Integrated Water Resources Science and Services (IWRSS)

An Integrated and Adaptive Roadmap for Operational Implementation

Don Cline, NOAA (Compilation)

IWRSS Workshop Participants (NOAA, USACE, USGS)

Cross-cutting Theme Teams for Human Dimensions and Technical Information Services

Regional Case Study Contributors

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List of Acronyms

AAAS	American Association for the Advancement of Science
ACWI	Advisory Committee on Water Information
AD	Applications Development
API	Application Programming Interface
ARS	Agricultural Research Service
ASFPM	Association of State Floodplain Managers
AWRA	American Water Resources Association
AMS	American Meteorological Society
CFS	Climate Forecast System (NOAA)
CHL	Coastal and Hydrology Laboratory (USACE)
CHPS	Community Hydrologic Prediction System (NWS)
CHyMP	Community Hydrologic Modeling Platform (CUAHSI)
CIO	Chief Information Officer
CLM	NCAR Common Land Model
COOP	Continuity of Operations
COP	Common Operating Picture
COTS	Commercial Off-the-Shelf (e.g. Software)
CRREL	Cold Regions Research and Engineering Laboratory (USACE)
CSC	Coastal Services Center (NOAA NOS)
CUAHSI	Consortium of Universities for the Advancement of Hydrologic Science, Inc.
CWMS	Corps Water Management System (USACE)
DB	Data Base
DCDS	Data Coordination and Digital Services
DHS	Department of Homeland Security
eGIS	Enterprise Geographic Information Systems
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center (USACE)
ESA	European Space Agency
ESRL	Environmental Systems Research Laboratory (NOAA)
F&WS	U.S. Fish and Wildlife Service
FASST	Fast All-Season Soil Strength Model (USACE)
FEMA	Flood Emergency Management Agency
FEWS	Flood Early Warning System (Delft; The Netherlands)
GFS	Global Forecast System (NOAA)
GIS	Geographic Information System
GISRS	Geographic Information System and Remote Sensing (NOHRSC)
GLRC	Great Lakes Regional Collaboration
GOES-R	Geostationary Operational Environmental Satellite R-Series (NOAA)
GWI	Global Water Index (Standard and Poor's)
HEC-FIA	Hydrologic Engineering Center Flood Impact Analysis (USACE)
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System (USACE)
HEC-RAS	Hydrologic Engineering Center River Analysis System (USACE)
HEC-ResSim	Hydrologic Engineering Center Reservoir Simulation System (USACE)

HHS	Department of Health and Human Services
HL-RDHM	Hydrology Laboratory Research Distributed Hydrologic Model (NWS)
HMT	Hydrometeorological Testbed (NOAA)
IA	Integration and Analysis
IAM	Integrated and Adaptive Management
IAEM	International Association of Emergency Managers
IHABBS	Integrated Hydrologic Automated Basin Boundary System
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
IWRM	Integrated Water Resource Management
IWRSS	Integrated Water Resources Science and Services
KML	Keyhole Markup Language (e.g. Google Earth)
LIDAR	Light Detection and Ranging
LIS	Land Information System (NASA)
MODFLOW	MODular three-dimensional finite-difference ground-water FLOW model (USGS)
MODIS	Moderate Resolution Imaging Spectrometer (NASA)
NAM	North American Mesoscale Model
NARR	North American Regional Reanalysis (NWS)
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction (NWS)
NDFD	National Digital Forecast Database (NWS)
NED	National Elevation Dataset
NHD	National Hydrography Dataset (USGS)
NHD+	National Hydrography Dataset Plus (Horizon Systems)
NHWC	National Hydrologic Warning Council
NGA	National Geospatial-Intelligence Agency
NOAA	National Oceanic and Atmospheric Administration
Noah	Community Noah Land Surface Model (NOAA)
NOHRSC	National Operational Hydrologic Remote Sensing Center
NOS	National Ocean Service (NOAA)
NRC	National Research Council
NSA	National Snow Analyses
NTM	National Technical Means
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
OGC	Open Geospatial Consortium
OHD	Office of Hydrologic Development
OMB	Office of Management and Budget
PET	Potential Evapotranspiration
PMSI	Production Management and Systems Integration
QPF	Quantitative Precipitation Forecast
R&D	Research and Development
R2O	Research to Operations
RFC	River Forecast Center
RMSE	Root Mean Squared Error
RSS	Really Simple Syndication
RUC	Rapid Update Cycle model (NOAA)

RWRS	Regional Water Resources Services
S&T	Science and Technology
SAC-SMA	Sacramento Soil Moisture Accounting Model
SIS	Shared Infrastructure Services
SOA	Service Oriented Architecture
THREDDS	Thematic Real-time Environmental Distributed Data Services (Unidata)
TRL	Technical Readiness Levels
TVA	Tennessee Valley Authority
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VIC	Variable Infiltration Capacity Model (University of Washington)
XEFS	Experimental Ensemble Forecast System (NWS)
WATERS	Water and Engineering Research System network (NSF CUAHSI)
WFA	Water for America (USGS)
WRF	Weather Research and Forecasting Model
WRGS	Water Resources Geospatial Services
WRMS	Water Resources Management Services
WRSS	Water Resources Science Services
WSC	Water Science Centers (USGS)

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Acknowledgements

Three planning workshops were held in 2008 to develop the design elements for the IWRSS project that are discussed in this plan. About 40 participants from three agencies contributed their time and intellect to help create the IWRSS Consortium and design the project. They're listed in Appendix 1. Their contributions are greatly appreciated. Special thanks are due to the theme teams formed to develop details for the Human Dimensions and Technical Information Services themes, and regional interest groups that contributed cases for regional demonstration projects.

In another workshop focused on Cold Region Hydrology in 2007, participants from multiple agencies and major water information customers conceived the idea of enhancing collaborations and operational scope between the NOAA/NWS NOHRSC and River Forecast Centers, which quickly lead to the IWRSS concept. Their contributions are also greatly appreciated.

