contaminants, and an increase in algal blooms. Heavy precipitation events have been statistically linked to an increased incidence of waterborne disease outbreaks in the United States (Interagency Working Group on Climate Change and Health, 2010; Curriero et al., 2001). The anticipated increase in the risk for waterborne disease with climate change will require improved surveillance systems and coordination of prevention efforts at local, State, and national levels. While the types of data systems needed to monitor the incidence and prevalence of waterborne disease differ from other monitoring networks, it is important to integrate geospatial water resource data with public health data.

Key issues include:

- endemic disease and outbreaks associated with exposure to waterborne pathogens;
- surveillance of diseases associated with waterborne contaminant exposures (chemicals and their byproducts and metabolites, toxins released by algae and cyanobacteria, etc); and

[63] USGS 2008. Water-Quality Web Services. http://qwwebservices.usgs.gov

- surveillance of developmental health effects relevant to waterborne contaminants (microbial and chemical).

Support is needed for improved monitoring systems for collecting data on waterborne disease, including outbreaks, endemic disease, algal toxins, and other waterborne contaminants.

Water use data are collected and compiled by several entities including Federal agencies, States, water management districts, and utilities. The USGS works in cooperation with local, State, and Federal environmental agencies to collect, compile, and disseminate water use information through the National Water-Use Information Program (NWUIP)[64]. Data are also searchable through the National Atlas[65]. Many water use data are estimated from surrogate measures, and collection methods vary from state to state. For example, some agricultural uses are estimated based on the number of livestock or the acres of cropland of a given type. The USDA conducts an agricultural census[66] and also conducts a farm and ranch survey to provide a snapshot of agricultural water use[67]. These data are compiled and summarized on the basis of political boundaries (states, counties) and do not necessarily reflect watershed characteristics.

In 2002, the National Research Council (2002) made a number of recommendations regarding the NWUIP. Recommendations included elevation of the program to a science activity that addressed statistical estimation of use and factors affecting use; systemic inclusion of other data sets into the NWUIP; determination of standard errors of estimates; and integration of water use information with other parts of the hydrologic cycle, including water quality. For the most part, these recommendations have yet to be implemented, although the Water Census could be a step in that direction.

Water-use information (withdrawals and return flows) are not collected consistently from state to state, if at all, and data are difficult to obtain in a timely manner. Recommendations by the National Research Council in 2002 on the National Water Use Information Program should be fully implemented.

[64] USGS 2009. National Water-Use Information Program. http://water.usgs.gov/watuse/wunwup.html
[65] National Atlas 2011. http://www.nationalatlas.gov/articles/water/a_wateruse.html
[66] USDA 2009. The Census of Agriculture. http://www.agcensus.usda.gov
[67] USDA 2008. 2008 Farm and Ranch Irrigation Survey. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Farm_and_Ranch_Irrigation_Survey/index.asp

The proposed National Water Census (USGS, 2007) is an important step towards providing a comprehensive perspective on water resources. The Census will be organized on a watershed basis and contain:

- water use information: withdrawals, return flows, and consumptive use for all water use sectors with special data collection efforts designed to track changing water use patterns relevant to public water systems, agriculture, energy, industry, and non-potable demands;
- water quantity and availability information including analysis of changes in storage (ground water) and flow (rivers);
- analysis of changes in water quality that are critical to its use (temperature, sediment, nutrients, pathogens, salinity, waterborne contaminants) and;
- identification of alternative water sources that may become available through technology advances including reuse, green infrastructure, conservation, desalination, aquifer storage and recovery and evolving energy production and industrial water use practices.

The condition of aquatic ecosystems is tracked through the USEPA's National Aquatic Resource Surveys (NARS)[68]. NARS provides biological, chemical and physical habitat data on rivers/streams, lakes, coastal waters and wetlands. The local data are aggregated and evaluated to provide basin, eco-region, state, and national perspectives. The data from NARS are incorporated into STORET and used at the National, State and Tribal scale to establish water quality thresholds, set baseline conditions, inform management decisions and track changes in water quality over specific time periods.

The Aquatic and Riparian Effectiveness Monitoring Program (ARAM)[69]is a multi-federal agency program developed to assess the effectiveness of the Aquatic Conservation Strategy in maintaining or restoring the condition of watersheds in the Northwest Forest Plan area. Watershed condition is assessed every five years. In-channel attributes are also measured each year in a subset of watersheds to supplement the watershed condition assessments and validate the models used to assess stream condition.

The National Wetland Mapping Standard was developed to provide a consistent standard to enable any entity to collect wetland mapping data and upload to U.S. Fish and Wildlife Service National Wetland Inventory. Wetland mapping is the critical step towards updating or creating accurate wetland data (e.g., geospatial databases and maps) to 1) know the spatial distribution of wetland types across the landscape so as to adequately monitor changes in their condition over time, 2) develop conservation and restoration strategies for impacts of sea level rise on coastal wetlands, and 3) understand their capacity to both mitigate climate change impacts and contribute to watershed resilience. By using the FGDC National Wetland Mapping Standard, data collected can be uploaded to NWI or the National Wetland Layer on the National Map,

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[68] EPA 2010. National Aquatic Resource Surveys. http://water.epa.gov/type/watersheds/monitoring/nationalsurveys.cfm
[69] http://reo.gov/monitoring/reports/watershed/aremp/Welcome.htm

thereby making these data available to anyone with internet access or GIS technology. Although the standard was developed, implementation is sporadic and underfunded.

Wetlands are a key indicator of climate change and water-resources stress. Wetland monitoring needs to be strengthened both in terms of frequency of monitoring and types of data available.

Review Element 2: Data Gaps in Current Water Monitoring Networks

Review Element from Section 9506:

"to identify data gaps in current water monitoring networks that must be addressed to improve the capability of the Federal Government and the States to measure, analyze, and predict changes to the quality and quantity of water resources, including flood risks, that are directly or indirectly affected by global climate change…"

Finding 3: Numerous documents and reports by agency, interagency, non-governmental and trade organizations provide excellent detailed information on monitoring network gaps and specify ways to close those gaps. These documents and reports are produced by the groups who operate the networks and utilize the data, and thus are most familiar with the needs.

Finding 4: Water-use information (withdrawals and return flows) are not collected consistently from state to state, if at all, and data are difficult to obtain in a timely manner.

Finding 5: Lake-level and reservoir content information is collected in some locations, but a true network of lake level data does not exist.