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Preface

As a Nation we face extraordinary water resources challenges. Complex water issues are found across the country, each involving a web of interrelated causes and effects, legal and economic ramifications, stakeholders, information providers, and information consumers. The scope of these issues and of the actors involved is enormous, as are the consequences of not addressing the issues. In every case, there are decisions that must be made, the decisions have consequences, and the consequences almost always affect somebody's pocketbook, business or way of life. The economic implications can be staggering. Recommended actions to restore water quality in Chesapeake Bay, for example, are expected to cost $1-2 billion per year[1]. There are hundreds of similar examples across the country.

Water resource managers and stakeholders come in all stripes – they may be responsible for municipal water supplies, or managing public lands, or providing energy, or developing policy, or ensuring healthy ecosystems. Their region of interest may be no larger than their local water conservation district, or it may an estuary and all the watersheds that feed it, or it may be the entire country. Their common denominator is they are all faced with a lot of questions that need answers. How much water will there be? How much is there now? Are these policy measures worthwhile? Will they work? What are the trade-offs? Who's impacted if measures are enacted, and who's impacted if they're not? Are there alternatives? Will any benefits be overwhelmed by the effects of climate change, the next flood, the next drought, the next hurricane, or even the next rainstorm? If crop yield is reduced for 5000 farmers because we enact policies to apply less fertilizer in order to reduce agricultural runoff, and some of these farmers go out of business as a result, is that OK? Could best practices in agricultural soil management prevent this? How do the fertilizer industry and their political lobby factor into this? If the alternative is losing an important downstream fishery and its related jobs, is that OK? How much maneuvering room is there within the existing legal and regulatory framework? When do I have to make a decision? When will critical thresholds be reached? Do I know enough to act? These are just a few of the questions facing water resources managers every day, in all sectors of water resources. The answers require information – preferably well-integrated, well-synthesized, consistent, comprehensive high-quality information.

How can we provide this? And when we do, how do we make sure decision makers will know about the information and how to use it effectively? As federal water information providers with missions in water science, observation, management and prediction, how do we rise to what many consider to be the greatest challenge of the 21st century, the challenge of putting it all together and making a quantum leap ahead to better support water resources decision making? And do it operationally, day after day? How do we make sure that these efforts make a real difference? That we're as useful as we can possibly be?

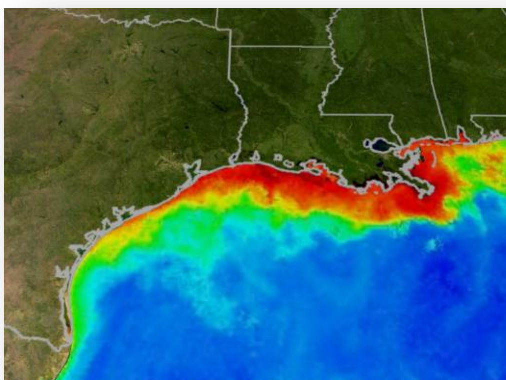
This report lays out a pathway to begin accomplishing this extraordinarily challenging task. Dubbed the IWRSS Project – Integrated Water Resources Science and Services – this plan identifies operational goals and the human dimensions, technical components, and science needed to leap ahead. Motivated to work together to make this leap, a consortium of federal water agencies developed the elements of the plan, taking a wide array of well-informed guidance into account in the process. The resulting project design involves making some key technical improvements to facilitate

[1] Source: Chesapeake Bay Foundation; www.cbf.org/site/PageServer?pagename=resources_facts_deadzone

the flow of information across organizational and geographic boundaries and establish a shared comprehensive view of the water resources landscape – a common operating picture. The design involves boosting collaboration efforts across these same boundaries and working to improve modeling and synthesis, and produce a new, comprehensive and consistent suite of high-resolution water resources analyses and prediction information. And it involves a full-court press to engage the water resource management community and other key stakeholders, to work closely with them on multiple fronts to make sure we're useful.

The IWRSS project is designed to demonstrate some basic capabilities nationally, and to demonstrate regionally a more intensive and comprehensive package – working towards an *integrative water resources information system* that knits together water resources information, products and services across geographic and organizational scales. To accomplish this, the project design necessarily reflects the broad scope of water resources issues, and includes many interrelated tasks and elements. The approach is fundamentally about synthesis and integration. To see why this approach is necessary, we can take a quick look at just three interrelated issues in one large watershed, the Mississippi River: the Dead Zone, Manure Management, and the Midwest Floods.

In the Gulf of Mexico, just beyond of the outlet of the river delta, there is a large zone where the water doesn't have enough oxygen to support life, a condition known as hypoxia. The size varies each year; it forms each summer and can extend out to 80 miles offshore. The cause is associated with high concentrations of fertilizer nutrients that runoff and erode from agricultural croplands throughout the vast watershed in spring and early summer. The nutrients stimulate algal growth in the Gulf, which eventually leads to deoxygenation of the lower reaches of the water column when the algae die. The result is the death of the ecosystem – fish, plant and microscopic species either leave or die. Contributing factors to increased amounts of nutrients delivered to the Gulf include landscape change in the drainage basin, especially losses of freshwater wetlands, and changes in the hydrologic regime of the Rivers and the timing of freshwater inputs that lead to stratification of the water column, which leads to hypoxia. This "Dead Zone" isn't a new phenomenon, nor is it limited to the Mississippi River. Dead zones associated with agricultural runoff occur in lakes and estuaries around the country and the world. In the case of the Gulf of Mexico, the potential economic impacts are huge. Recognizing this, a task force of five federal agencies (EPA, NOAA, USACE, USGS, and USDA) and ten states has worked to develop federally mandated action plans with measures to reduce nutrient loading within the huge Mississippi River and its tributary network, which includes 31 states and tribal lands and



drains 41% of the United States. Their strategy calls for a 45% reduction in both nitrogen and phosphorous loads in the river, requiring landowners and resource managers to adapt to new methods and practices to reduce nutrients in surface waters throughout the basin.[2]