Finding 6: Wetlands are a key indicator of climate change and water-resources stress. Wetland monitoring needs to be strengthened both in terms of frequency of monitoring and types of data available.

Finding 7: Indirect effects of climate change, such as changes in the Nation's energy portfolio (increased use of biofuels; new hydrocarbon energy extraction methods) and increased use of carbon sequestration, will have an effect on water resources. Monitoring networks do not exist to address these issues.

Finding 8: Monitoring networks are inadequate to detect changes in waterborne disease as a function of climate change.

Finding 9: Research can play a key role in the design of monitoring networks and in filling gaps. Research on new measurement technologies and on models for extending data should be strengthened. Research on the linkages among water use, climate drivers, and water availability also is inadequate. Adoption of common open standards among data systems would increase the utility and lower the cost associated with information integration.

In today's world, the term "network" is applied to a wide array of interconnected systems that vary in scale and complexity. The technology to develop integrated networks is becoming increasing available. Some of the observational data described under Review Element 1 are collected using a network concept, whereas other data systems are less coordinated. A proposed definition of water monitoring networks is:

Water Monitoring Networks: Systematic and coordinated monitoring of water-relevant parameters at defined spatial and temporal scales. Monitoring approaches include quantitative and qualitative physical, chemical, biological, and remotely sensed measures of the Earth's atmosphere and surface (land and ocean) using a combination of discrete, continuous, and direct observations of water characteristics and other Earth processes. Remote sensing methods include remote aerial and satellite geo-referenced imagery and satellite profiling (i.e., temperature and water vapor used in weather prediction models).

As discussed under Review Element 1, a wealth of water resources information is generated by the public and private sector. Gaps in those programs also were highlighted under Review Element 1. Examples of actions to address those gaps include implementation of the National Streamflow Information Program; implementation of the National Groundwater Monitoring Program; implementation of the National Monitoring Network; improved coordination of weather and climate observations and expansion of those observations in some areas; continued and perhaps expanded glacier monitoring; and greatly enhanced water-use data collection and science.

There a number of ongoing efforts to coordinate and link water monitoring networks with centralized databases to provide seamless and cohesive information that can be mapped and interpreted. These efforts need to be encouraged and supported. However, the existing networks were not designed to support decision-making in a changing climate, and issues of significant social concern, such as increased stresses on public health systems, have generally not been primary objectives of these systems.

The Climate Change and Water Working Group (CCAWWG)[70] is an interagency group that has been working to identify critical gaps relevant to climate change adaptation. Several recent reports (Brekke et al., 2009[71]and 2011[72]) have highlighted the need for collaborative efforts across the water management and scientific communities to develop, test, and apply new methods, tools, and capabilities. Key goals include:

- **Monitoring and Data Collection**: Need for supporting current data collection networks and understanding their adequacy to support water management in a changing climate.

- **Making Decisions Under Uncertainty**: Need for understanding the relative merits of various tools/concepts (e.g., adaptive management, robustness, resilience, flexibility) to support water management and development under a changing climate, and also understanding the compatibility of these tools/concepts with current influences on management (e.g., legislation, appropriations, policy).

[70] ESRL, 2008. CAWWG. http://www.esrl.noaa.gov/psd/ccawwg
[71] Brekke et al. 2009. http://pubs.usgs.gov/circ/1331
[72] Brekke 2011. http://www.usbr.gov/climate/userneeds/docs/LTdoc.pdf

An important gap in water data systems related to climate change is the lack of a comprehensive system to monitor and report the occurrence and prevalence of waterborne disease. The Centers for Disease Control and Prevention (CDC)[73] has recognized the need to enhance and expand the ability of state and local public health authorities to collect comprehensive data on the incidence and occurrence of waterborne disease and other potential climate-related public health impacts.

[73] http://www.cdc.gov/climatechange

Review Element 3: Improve Data Management to Increase Efficiency of Data Acquisition and Reporting

Review Element from Section 9506:

"to establish data management and communication protocols and standards to increase the quality and efficiency by which each Federal agency acquires and reports relevant data…"

Finding 10: While existing observational data systems address the essential physical and chemical dimensions of freshwater resources, improved coordination among the data systems is needed. Particular attention should be focused on improving the capability to monitor waterborne disease.

Finding 11: Access to the full range of hydro-climatic data collected by multiple government agencies (Federal, State, local, Tribal), and other interests (academic organizations, non-governmental organizations, and others), is inadequate. Data are collected using a range of protocols, which are not always documented, and are archived in a variety of ways, from modern relational databases to paper copies in files. There is much to be gained from use of consistent documentation standards and improvements in interoperability of data systems.

Finding 12: Data are insufficiently integrated to support important management decisions. For example, most water-quality data are not integrated with water quantity data. Likewise, groundwater and streamflow data generally are not integrated, thereby limiting, for example, understanding the effects of groundwater pumping on streamflow.

Finding 13: Data that are critical to climate impact assessment in a multi-stress context are often missing entirely. For example, both the data and the information systems that would be needed are very limited. As an example, the capacity does not exist to link information about vulnerable human populations with data about implications of changes in the hydro-climatic cycle (i.e., frequency and magnitude of floods and droughts).

Finding 14: Current efforts to design a Hydrologic Information System, funded by the National Science Foundation are important investments that are leading to more tools to support interoperability of data sets. It is unlikely, however, that this effort will be sufficient to integrate data at the state, regional, and local levels, where most water management decisions are made.

Today's information-rich world provides new opportunities to better coordinate, manage, disseminate, and use the enormous volume of data and information that are relevant to local, state, national, and international water resources managers. Effective tools for managing data are essential for improving decision-making. Data management practices have advanced over the past decade due to the evolution of information technology, improved communication tools, and new forms of data storage such as cloud computing. Currently there are dozens of data management approaches that are in use and a host of databases that house various types of water data and information. The interoperability of these systems varies and there are ongoing efforts at coordination. Many data are accessible via the internet and most can be downloaded. Examples of data systems are provided in Appendix C.

Access to the full range of hydro-climatic data collected by multiple government agencies (Federal, State, local, Tribal), and other interests (academic organizations, non-governmental organizations, and others), is inadequate. Data are collected using a range of protocols, which are not always documented, and are archived in a variety of ways, from modern relational databases to paper copies in files. There is much to be gained from use of consistent documentation standards and improvements in interoperability of data systems.

A major challenge facing producers of water information is ensuring that all hydro-climatological data and model results are accessible, quality-controlled, and available in formats that facilitate their use by stakeholders. Over the past decade, a number of federal agencies and other institutions have expanded their water data bases, and developed a range of information management tools. Ensuring compatibility and interoperability of disparate data sets so they can be applied to a variety of purposes is paramount. Current efforts to update the variety of water level measurement systems to NAVD88, the current official vertical datum of the U.S., is also critical to facilitating interoperability of data. A variety of institutions are exploring options for enhancing interoperability.

One effort that has seen some initial promising results is the Consortium of Universities for the Advancement of Hydrologic Science Inc (CUAHSI)[74] Hydrologic Information System (HIS) project, funded by the National Science Foundation (NSF) and led by a multi-institutional research team. This group has been studying how to synthesize the water observations data by means of a services-oriented architecture. However, the system does not yet connect to state or local-based water data very effectively and is only accessed by relatively small number of sophisticated users.

The U.S. Integrated Ocean Observing System (IOOS®) is a national observing system that integrates, coordinates and enhances efforts to deliver critical information to decision-makers to improve safety, enhance our economy and protect our environment. The integration of information facilitated by open source standards and protocols, such as the Open Geospatial Consortium Sensor Observation Service, and data formats that enable more efficient, routine, and effective use of data is key to building IOOS®. IOOS® and the National Water Quality Monitoring Network for U.S. Coastal Waters and their Tributaries have been coordinating to bridge water quality data collected in rivers and watersheds with data from the estuaries to coastal waters and the Great Lakes and to make these observations seamless to improve use of the data to the public health official, scientist or coastal resource manager.

The Open Geospatial Consortium (OGC)[75] is an international entity, representing about 400 companies and agencies, which has developed the most widely used standards for sharing

[74] CUAHSI 2010. http://www.cuahsi.org
[75] http://www.opengeospatial.org

geospatial data through the internet. In 2008, CUAHSI proposed to the OGC that there should be established a Hydrology Domain Working Group to harmonize WaterML with OGC standards, and later the OGC and the World Meteorological Organization expanded this mission to included joint development of data standards for hydrology, climatology, oceanography and meteorology.

Many agencies now agree that the best approach to enhance internet-based water data sharing in the United States is to adapt existing OGC data standards. The ACWI/FGDC Subcommittee on Spatial Water Data supports this approach to developing water data services in the United States. Leadership at the Federal level, perhaps through the Subcommittee on Water Availability and Quality, will be needed to develop strategies to enhance water data sharing across all levels of government, among water disciplines, and between water science and water management in the United States and with bordering nations.

Data are insufficiently integrated to support important management decisions. For example, most water-quality data are not integrated with water quantity data. Likewise, groundwater and streamflow data generally are not integrated, thereby limiting, for example, understanding the effects of groundwater pumping on streamflow. There is little capacity to connect hydro-climatic data with issues of social relevance. As an example, the capacity does not exist to link information about vulnerable human populations with data about implications of changes in the hydro-climatic cycle (i.e., frequency and magnitude of floods and droughts).

Federal agency actions towards improving data integration should continue and the Subcommittee on Water Availability and Quality (SWAQ) should promote cross-agency communication and additional coordination opportunities as appropriate.

Accelerated progress is needed on:

- ***multi-agency cooperation to deliver information seamlessly;***
- ***national integration of in situ and remotely-sensed data and metadata;***
- ***adoption of common operational standards, quality assurance procedures, and data exchange formats;***
- ***data interoperability; and***
- ***integration of water quantity (streamflows, groundwater levels) and water quality monitoring.***

These efforts need to be coordinated with hydrogeological and biogeochemical modeling of freshwater resources and ensure the right types of data are being collected at the right locations and frequency.

Review Element 4: Options for Establishment of a Data Portal

Review Element from Section 9506:

"to consider options for the establishment of a data portal to enhance access to water resource data…"

Finding 15: There is a well-established need for an interagency data portal to provide access to climate related data, including hydrologic data. The U.S. Global Change Research Program is an appropriate entity to develop a strategic plan for implementation of such a portal.

There are ongoing efforts to develop data portals that allow for data integration within multiple agencies, but requests for "one-stop shopping" for climate related data across multiple agencies continue. Among other requests, easy Internet access to climate information and data is a high priority for all stakeholders.

In recognition of the need for a coordinated way to deploy climate-related data, there have recently been broad, interagency discussions about ways to design and deploy a portal that provides links to relevant agency data, models, and resources and also provides key tools for understanding and using the data. In the context of the newly established Climate Information and Services Roundtable of the Committee on Environment, Natural Resources and Sustainability, the US Global Change Research program has been directed to develop a strategic plan for such a portal. The initial phase of this process, conducted with strong coordination among Federal and non-Federal partners, is expected to focus on data generated in support of the National Climate Assessment. The portal is also expected to provide guidance on appropriate use of data and on the use of probabilistic information. There are opportunities for integrating geospatial analyses with other types of observational data. There also are opportunities to ensure that data and information published through the portal adhere to open data standards, thereby maximizing interoperability and increasing utility. The USGCRP effort, Data.gov, and the NOAA Climate Services are examples of portals that are being used to provide information[76,77, and 78], although in most cases, data are not integrated.

Language, semantics, and criteria need to be developed collaboratively with inputs from all stakeholders (decision-makers, modelers, information technology, database developers, the user community, etc.) so that information is accessible and useful to the appropriate audiences

[76] Data.gov 2011. http://www.data.gov

[77] NOAA 2011. Climate Services. http://www.climate.gov/#climateWatch

[78] USGCR 2011. http://globalchange.gov; USDOI 2011. http://www.doi.gov/whatwedo/climate; EPA 2011. Climate Change http://www.epa.gov/climatechange; USGS 2011. Office of Global Change http://www.usgs.gov/global_change; USDA 2011. CCRC http://www.fs.fed.us/ccrc

and guidance is provided on best management practices. Portal design needs to consider how to best link information to its original source to enable users to query the data in different ways and access more details as necessary. The portal design needs to be flexible enough to adapt to changing information technology. In addition, robust quality standards are needed to ensure the credibility and reliability of the portal.

A key challenge is to ensure that a data portal is designed to maximize access to and utility of the data. Consequently, decision-makers and other end-users need to play an integral role in portal development and testing. The entry point needs to be self-explanatory and allow for data to be accessed by a range of users with different levels of experience and expertise.

Review Element 5: Adequacy of Hydrologic and Other Models

Review Element from Section 9506:

"to facilitate the development of hydrologic and other models to integrate data that reflects groundwater and surface water interactions…"

Finding 16: Existing groundwater models are adequate for some hydrogeologic settings, but not all (e.g., fractured rock environments).