A thousand miles north in Wisconsin, landowners and resource managers are working to do their part. The Wisconsin Department of Agriculture, Trade and Consumer Protection has recently instituted a Manure Management Advisory System (MMAS).[3] Farmers apply manure and other nutrients in the spring and early summer, which coincides with a higher risk of runoff due to snowmelt and spring rains. The State restricts application when and where runoff into surface waters is likely. Since runoff processes are very local in nature and involve individual hill slopes, the first steps towards reducing hypoxia in the Gulf of Mexico require very high-resolution information for decision-making in Wisconsin. The MMAS is a two-pronged decision support system that includes nutrient and manure application restriction mapping and a runoff risk assessment and advisory model. Each individual restriction map covers one square mile and shows restricted areas as small as 30 meters in size. The example at left shows a subset from one of these maps, about one-half mile on each side, and depicts watercourses, buffer zones, and restricted hill slopes. The risk assessment and advisory model is being developed to predict the risk of runoff for any particular day, which is expected to greatly assist farmers when making decisions about when to apply manure or other nutrients. This tool requires surface runoff event data, models, and weather forecasting necessary to build and maintain an assessment model that will identify when the likelihood for surface runoff may be greatest and therefore, when the spreading of nutrients on agricultural fields should be avoided. The risk assessment model and website will alert farmers to the likelihood of runoff events that might occur on a given day and on specific fields, based on weather, soil, and, ultimately, landscape conditions. It includes consideration of soil moisture content, rainfall, snow, and snow melt forecasts. Providing this information at sufficiently high resolution is a particularly

[2] Source: Gulf Hypoxia Action Plan 2008; www.epa.gov/msbasin/pdf/ghap2008_update082608.pdf
[3] Source: www.datcp.state.wi.us/arm/agriculture/land-water/conservation/manure-mngmt/index.jsp

challenging task, but that's what farmers need to make decisions. Currently there's a significant mismatch between the scales of available information to support this system.

These first two examples begin to help us see the range and scales of information needed to tackle complex water resources issues. Hypoxia reduction in the Gulf of Mexico and manure management in Wisconsin are related. Both are large-scale water resources enterprises with a lot of actors, policies, and consequences, operating at two ends of the same plumbing system. Both are aimed at solving a problem with significant economic implications for both the problem, if left unchecked, and the solutions.

But what happens when things get out of control? When task force policies and manure management restrictions are overwhelmed by natural events? In June 2008, many locations in Iowa, Indiana, Wisconsin, Illinois, Missouri, and South Dakota experienced record flooding. Heavier than normal winter snow amounts in late 2007 and early 2008, a generally wet spring, then heavy rain in late May and early June resulted in major damage to residences, agriculture, other businesses, public services, and transportation, with preliminary damage estimates in the range of $5-10 billion. Decision-making related to the production of river and flood forecasts was hampered by levee failures and overtopping, uncertainty about the location of levees and breaches, a lack of modeling tools for handling some of the extreme conditions, changes in land-use characteristics, effects of delayed crop progress due to the wet spring, man-made alterations to drainage in agricultural areas, and communication bottlenecks and awareness of activities across agencies. By late July 2008, the high runoff from extensive flooding in these agricultural areas lead to the second largest Gulf dead zone on record, nearly 8000 square miles and four times the task force's reduction goal. It was predicted to be the largest, but Hurricane Dolly may have churned the waters enough to add oxygen and reduce the hypoxic area.

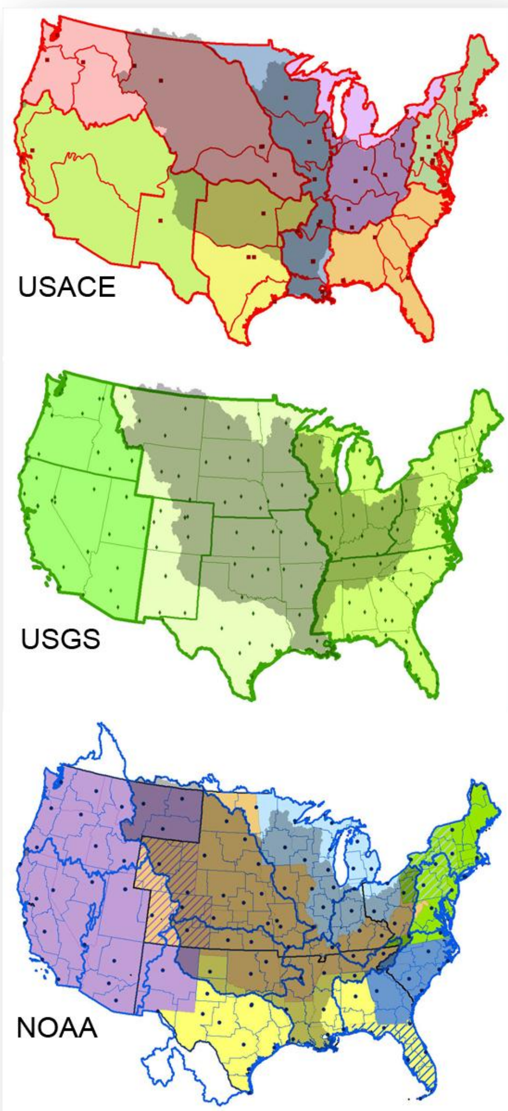
So, what does it take to predict the size of the dead zone? What does the end-to-end water resources prediction system have to look like for just this one issue? Very high-resolution information on agricultural practices, precipitation, snowpack and snowmelt, and runoff is just a start. High-resolution land-surface models are needed to link the local processes together and estimate runoff and inflow to river channels. Improvements in river and flood forecasting models, tools, data, information, and communication infrastructure are needed to predict the flow of the river and the risk of floods. When there are floods, we need additional models and tools to assess and model what exactly is inundated and how the water returns to the river. Then we need understanding and models of the interactions when freshwater arrives at the sea, of marine ecosystem dynamics, and as we've seen in 2008, the effects of passing hurricanes.

This is a tall order, but the good news is that many of the parts needed are close at hand – many of these capabilities and components are available, but they just aren't fully connected in an operational environment. No agency has all of the components necessary, but together we have much of what we need to get started. This is a key premise for the IWRSS project design: assemble and integrate what we already have or can obtain relatively easily to create a baseline working system that gets us started producing integrated information, then keep working to make it better. The project design recognizes that the system has to be flexible to support different kinds of water resources issues, it needs operational support at national, regional and local scales, and it needs stakeholder involvement.

The strategy, then, is to assemble a baseline capability to begin providing fundamental high-resolution information nationally, and in a few smaller demonstration regions work to provide more intensive and comprehensive information, emphasizing collaboration across both geographic scales and organizational scales, and moving towards a comprehensive end-to-end integrated system. As we learn how to make the system and the collaborations work well in the day-to-day operational workflow, we can begin exporting capabilities to other regions.

Some will argue that water resources issues are too important to take this approach, that every region of the country needed this capability yesterday, and demonstrating in a few smaller regions is too slow. This raises a good question – why not take on the Mississippi Basin, or the whole country, all at once? One of the key answers is that a lot of what IWRSS is all about is integration and synthesis. It's about developing effective workflow and collaboration across boundaries – moving information through the network of multiple agencies and partners, communicating and collaborating, and developing operational habits that expand a traditional focus on river and flood forecasting to include the full gamut of water resources prediction. It's a complicated undertaking. Trans-boundary communication and information flow, even in a small region, involves a lot of nodes on the network, a lot of moving parts. Just look at the Mississippi River example again, this time in terms how the basin is represented by NOAA, USACE and USGS.

The maps below show USACE Divisions, Districts, and office locations (top), USGS regions, sub regions, State Water Science Centers and field offices (center), and NOAA regions, NWS regions, River Forecast Center domains, and Weather Forecast Office domains (bottom). Administrative organization in USGS and NOAA mostly follows political boundaries of states, while organizational structure for operational water forecasting and management mostly follows watershed boundaries. On all three maps, the Mississippi Basin is highlighted in gray.



If IWRSS was launched for the entire Mississippi Basin, and we called a coordination meeting of all of the actors at all levels within the three agencies, and included the States as the principal stakeholders, we would have about 250 representatives from:

- 31 States
- 6 NOAA Regions
- 4 NWS Regions
- 5 NWS River Forecast Centers
- 65 NWS Weather Forecast Offices
- 5 USACE Divisions
- 20 USACE Districts
- 2 USGS Regions
- 6 USGS Sub-regions
- 92 USGS Water Science Centers and field offices.
- A handful of national centers, laboratories and headquarters offices.

The IWRSS design is pragmatic – integration and synthesis are difficult, and you have to learn to walk before you can run. Integration and synthesis also require resources – component parts don't just magically connect themselves. The IWRSS design involves very scalable elements and is definitely aimed at enabling large-scale coordination and interaction to address problems like Gulf hypoxia, but to get there it's important to first sort out the science, technical and human dimensions on a smaller scale. However, by providing a basic set of high-resolution water resources analyses and prediction products nationally, IWRSS does provide some services everywhere and creates national opportunities to start working towards a broader integrated water resources information system.

So what will IWRSS be like? What will it do, and how will it make a difference in addressing the water resources challenges of the 21st century?

From an internal, operational point of view, IWRSS will implement a number of technical capabilities to streamline information transfer across boundaries, make much more information more widely available, and provide a common operating picture for situational awareness. IWRSS is very geospatially oriented, so most of these benefits will be seen by the user through enterprise GIS and geospatial visualization. The capabilities that enable this also enable some other important benefits. IWRSS exploits the service-oriented architectures of NOAA and USACE river forecasting and management systems to make them interoperable. By introducing interoperability between systems, models, tools and utilities can be shared much more easily. Through IWRSS many of these capabilities will become available as plug-in applications, much like downloading a new app for a GIS or a cell phone.

At a fundamental technical level, IWRSS views agency offices across the country a lot like nodes in a communication network; information flows between nodes in configurable ways. This view has many beneficial implications for day-to-day operational workflow; it will be easier to share data and tasks, and easier to provide operational backup. Most of the nodes in the network are local and regional offices – NWS River Forecast Centers and Weather Forecast Offices, USACE District offices, USGS Water Science Centers. These comprise the front lines for IWRSS – the principal interface to local and regional stakeholders. The ability to move information across boundaries between these nodes also makes it much easier to provide a unified front to external stakeholders. Using contemporary tools like web services, stakeholders' decision support systems can be fed information from multiple nodes transparently. This means that customers can get the information they need from what appears to them to be one-stop-shopping, when in fact it may come from several sources across multiple agencies. That's consistently a high priority in customer surveys. To see why, mentally overlay the three maps on the previous page, pretend you're a customer at location XY, and ask where you need to go to get water resources information. Today, water resources information is often likened to the Tower of Babel – there are too many voices, and too much disparate information gets in the way of effective decision-making. IWRSS information services will provide the mechanisms needed to present a unified front.

Streamlining and improving information services is a big part of IWRSS. It supports another big part: producing new science products and services to support the needs of water resources stakeholders. The centerpiece of this will be new "summit-to-sea" high-resolution water resources information and forecasts. Using a suite of state-of-the-art land-surface modeling and data assimilation systems, IWRSS will produce national high-resolution gridded analyses and forecasts of key water budget variables, including snowpack, soil moisture, evapotranspiration, groundwater, runoff, and others. Products from this component will include the downscaled weather forcings used to run the models as well as the model outputs and forecasts, so that others wishing to run their own models will have easier access to the necessary forcing data, using contemporary data services for distribution. By developing and exploiting system interoperability and establishing strong collaborative workflow and communication, these systems can be operated in concert with river forecasting and management systems and site-specific, special purpose modeling at local or regional scales, and information from each can be integrated and fused. A high-resolution hill slope model used to calculate runoff potential in Wisconsin can inform a national high-resolution land-surface model, which in turn can support decision making for the Gulf of Mexico.

This component of IWRSS builds on the foundation of improved information services in a couple of very important ways. The modeling activity will involve routine collaboration and workflow between regional offices and a national support center, which are enabled by the enhanced communications capabilities. The national support center will provide a locus of shared services that includes water resources science expertise, technical information services, operational capabilities, and synthesis functions. It will run the land-surface models in a consistent fashion nationally, and regional centers will have flexible alternatives for interaction that range from simply accepting the national model output for use in their operations, to operating the same models in different configurations, such as at higher resolution to sharpen and improve the national information. In turn the national support center will be able to assimilate improved regional information back into the national product. The support center will provide a variety of shared services, where economies of scale or practical considerations would prevent locating these services at every regional office. The regional demonstration projects will be the mechanism for working out national and regional interactions and workflow.