Finding 17: Fully coupled groundwater – surface-water models are relatively recent innovations and have been applied in a limited number of locations. In addition, there is a great need for development of integrated groundwater-surface water models that incorporate water quality components.

Finding 18: Models that are capable of assimilating real-time spatial, *in situ*, and remotely-sensed data do not exist. Such models could become integral to more effective water-resources management.

Finding 19: Models for estimating hydro-climatic statistics are inadequate. The effects of climate and management changes (i.e., changes in trends in temperature and precipitation, land use, water management, land management practices, etc.) currently are not considered when estimating the probability of future hydro-climatic events, such as large storms, floods (and associated groundwater impacts), droughts, etc.

Finding 20: Guidance for using output from global and regional climate model output as input to hydrologic models is needed. A particular need is the ability to translate uncertainties in climate models to uncertainties in water-resources forecasts.

Finding 21: In many cases, existing hydro-climatic records have been inadequately explored to fully determine regional and national trends in hydro-climatic conditions or to satisfactorily explain the relation of some changes to causative factors.

Successful management of our Nation's water resources requires a sophisticated and integrated approach to monitoring, modeling and data management. Models provide decision-makers with tools that can be used to simulate and visualize water quantity and quality under the range of climatic, hydrologic, and environmental conditions that reflect the current and potential future state of water resources. Understanding how future climate and other global change conditions could affect water resources is crucial for decisions confronting farmers, energy or water utilities, dam designers and operators, environmental regulators, and society at-large. Models also help explore potential future climate scenarios for:

- predicting how a basin might respond to extreme rainfall and snowmelt through applying precipitation-runoff models to evaluate changes in water-balance relationships, flow regimes, flood peaks and volumes, soil-water relationships, sediment yields, and ground-water recharge resulting from climate change;

- evaluating how predicted climate scenarios will impact streamflow, sediment delivery, and water balance in watersheds;
- evaluating interactions between streamflow and groundwater levels; and
- planning and design of urban drainage systems and flood control structures.

The capabilities of hydrologic and water quality models is continuing to advance. Regional climate models or down-scaled general circulation models/global climate models (GCMs) are also evolving and help to provide insight on possible future climate scenarios. Typical applications include evaluating impacts of climate changes on watersheds, surface water bodies, groundwater systems, ecosystems, and engineered systems such as water and wastewater treatment and conveyance systems under different scenarios. Nevertheless, guidance for using output from global and regional climate models as input to hydrologic models is needed. A particular need is the ability to translate uncertainties in climate models to uncertainties in water-resources forecasts future scenarios. Models also are important in evaluating the underlying mechanisms that affect the stability of environmental systems, their interrelationships and their responses to different stressors and policies.

Existing groundwater models are adequate for some hydrogeologic settings, but not all (e.g., fractured rock environments). Fully coupled groundwater – surface-water models are relatively recent innovations (Markstrom et al., 2008) and have been applied in a limited number of locations. A significant limitation of directly using the output of global climate models is the scale at which projections of future conditions are generated. Due primarily to limitations in computing capacity, the amount of data that can be generated at a relatively fine scale, given all of the variables and computations involved, is limited. This means that projections of future conditions are generally not available at the scales at which most water management decisions are made. As a result, there is significant investment both in more fine-scaled models and in ways to "downscale" the output of global models to more regional scales.

Because hydrologic and water quality models that are intended to project possible future conditions require inputs from climate models, there is an added layer of complexity in understanding the implications of climate change on water resources. The diagram of the CHPS system below illustrates this point (Figure 10).

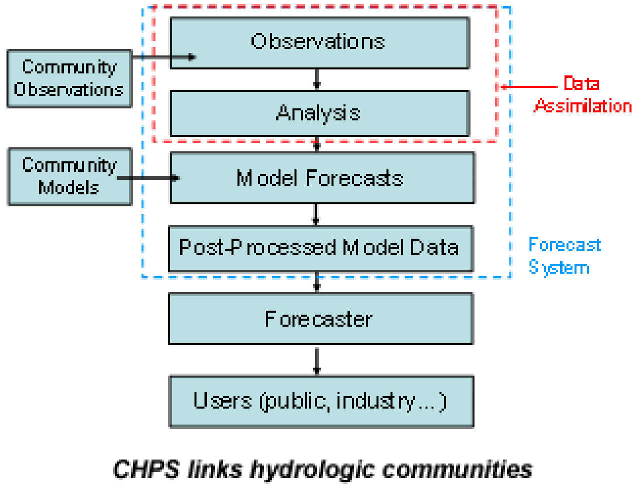

Figure 10. Architecture of the Community Hydrologic Prediction System.[79]

Although the capacity of hydrologic and water quality models is continuing to advance, proper framing of the uncertainties associated with both climate models and hydrologic models is important to ensure that decision-makers do not have unrealistic expectations. The skill of both global and regional climate models is increasing rapidly, but water managers continue to depend heavily on "downscaled" information, which has limitations that need to be properly understood. There is no central source of guidance for effective ways to use output from these climate models as input to hydrological models. The ability to translate uncertainties in climate models to uncertainties in water-resources forecasts is critical, but the human capital required to do this translation is quite limited.

As a result, additional experience in the performance of these models is needed. Coupled groundwater – surface-water – and water-quality models do not exist, other than perhaps in the research mode. There is a great need for this type of integrated modeling system. There also is a great need for models that are capable of assimilating real-time spatial, *in situ*, and remotely-sensed data and providing near-real time forecasts. Such models could become integral to more effective water-resources management.

As previously suggested, statistical models for estimating hydro-climatic statistics are inadequate. The effects of climate and management changes (i.e., changes in trends in temperature and precipitation, land use, water management, land management practices, etc.) currently are not considered when estimating the probability of future hydro-climatic events, such as large storms, floods (and associated groundwater impacts), droughts, etc.

In addition to inadequate statistical models, in many cases, existing hydro-climatic records have been inadequately explored to fully determine regional and national trends in hydro-climatic conditions or to satisfactorily explain the relation of some changes to causative factors.

[79] http://www.nws.noaa.gov/ohd/hrl/chps/index.html

Moreover, a significant portion of hydro-climatic records collected 50 – 150 years ago are not digitally stored, and thus unavailable for analysis. A targeted data rescue is needed.

Models require large amounts of data for construction, testing, and operation. Important data for water-resources models include:

- Components described in **Review Element 1**: Streamflow and surface-water data, groundwater-level data, soil moisture and evapotranspiration, precipitation (including rainfall, snowfall, snowpack characteristics, soil characteristics, and glacier mass), and water quality,
- Climatic measures such as temperature, wind speed and direction, and
- Physical measures of the landscape such as elevation, slope, and land use / land cover
- Paleo climatic data for understanding the severity of droughts and flood[80]

The capabilities for many of these modeling functions are improving along with improved integration across federal and non-federal agencies[81]. A host of numerical models have been developed for specific mission or research goals. These models reflect the current theoretical understanding of hydrologic responses to climate, the availability of information to inform calculations, and the limits of computational power. Both mechanistic (e.g., the Soil & Water Assessment Tool[82]) and statistical models are widely applied (e.g., Soil Moisture Accounting Model[83]) to evaluate water supplies, infiltration capacity, and other operational goals.

An example of operational water-resources models include the Community Hydrologic Prediction System (CHPS)[84], which provides an open architecture that integrates observations, analytical tools, and models to produce water resource forecasts for a wide array of users (Figure 10). Another example is the Precipitation Runoff Modeling System (PRMS)[85] which integrates data collection with modeling using input from remote sensed layers and other digitally available data streams. Approaches are also under development to downscale GCM outputs to regions and localities, to assist in resource decision-making (e.g., Means et al., 2010[86]). Some of the key objectives of current modeling efforts include understanding land surface-atmospheric interactions, complex terrain, and the role of decadal scale oscillations in ocean temperatures.

With regard to water-resources management, key roles that models can fill include:

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[80] http://www.climate.noaa.gov/index.jsp?pg=cpo_pa/cpo_pa_index.jsp&pa=sarp&sub=projects/water/2008/woodhouse_connie.jsp
[81] NOAA 2007. Managing Climate in a Collaborative Community http://www.weather.gov/oh/hrl/chps/docs/HighLevelCHPSBriefing_34.pdf
[82] Soil & Water Assessment Tool, SWAT. http://swatmodel.tamu.edu/software/swat-model.
[83] http://www.nws.noaa.gov/oh/hrl/frzgrd/index.html
[84] NWS 2010. Community Hydrologic Prediction System. http://www.nws.noaa.gov/oh/hrl/chps/index.html
[85] USGS 2011. Precipitation Runoff Modeling System (PRMS). http://wwwbrr.cr.usgs.gov/projects/SW_MoWS/software/oui_and_mms_s/prms.shtml
[86] Means et al., 2010. http://www.wucaonline.org/assets/pdf/actions_whitepaper_012110.pdf

- prediction effects of point and nonpoint-source loadings on stream water quality (expand current capabilities to include a broad suite of contaminants);
- forecasts of effects of proposed land-use changes on water resources;
- evaluation of the effects of management actions (BMPs, etc.) on water quality and quality; and
- evaluation of interrelations among climate change, water quantity, and water quality transformation processes.

Review Element 6: Apply Hydrologic Models to Water Resource Management Problems

Review Element from Section 9506:

"to apply the hydrologic and other models developed under paragraph (5) to water resource management problems identified by the panel, including the need to maintain or improve ecological resiliency at watershed and aquifer system scales…"

Finding 22: Significant ecological and social benefits are expected from enhanced coordination of water related data collection and integration activities across the federal government. Better use of models, tools and information currently available through improvements in data management and interoperability, as well as continued investments in new understanding of hydroclimatic changes, will make significant contributions to human and ecological resiliency.

Finding 23: Even though there have been improvements in the ability to use hydrologic data and models to resolve water management problems, there is a significant need for enhanced federal coordination of water management efforts as well as monitoring and research.

Adaptive management of ecosystems and the services they provide is directly linked to water resources management. Sustained, coordinated monitoring and ongoing analysis of data are needed to develop and implement effective structural and operational adjustments in response to observed system changes. A key barrier to applying climate change vulnerability assessment tools to ecosystems is the need to ensure that information and models used are appropriate for the scale of the decision (water body, watershed, regional, national). Adaptive management also requires institutions and support to re-evaluate project and program performance and to revise decisions based on the most recent information.

There are several efforts currently underway to assist in meeting these challenges, including the Water Utilities Climate Alliance and the Integrated Water Resources Science and Service (IWRSS).[87] The IWRSS is a partnership of Federal agencies with complementary operational missions in water science; observation; prediction and management (Figure 11).

Watershed models are commonly applied, adapted, and shared by Federal and state agencies, and universities to evaluate watershed hydrology in terms of streamflow, groundwater levels, erosion, and water balance and water resources availability. In most cases, models are calibrated using existing datasets. While there are significant efforts underway to develop ecosystem models and evaluate the services that ecosystems provide, there is a need to better integrate work on ecological processes with water resources data, models, and tools. Models for predicting how aquatic habitats respond to changing hydrology, water quality, and climate are needed. As aquatic habitats change, plant and animal communities will also adapt to

[87] http://www.nohrsc.noaa.gov/~cline/IWRSS/IWRSS_ROADMAP_v1.0.pdf

changes in flow and water quality and a better understanding of these interrelationships is needed to evaluate the potential outcomes of climate mitigation and adaptation approaches.