In other words, this isn't business as usual. The vision for IWRSS is little like Google for water resources. It's interactive. It's national, or at least the interface looks like it is, even though production and distribution elements are distributed in several places. It produces useful and innovative tools and capabilities, it provides information or finds it for you, and it's there when you need it. Consequently in IWRSS, there is no concept of a national center as an isolated, monolithic data factory and exporter. Instead, the concept for a national support center transcends scales and traditional boundaries to become an extension of regional capability and a source of commonly shared services, including an epicenter of subject matter expertise at the disposal of both national and regional services, and at the same time provides national synthesis and a unified front. The national support center will work on behalf of the consortium of agencies, working in concert with the network of regional centers and local offices across agency boundaries, to provide high-resolution water resources information products and services nationwide through a distributed services-oriented architecture. System interoperability, enhanced data and information communications, and a common operating picture are keys that make this possible. These same capabilities also enable stakeholder access to IWRSS information through distributed web services.

To answer the last question – how will IWRSS make a difference in addressing the water resources challenges of the 21st century? – there is a third component focused on human dimensions. Creating the technical opportunities for information services is critical, and so is implementing the science and operations involved in summit-to-sea water resources information and forecasts. But the lynchpin to make these parts work, and to make the whole system useful, is to talk – a lot – with each other and with stakeholders. Stakeholders are just about everyone who has an interest in the enterprise. The national support center is a stakeholder of regional information, regional centers are stakeholders of national support services, water resource managers, decision makers, and professionals across all sectors and scales are stakeholders of IWRSS. In the broad gamut of water resources, we have to use the network of local, regional and national offices as a communications tool for engaging with stakeholders at a whole new level. One big part of this is working with stakeholders to understand their needs and ensure that we're addressing them. IWRSS will foster a rich participatory process with stakeholders, with frequent reassessment of evolving needs and evaluation of outcomes. But the human dimension of IWRSS goes beyond needs assessments and outcome metrics. IWRSS is ultimately about helping water resources managers manage better, become more adaptable, make better decisions, and reach their management objectives. Its about working with communities to help them understand risk, and to help them build resilience to water resources problems. To do this, IWRSS must also provide education and training, forums for sharing best practices, professional expertise, and other forms of professional outreach. IWRSS is focused outward, on being helpful and being useful. It requires science, technical and human dimensions.

Executive Summary

Water resources are widely considered to be one of the most significant challenges facing this nation in the 21st century. Managers and decision-makers in all sectors of water resources require new and more integrated information and services as they strive to adapt to uncertainty, change and increasing stresses on limited resources. The scope of water resources is polydisciplinary; as federal agencies with significant responsibilities and authorities in this area, the information needs of the broad scope of stakeholders must be considered and addressed in an integrative fashion.

This roadmap responds to the demand for additional operational water resources information and integrated services. Through a consortium of federal agencies with operational missions in water science, observation, prediction and management, the Integrated Water Resources Science and Services (IWRSS) project has been started to integrate service and service delivery, improve river forecasts, and provide new "summit-to-sea" high-resolution water resources information and forecasts. Collaboration and innovation are paramount. Together, the IWRSS Consortium seeks to be the most useful government organization for stakeholders of our nation's water resources and an unbiased, trusted broker of water resources information.

Objectives and Goals

With this vision, the overarching objective of the IWRSS project is to demonstrate a broad integrative *national water resources information system* to serve as a reliable and authoritative basis for adaptive water-related planning, preparedness and response activities from national to local levels. The project seeks to make intersections between relevant systems more seamless, synthesize information better across systems to improve services and service delivery and improve the overall quality of information, and provide new information and services to better support the needs of water resources stakeholders.

Operational Goal 1
Integrate Services and Service Delivery

Operational Goal 2
Increase Accuracy and Lead Time of River Forecasts

Operational Goal 3
Provide New "Summit-to-Sea" High-resolution Water Resources Information and Forecasts

Three operational goals (right) guide the IWRSS design. These goals reflect agency missions and goals, programmatic plans and objectives, and other drivers. The first goal has an inward component concerned with developing a Common Operating Picture (COP) by improving interoperability between systems, exchanging data and information seamlessly between systems and actors in the consortium, and making a significant leap-forward in the realm of geospatial information accessibility, visualization and interpretation. It also has an outward component that seeks a similar COP experience for IWRSS consumers by providing a transparent front for water resources information, i.e. "one-stop-shopping" for well-integrated water resources information.

The second goal is aimed at strengthening collaboration to improve several key themes important to river forecasting and management. These include flow forecasting and water management (including low flows in particular), flood forecasting, levee and dam failures, river ice, climate and drought mitigation, water supply, coastal environments, geo-intelligence, and research and development. Improved data access and modeling capability are common denominators for all of these themes. Here the project exploits the fundamental systems-level capabilities gained in Goal 1 within the workflow of specific forecast systems and modeling tools used by the agencies to perform their missions.

The third goal is at the core of the envisioned national water resources information system and is the grand synthesis challenge for the IWRSS project. This goal is concerned with putting together the development and implementation of high-resolution models, interoperable tools and collaborative workflow that together enable comprehensive description and prediction of the water resources environment at all locations, from the mountain summits to the sea, coasts and estuaries. This goal is to 1) provide stream-flow forecasts throughout the river and stream network from headwaters all the way to the coasts and estuaries, advancing the current capability in which forecasts are only available at selected locations and generally stop short of the coasts, and 2) provide consistent and seamless high-resolution GIS-ready geospatial data and information describing past, current and future soil moisture, snowpack, evapotranspiration, groundwater, runoff and flood inundation conditions, and the uncertainty associated with this information. This goal exploits the efficiencies and information access gained in Goal 1 and the enhanced forecast tools and workflow gained in Goal 2. Marshalling the intellectual resources of the consortium partners and implementing new subject-matter expertise within the consortium is essential to achieve the desired level of synthesis and integration.