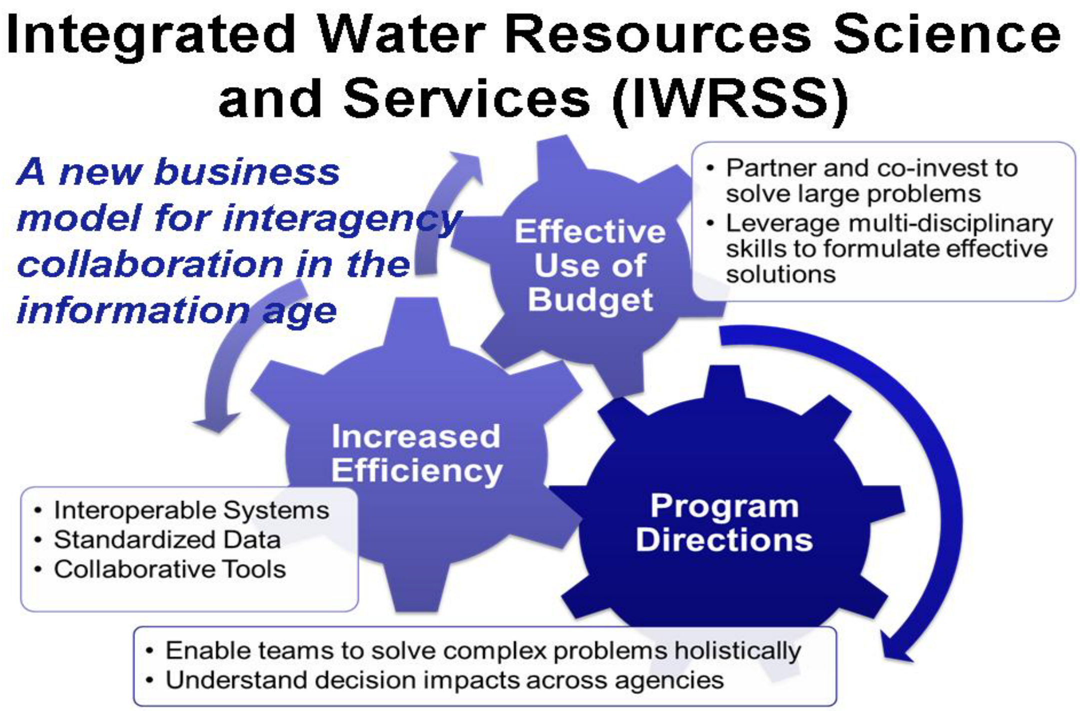

Figure 11. Overview of the Integrated Water Resources Science and Service Business Model. The IWRSS is a partnership of Federal agencies with complementary operational missions in water science, observation, prediction, and management.

It is also important to better understand the complex role that wetlands play under a changing and changed climate. To better manage these valuable resources, geospatial data are needed to continue existing efforts to generate maps that can be used to:

- determine the distribution of various types of wetlands across the landscape;
- develop wetland conservation strategies to monitor changes in wetlands across the United States;
- gain insight on opportunities for wetland restoration and understand how they can help improve wetland functions; and
- understand interrelationships between groundwater and wetlands in arid regions.

The development and integration of models can be used to design follow-up field studies and also to inform policy decisions. Conversely, models can be used to optimize sampling programs and the development of monitoring networks.

Next Steps

Key next steps to implement the findings of this report are described below.

1. **Strengthen observational data systems for freshwater resources and climate change**

    - Implement recommendations from existing reports describing needed enhancements to the observational network, giving priority to information that is critical from a health, safety and welfare perspective, as well as considering the data needs of land, water and environmental resource managers. Give consideration to monitoring effects on water resources of energy extraction and production and to geologic carbon sequestration.

2. **Prioritize observations that fill important gaps in understanding of water supply reliability**

    - Enhance collection of water use information, including provision of timely information on withdrawals and return flows (quantity and quality) from surface and groundwater resources and information on withdrawals by sector.
    - Implement a national lake/reservoir level and contents data network.
    - Enhance interagency efforts to monitor wetland areas and habitat quality on a seasonal basis.
    - Implement a waterborne disease tracking network, including all appropriate ancillary data.
    - Conduct research on new monitoring technologies, including sensors, data transmission, automated quality assurance, and remote-sensing technologies.

3. **Strengthen links between water observational data systems and climate models; improve data management, acquisition and reporting**

    - Link monitoring, observational systems, climate model outputs and other data systems, to support high-priority water management decisions (particularly related to water supply reliability and quality).
    - Establish and encourage the use of consistent data standards across agencies and with non-governmental partners and other ways to integrate existing data into more comprehensive water information systems.

4. **Support the establishment of an interagency climate data portal and provide access to high priority water-related datasets**

    - Promote interagency coordination to assess climate impacts on freshwater resources in national and regional climate assessments.
    - Develop guidance for water managers on appropriate use of probabilistic projections and model outputs.

5. **Make strengthening water data a key priority in the national freshwater climate action plan now under development, including a focus on a better understanding of groundwater-surface water interactions and modeling needs**

6. **Strengthen federal agency coordination to improve the quality and accessibility of freshwater data systems including technical outreach and support to stakeholders and decision-makers**

   - Federal agency actions towards improving data integration should continue and the Subcommittee on Water Availability and Quality (SWAQ) should promote cross-agency communication and additional coordination opportunities as appropriate.
   - SWAQ should monitor progress on implementing the findings and recommendations of this report and provide periodic updates to the USGCRP and the Interagency Climate Change Adaptation Task Force.
   - Promote interagency coordination and cooperation to implement the National Water Census.[88]
   - Encourage the Advisory Committee on Water Information, an existing Federal Advisory Committee, to establish a new subcommittee or other appropriate mechanism, to solicit and consider input from the public and stakeholders on matters related to freshwater resources and a changing climate and relay these views to Federal water data program managers and the SWAQ.

[88] http://water.usgs.gov/wsi

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Acronyms

Acronym	Definition
ASTAR	Advanced Spaceborn Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resloution Radiometer
ACWI	Advisory Committee on Water Information
ATTAINS	Assessment Total Daily Maximum Load Tracking and Implementation System
ASOS	Automated Surface Observing System
ALI	Hyperion and Advanced Land Imager
BMPs	Best Management Practices
BoR	Bureau of Reclamation
CHS	Canadian Hydrographic Service
CCAWWG	Climate Change and Water Working Group
CEN	Climate Effects Network
CENRS	Committee on Environmental and Natural Resources and Sustainability
CHPS	Community Hydrologic Prediction System
CUAHSI	Consortium of Universities for the Advancement of Hydrologic Science Inc
COOP	Cooperative Observer Program
CRN	United States Climate Reference Network
DOQQ	Digital Orthophoto Quadrangles
ELGs	Effluent Limitation Guidelines
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
FRS	Farm and Ranch Survey
GCMs	Global Climate Models
HIS	Hydrologic Information System
IWRSS	Integrated Water Resources Science and Services
ICCATF	Interagency Climate Change Adaptation Task Force
IPCC	Intergovernmental Panel on Climate Change
LDCM	Landstat Data Continuity Mission
LIDAR	Light Detection and Ranging
MODIS	Moderate Resolution Imgaing Spectroradiometer
MMS	Modular Modeling System
NAPP	National Aerial Photography Program
NACC	National Asessment on Climate Change
NARS	National Aquatic Research Survey
NASA	National Areonautics and Space Agency
NCDC	National Climate Data Center
NCCR	National Coastal Commission Report
NEP	National Estuary Programs

Acronym	Definition
NHANES	National Health and Nutrition Examination Survey
NHAP	National High Altitude Photography
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NPS	National Park Service
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation System
NSF	National Science Foundation
NSTC	National Science and Technology Council
NSA	National Snow Analysis
NASQAN	National Stream Quality Accounting Network
NSQAP	National Stream Quality Assessment Program
NSIP	National Streamflow Information Program
NWIS	National Water Information System
NWS	National Weather Service
NAWQA	National Water Quality Assessment Program
NWUIP	National Water Use Informaiton Program
NFDM	Nations' Freshwater Data and Models
NEXRAD	Next-Generation Raadar
OSTP	United States Office of Science and Technology Policy
RUSHCN	Regional US Historical Climate Network
RESSED	Reservoir Sedimentation Database
RLLN	River and Lake Level Network
SCAN	Soil Climate Analysis Network
SDWA	Safe Drinking Water Act
SRTM	Shuttle Radar Topographic Mission
SS-WSF	Snow Survey and Water Supply Forecasting
SNOTEL	Snowpack Telometry
SMAP	Soil Moisture Active Passive
STORET	Storage and Retrival Data Warehouse
SWAQ	Subcommittee on Water Availability and Quality
TMDLs	Total Maximum Daily Loads
TVA	Tennessee Valley Authority
UIC	Underground Injection Control
USACE	United States Army Corps of Engineers
USCRN	United States Climate Reference Network
USDA-ARS	United States Department of Agriculture-Agriculture Research Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USGCRP	United States Global Change Research Program
WSA	Wadeable Streams Assessment

Acronym	Definition
WaterML	Water Mark-up Language
WQS	Water Quality Criteria and Standards
WRCCW	Water Resources and Climate Change Workgroup
WHCEQ	White House Council on Environmental Quality

Appendices

Appendix A: SECURE Water Act: SEC. 9506. CLIMATE CHANGE AND WATER INTRAGOVERNMENTAL PANEL

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Observational data

Aerial imagery maintained by the Land Remote Sensing Program

Satellite imagery maintained by LRS

Appendix A: SECURE Water Act: SEC. 9506. CLIMATE CHANGE AND WATER INTRAGOVERNMENTAL PANEL

123 STAT. 1338 PUBLIC LAW 111–11—MAR. 30, 2009

SEC. 9506. CLIMATE CHANGE AND WATER INTRAGOVERNMENTAL PANEL.

(a) ESTABLISHMENT.—The Secretary and the Administrator shall establish and lead a climate change and water intragovernmental panel—

(1) to review the current scientific understanding of each impact of global climate change on the quantity and quality of freshwater resources of the United States; and

(2) to develop any strategy that the panel determines to be necessary to improve observational capabilities, expand data acquisition, or take other actions—

(A) to increase the reliability and accuracy of modeling and prediction systems to benefit water managers at the Federal, State, and local levels; and

(B) to increase the understanding of the impacts of climate change on aquatic ecosystems.

(b) MEMBERSHIP.—The panel shall be comprised of—

(1) the Secretary;

(2) the Director;

(3) the Administrator;

(4) the Secretary of Agriculture (acting through the Under Secretary for Natural Resources and Environment);

(5) the Commissioner;

(6) the Secretary of the Army, acting through the Chief of Engineers;

(7) the Administrator of the Environmental Protection Agency; and

(8) the Secretary of Energy.

(c) REVIEW ELEMENTS.—In conducting the review and developing the strategy under subsection (a), the panel shall consult with State water resource agencies, the Advisory Committee, drinking water utilities, water research organizations, and relevant water user, environmental, and other nongovernmental organizations—

(1) to assess the extent to which the conduct of measures of streamflow, groundwater levels, soil moisture, evapotranspiration rates, evaporation rates, snowpack levels, precipitation amounts, flood risk, and glacier mass is necessary to improve the understanding of the Federal Government and
the States with respect to each impact of global climate change on water resources;

(2) to identify data gaps in current water monitoring networks that must be addressed to improve the capability of the Federal Government and the States to measure, analyze, and predict changes to the quality and quantity of water resources, including flood risks, that are directly or indirectly affected by global climate change;

(3) to establish data management and communication protocols and standards to increase the quality and efficiency by which each Federal agency acquires and reports relevant data;

(4) to consider options for the establishment of a data portal to enhance access to water resource data—

(A) relating to each nationally significant freshwater watershed and aquifer located in the United States; and

(B) that is collected by each Federal agency and any other public or private entity for each nationally significant freshwater watershed and aquifer located in the United States;

(5) to facilitate the development of hydrologic and other models to integrate data that reflects groundwater and surface water interactions; and

(6) to apply the hydrologic and other models developed under paragraph (5) to water resource management problems identified by the panel, including the need to maintain or improve ecological resiliency at watershed and aquifer system scales.

(d) REPORT.—Not later than 2 years after the date of enactment of this Act, the Secretary shall submit to the appropriate committees of Congress a report that describes the review conducted, and the strategy developed, by the panel under subsection (a).

(e) DEMONSTRATION, RESEARCH, AND METHODOLOGY DEVELOPMENT PROJECTS.—

(1) AUTHORITY OF SECRETARY.—The Secretary, in consultation with the panel and the Advisory Committee, may provide grants to, or enter into any contract, cooperative agreement, interagency agreement, or other transaction with, an appropriate entity to carry out any demonstration, research, or methodology development project that the Secretary determines to be necessary to assist in the implementation of the strategy developed by the panel under subsection (a)(2).

(2) REQUIREMENTS.—

(A) MAXIMUM AMOUNT OF FEDERAL SHARE.—The Federal share of the cost of any demonstration, research, or methodology development project that is the subject of any grant, contract, cooperative agreement, interagency agreement, or other transaction entered into between the Secretary and an appropriate entity under paragraph (1) shall not exceed $1,000,000.

(B) REPORT.—An appropriate entity that receives funds from a grant, contract, cooperative agreement, interagency agreement, or other transaction entered into between the Secretary and the appropriate entity under paragraph (1) shall submit to the Secretary a report describing the results of the demonstration, research, or methodology development project conducted by the appropriate entity.

(f) AUTHORIZATION OF APPROPRIATIONS.—

(1) IN GENERAL.—There is authorized to be appropriated to carry out subsections (a) through (d) $2,000,000 for each of fiscal years 2009 through 2011, to remain available until expended.

(2) DEMONSTRATION, RESEARCH, AND METHODOLOGY DEVELOPMENT PROJECTS.—There is authorized to be appropriated to carry out subsection (e) $10,000,000 for the period of fiscal years 2009 through 2013, to remain available until expended.