Integrated Approach

The IWRSS project will demonstrate a new integrated interagency operations approach for the end-to-end water resources forecast process and service delivery. This type of water resources prediction is a new business area and IWRSS is a new model for the way we do business together. Part of this model is to strengthen and enhance the numerous intersections that exist between the three operational goals of IWRSS. The IWRSS project design focuses on three crosscutting collaboration themes focused directly on key intersections (right).

CC Theme 1: Human Dimensions
Stakeholder Interactions and Communications

CC Theme 2: Technical
Information Services

CC Theme 3. Operational Science
Summit-to-Sea Modeling and Prediction Framework

The first theme is concerned with establishing and maintaining a strong participatory process for IWRSS and building the social capital necessary for success. It involves all aspects of stakeholder interactions and communications at both national and regional levels, including internal and external communications strategies, outreach, and the development and implementation of social science strategies for stakeholder engagement.

The second theme is concerned with information services and involves all technical aspects of the national water resources information system, including system interoperability and data exchanges, eGIS and geo-Intelligence, integrated information delivery, the acquisition and management of observations and surveillance, and technological research and development. In particular it is concerned with the intersections between these focal areas, and emphasizes the implementation of sound information technology (IT) engineering practices to promote the coordination, integration and facilitation of interagency activities to pursue common goals in water resource management.

The third theme is concerned with the physical and social science aspects of developing a well-integrated national water resources information system that is responsive to the needs of stakeholders. It includes the physical science aspects necessary to advance operations in five focal areas: 1) develop and implement the summit-to-sea modeling and prediction framework, 2) provide the historical context and trend information necessary to understand the present and the future, 3) advance water flow and management capabilities, 4) improve the use of observations, and 5) quantify uncertainties and validate analyses and forecasts. A sixth focal area includes the social science aspects necessary to identify and understand specific information needs, relate these needs to the design and function of operational tools that provide the information, and to effectively communicate this information back to the stakeholder. This theme recognizes that there is a large resource of mature science capability available; it focuses more on science implementation and integration than on science development. Thus IWRSS is not a research instrument; it is principally an instrument for operational implementation that aggressively mines and assembles existing capability.

Strategies

The IWRSS project takes a program approach to delivering capability and outcomes. Its aim is to improve the delivery of capability by aggregating related projects and associated lines of development and manage their delivery coherently and jointly. In this way interdependencies, risks and opportunities can be managed more effectively to focus on achieving outcomes with good value. This approach embraces the strengths of all actors at all scales in each agency, and seeks to draw the best solutions from the mix. This greatly increases flexibility, which is essential for IWRSS because water resources stakeholders are themselves working to become more flexible and adaptable, and IWRSS must be positioned to adapt with them.

Therefore the project design uses adaptive strategies for operational development and implementation. A spiral development model provides the high-level strategic framework for the project, and agile development methods form the low-level tactical approach. The comprehensive vision and design for integration and collaboration positions IWRSS to take advantage of opportunities, both large and small.

The cross-cutting human dimensions theme and the spiral development model are designed to engage stakeholders early and often to improve understanding of needs, planning and operations, and to update this knowledge regularly. In this way IWRSS can better anticipate emerging needs, target high-value and high-impact opportunities, manage resources to sustain high-value functions and guide investments in new capabilities. By participating more closely with stakeholders, it’s likely that it will be easier to recognize important opportunities.

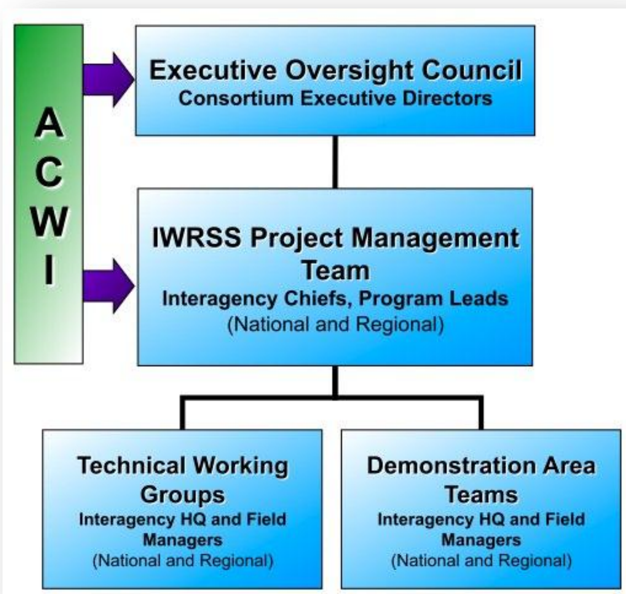
The program approach is manifest throughout the IWRSS design; integration, interoperability, trans-boundary data synchronization and workflow are all aspects of this approach. Research and development is another important aspect of this approach. By considering the wide array of water-related research and development activities across multiple agencies as a virtual, integrated program, R&D assets can be managed more effectively with limited resources. In particular, by adopting a common framework for characterizing the readiness of science and technical capabilities, IWRSS can more readily identify capability sources and focus resources on advancing needed capability to operational levels.

National, Regional and Local Framework

The IWRSS project design is regionally focused. Regional demonstration projects will be the venue for implementing and operationally proving many IWRSS capabilities. To enable broad, trans-boundary integration and synthesis, an innovative national IWRSS operational support center is planned. This facility will provide a number of centralized shared services and place staff in regions to support demonstrations. It will operationally and interactively produce national high-resolution water budget analyses and forecasts to provide a contextual backdrop for regional products and services. Together, with regional and local facilities providing focused services and a national facility providing integrative "glue", the national integrated water resources information system is designed to provide information, products and services that transcend geographic and organizational boundaries. With interoperable systems and data services, national coverage and sharper regional coverage, some aspects of the IWRSS design consider the combined offices of the three agencies as nodes on a mesh-like communications network, and exploit this abstraction to broaden intersections and improve the flow and integration of information across boundaries.