Appendix B: Examples of existing networks that incorporate observational data relevant to climate change and water resources

- Streamgage network: approximately 7,500 streamgages (ref ACWI) where observations are made at specific time intervals that range from 15-minutes to 1-hour with data transmitted via satellite for dissemination to the public via the Internet
- Groundwater monitoring network
- Groundwater Climate Response Network
- Precipitation: Cooperative Observer Program (COOP), Automated Surface Observing System (ASOS), Snow Survey and Water Supply Forecasting (SS-WSF), and SNOTEL, US Climate Reference Network and the Regional US Historical Climate Network
- Water quality: National Water Information System (NWIS) includes surface water, groundwater, and water qualitydata spanning all 50 states, plus border and territorial sites, and include data from as early as 1899 to present.
- Land remote sensing: Remote sensing products are developed by NASA, NOAA, USGS, and other Federal, State, and private sector partners using satellites and aircraft monitor the Earth. The satellite imagery and aerial photographs are archived and used to compare current conditions with historical land features. Data can be interpreted over time and space to assess the impact of natural disasters, climate, and other global changes. A summary of the components of the USGS Land and Remote Sensing (LRS)(http://remotesensing.usgs.gov/) is provided in the appendix and can be accessed on-line.
- National Stream Quality Accounting Network (NASQAN): concentrations and loads of selected constituents delivered by major rivers to the coastal waters of the United States and selected inland sub-basins in priority river basins to determine the sources and relative yields of constituents within these basins. These priority basins have significant management interest in reducing delivery of constituents that contribute to adverse conditions in receiving waters. Other objectives include monitoring for climate change and describing long-term trends in the loads and concentrations of select constituents at key locations.
- Nationally notifiable disease surveillance system
- National Health and Nutrition Examination Survey (NHANES): Collection of data on the health and nutritional status of a nationally representative sample of about 5,000 persons each year.
- Benchmark glacier monitoring http://ak.water.usgs.gov/glaciology/

Appendix C: Examples of current databases that incorporate information relevant to climate change and water resources

Observational data

- The Natural Resources Inventory (NRI): database of the status, condition, and trends of land, soil, water, and related resources on the Nation's non-Federal lands, which is maintained by (Jeff Goebel) USDA-NRCS. The data are collected yearly and continually updated and used by natural resource managers; policymakers and analysts; consultants; the media; other Federal agencies; State governments; universities; environmental, commodity, and farm groups; and the public. Much of the farm-scale data are not publicly available.
- National Water Information System (NWIS) database: database containing streamflow, water-quality, ground-water levels and quality, algal composition, quality of bed material, and composition of animal tissue.
- National Ambient Water Quality Assessment Program (NAWQA): Database of physical, chemical, and biological data from specific sites across the US
- Storage and retrieval Data Warehouse (STORET): repository for water quality, biological, and physical data and is used by state environmental agencies, EPA and other federal agencies, universities, private citizens, and many others.
- Assessment Total Daily Maximum Load Tracking and Implementation System (ATTAINS): provides access to information on impaired waters.
- NOAA's National Weather Service interactive website: provides easy access to data on weather, rainfall, snow, flood-stage status, hydrographs, digital tools to generate flood inundation maps
- National Streamflow Information database (NSIP)
- National Climatic Data Center: Maintains a broad range of national and global climate data sets, as well as model archives.

Aerial imagery maintained by the Land Remote Sensing Program:

- National Aerial Photography Program (NAPP) - The National Aerial Photography Program (NAPP), is an interagency Federal effort coordinated by the USGS, which uses NAPP products to revise maps.
- National High Altitude Photography (NHAP) - The National High Altitude Photography (NHAP) program, which was operated from 1980-1989, was coordinated by the U.S. Geological Survey as an interagency project to eliminate duplicate photography in various Government programs.
- Digital Orthophoto Quadrangles (DOQQ) - Digital images of aerial photos which combine the image characteristics of the photo with the georeferenced qualities of a map
- Light Detection and Ranging (LIDAR) - **LIDAR** (Light Detection and Ranging) is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target.
- Aircraft scanners - Digital imagery acquired from several multispectral scanners on board NASA ER–2, NASA C–130B, and NASA Learjet aircrafts
- Historical, commercial, and Scientific Committee on Antarctic Research (SCOR) imagery

Satellite imagery maintained by Land Remote Sensing Program:

- Advanced Spaceborn Thermal Emission and Reflection Radiometer (ASTAR) - High-resolution multispectral data from the Terra satellite
- Advanced Very High Resolution Radiometer (AVHRR) - 1-km multispectral data from the NOAA satellite series
- Hyperion and Advanced Land Imager (ALI) - 10- to 30-meter multispectral and hyperspectral data from the Earth Observing-1 (EO-1) Extended Mission
- LANDSAT - Landsat satellites have been providing multispectral images of the Earth continuously since the early 1970's.
- Landsat ETM+ (Enhanced Thematic Mapper Plus) – High-resolution (15- to 60-meter) multispectral data from Landsat 7 (1999 to present)
- Landsat MSS (Multispectral Scanner) - 80-meter multispectral data from Landsats 1 to 5 (1972 to 1992).
- Landsat TM (Thematic Mapper) - 30- to 120-meter multispectral data from Landsat 4 and 5 (1982 to present).
- LDCM (Landsat Data Continuity Mission) - Multispectral data from the proposed Landsat Data Continuity Mission.
- MODIS (Moderate Resolution Imaging Spectroradiometer) - Moderate-resolution (250- to 1000-meter) multispectral data from the Terra Satellite (2000 to present) and Aqua Satellite (2002 to present).
- SRTM: Shuttle Radar Topographic Mission - SRTM data are used to generate a digital topographic map of the Earth's land surface with data points spaced every 1 arc second of latitude and longituded for the United States (approximately every 30 meters).
- SIR-C (Spaceborne Imaging Radar C-band) - Imaging radar data (C-band and L-band) from two Space Shuttle missions (1994).
- Declassified Satellite Images - Category 1 - Photographic imagery from the CORONA, ARGON and LANYARD satellites (1959 to 1972).
- Declassified Satellite Images - Category 2 - Photographic imagery from KH-7 Surveillance and KH-9 Mapping system (1963 to 1980).
- USGS Commercial Data Purchases (UCDP) Imagery - The UCDP Imagery Collection consists of imagery from several commercial vendors. The UCDP supports the Commercial Remote Sensing Space Policy (CRSSP) by providing data to qualified users, primarily U.S. Federal agencies, at no cost for File Transfer Protocol (FTP) downloads or at a nominal cost for media.