Governance

The governance structure planned for IWRSS consists of an Executive Oversight Council, a Project Management Team, Technical Working Groups, and teams for each selected regional demonstration area. The Executive Oversight Committee will provide high-level agency oversight and programmatic authority for the IWRSS Project. Its members will consist of senior executive service leadership representing water resources programmatic interests from each agency, who will meet twice annually to discuss IWRSS agenda. The Council will engage the Federal Advisory Committee for Water Information (ACWI) as a source of guidance and direction for the IWRSS project.



The Project Management Team will be responsible for overall strategic planning, integration and operations of the Project. Consisting of national and regional chiefs and program leads from each agency, this team will be the primary planning and decision-making body for IWRSS operations, services, science and technology. Technical Working Groups consisting of national and regional managers will be formed to focus on specific topical areas identified for the human, technical and science themes of IWRSS.

Business Concept

The project's outcomes are expected to include:

1. **Integrated Water Resources Services.** IWRSS will result in improved internal and external communication and better, more productive engagement with stakeholders. Delivery of water resources data, services and products will be more integrated to provide stakeholders with an experience that appears to be one-stop shopping. Communication of risk and uncertainties will be improved, both in terms of quantitative measures and through the efforts of enhanced training and outreach.
2. **System Interoperability, Collaborative Tools and Workflow.** Major systems in use across multiple agencies will be made interoperable, meaning data and information will be able to flow between them more seamlessly and models, tools and other applications will be cross functional across systems. Models used nationally will be made available regionally, and new models will be made accessible. Toolkits will be provided to improve access and analysis of information and improve collaborative workflow.
3. **Common Operating Picture.** Several elements of the IWRSS project will work in combination to provide a common operating picture across multiple agencies, enabling river forecasters in one agency using their system to see the same information as river managers in another agency using a different system, and external stakeholders to see much of the same information through common web services. The Common Operating Picture will be dominantly geospatial, meaning enterprise GIS and geo-Intelligence will be ubiquitous within agency systems.
4. **Integrated, Sustainable Consistent Water Resources Modeling and Forecasts.** The centerpiece of IWRSS for IWRSS stakeholders will be a new national suite of integrated high-resolution water resources analyses and forecasts. Analyses will include historical water budget studies going back as long as records permit, current conditions for immediate situational awareness, and forecasts of future water budget conditions. This suite will include basic short-term ensemble water budget forecasts at 1 km^2 resolution for the U.S., advanced modeling in selected regional demonstration areas with mechanisms to transition best practices to other regions, and advanced regional river and flood forecasting and water management models, including linkages between terrestrial and coastal/estuarine environments, surface water and groundwater, and water quality.

The project has been designed to ensure that IWRSS is sustainable and well aligned with water resources business areas of the Consortium agencies. The legal authority for these agencies to engage in the scope of activities planned for IWRSS is well documented. The IWRSS project design has drawn from an extensive array of agency planning instruments to identify and align with broadly held goals and objectives. The Consortium is open, and it is expected that other agencies will join in this activity as it begins and evolves.

The stakeholders for the IWRSS project are consumers of water resources information who can benefit from the new and improved information and integrated service delivery that IWRSS will provide. They require data and information to develop knowledge necessary to make decisions and take actions. IWRSS stakeholders include decision makers who manipulate water, water and environmental resource managers and planners, emergency managers and responders, public-sector information consumers with a wide variety of commercial and private interests, and "internal" stakeholders involved in the enterprise collection, analysis, prediction and delivery of water information and services.

Budget and Implementation

The IWRSS project design builds on existing capabilities by focusing on elements that support and foster integration, and develops new capabilities through implementation and regional demonstration. The design strategy is deliberately flexible and adaptable to allow the project to be opportunistically driven and executed. For planning purposes, multiple budget options ranging from $100M to $500M per year are being prepared to develop the scope of elements and capabilities to be addressed by the project, including: 1) interoperability and data synchronization capabilities, 2) eGIS and geo-intelligence capabilities, 3) national high-resolution water budget modeling and prediction, 4) the national IWRSS operational support center, and 5) regional demonstration projects. The resulting design provides a comprehensive programmatic approach to delivering a national integrated water resources information system.

There are five fundamental steps necessary to demonstrate a baseline summit-to-sea modeling and prediction framework. The first is to start bringing the right people together. Workshops and a series of technical working groups are planned to work on details of major design components, and early stakeholder engagement is a key element. The second step is to assemble key science components and make necessary connections. Third is to begin early production to provide experience and examples. Fourth is to begin developing the workflow between actors. The fifth step is to engage more stakeholders in the process to begin refining product and service, following the spiral development strategy.

Structure of the Report

The first three chapters introduce the project, describe the vision, objective and goals, and discuss the approach for the project design and implementation. The next three chapters describe each of the three crosscutting themes in detail; here are found the specific elements and capabilities that IWRSS will focus on. The next two chapters describe the plans for the national IWRSS operational support center and the regional demonstration projects. The concept of operations is summarized from a system or user point of view in Chapter 9, and the business concept is discussed in Chapter 10.

Chapter 1 Introduction

One of the most critical and potentially contentious issues facing society and governments at all levels in the 21st century is the provision of fresh water resources for people and ecosystems [*AMS, 200X*]. In this century, the U.S. will be challenged to provide sufficient quantities of high-quality water to its growing population [*NRC, 200X*]. Increased demand and limited supplies will make water resources a major economic driver [*Nature, 200X*], already evident by the emergence of the global water market. The urgency, magnitude and complexity of water resources issues demand a broad view. Communities need to understand the risks and develop resilience to variations in water supplies. Today's water and ecosystem management requires agility to adapt to uncertainty and change. The knowledge needed for agility, actions and decision-making at all levels requires comprehensive, well-integrated water resources information.

This plan responds to the demand for additional operational water resources information and integrated services. Through a consortium of federal agencies with operational missions in water science, observation, prediction and management, the Integrated Water Resources Science and Services (IWRSS) project has been started to integrate service and service delivery, improve river forecasts, and provide new "summit-to-sea" high-resolution water resources information and forecasts. Collaboration and innovation are paramount. Together, the IWRSS Consortium seeks to be the most useful government organization for stakeholders of our nation's water resources and an unbiased, trusted broker of water resources information.

This chapter describes the scope of water resources issues that IWRSS must consider, describes drivers and key challenges, and introduces the IWRSS project. Chapter 2 describes the IWRSS vision, its major goals and its three crosscutting themes. Chapter 3 provides an overview of the organizational, management and implementation concepts that shape the design of the IWRSS project. The next three chapters describe each of the crosscutting themes in greater detail. Chapter 7 describes the function and role of a national IWRSS support center, and Chapter 8 discusses regional demonstration projects. Chapter 9 summarizes the overall concept of operations from a system user perspective, and Chapter 10 discusses the business concept from a system management perspective, including a summary of implementation tasks. Supporting material is included in Appendices.

1.1 The Scope of Water Resources

Definitions of water resources share certain fundamental concepts involving sustainability of humans and ecosystems. The American Meteorological Society defines water resources as "water in all states, in storage or within flux within the hydrologic cycle, which is necessary for a sustainable quality of life, as well as for sustaining the natural environment" [*AMS, 2009*]. The American Association for the Advancement of Science specifies three key concepts: 1) *availability* (the location, spatial distribution, or natural fluctuations of water); 2) *accessibility* (given availability, whether people can access it or afford water in adequate quantities); and 3) *quality* (whether accessed water is free of contaminants and safe for consumption) [*AAAS, 2009*]. Sustainability of ecosystems involves a broad set of factors, including habitat, vegetation health, biodiversity, biogeochemistry and water quality, and many more. Sustaining and enhancing the environment involves concepts of water use, management, equity and risk. Together, all of these make water resources a highly complex, polydisciplinary fabric involving scientific, technical, economic, policy, legal and political enterprises. To be truly relevant, IWRSS must recognize this scope and work to ensure that a broad range of needs is addressed.

Increased stress on water resources, driven by climate change and increased variability, increased demand and other factors, has consequences across the entire fabric. Managers and decision makers in all sectors and at all scales from local to global are concerned with finding new ways to cope with these changes, adapt to greater uncertainties, and manage risks. Timely, reliable, authoritative, *well-integrated,* and *well-communicated* information about past trends, current conditions, and future states is of paramount importance; providing this operationally is the purpose of IWRSS. To help understand the scope of information needed from IWRSS, the following three sections look briefly at change and transition in water resources.

1.1.1 Climate Change

One of the greatest factors driving the urgency of water resources issues is climate change. The Intergovernmental Panel on Climate Change (IPCC) has determined with high confidence that the overall impact of climate change on freshwater systems and their management will be negative (*IPCC, 2007*). The leading reasons for this are observed and projected increases in temperature, sea level and precipitation variability.

Seasonal shifts in stream flow and reductions in low flows will be among the impacts for basins fed by snow or glacier melt, including much of the northeastern U.S., most of the western U.S., and all of Alaska (Figure 1.1). Risks of flooding and drought will increase in response to increased precipitation intensity and variability. Semi-arid and arid areas of the western U.S. are particularly vulnerable because water stresses are already high and rapid increases in population in this region have resulted in increased demand for water. The extent of salinization of groundwater and estuaries will increase with sea level rise and low flows, with a corresponding decrease in freshwater availability for humans and ecosystems in coastal areas.

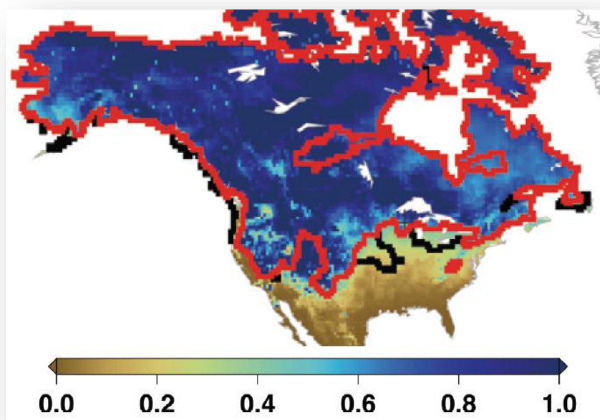


Figure 1.1. Climate change is expected to have significant changes on water resources throughout all areas where stream flow is dominated by snowmelt, indicated here by the red lines. The black lines indicated additional areas where water availability is predominantly influenced by snowmelt generated upstream. The color scale indicates the ratio of accumulated annual snowfall divided by annual runoff. [*From Barnett et al., 2005*].

In turn these effects will worsen water pollution associated with sediments, nutrients, pathogens, pesticides, salt, and thermal pollution, with resulting impacts on ecosystems, human health, water system reliability and operating costs. Together these climate change impacts exacerbate other stresses on water infrastructure and management practices, including aging infrastructure, increased demand, land-use change and urbanization, and changing economic conditions. Changes in river discharge resulting from climate change are expected to have important impacts on water availability for in-stream uses (hydropower, fisheries, navigation, and recreation) and out-of-stream uses (irrigation, domestic, municipal, and industrial withdrawals). Already, locations where water was once plentiful are now experiencing competing demands on finite fresh water quantities for human health, ecosystem integrity, agriculture, aquaculture, hydropower generation, river commerce, recreation, tourism, and the economic vitality of communities and the nation.

Consequences of Climate Change on Water Resources

"Of all sectoral water demands, the irrigation sector will be affected most strongly by climate change."

"Of all ecosystems, freshwater ecosystems will have the highest proportion of species threatened with extinction due to climate change."

"In cold or snow-dominated river basins, atmospheric temperature increases do not only affect freshwater ecosystems by the warming of water but also by causing water flow alterations. Where river discharges decrease seasonally, negative impacts on both freshwater ecosystems and coastal marine ecosystems can be expected."

"Changed freshwater inflows into the ocean will lead to changes in turbidity, salinity, stratification, and nutrient availability, all of which affect estuarine and coastal ecosystems."

IPCC, 2007

1.1.2 Blue Gold, The New Oil: The Water Economy

Water and economics have always been closely linked. Fresh water is required, reliably and often in very large quantities, to support a vast array of economic activities spanning industry, agriculture, thermo- and hydro-electric power production, fisheries, recreation, urban development and growth. The costs of extracting, storing, and delivering fresh water are substantial. Economies associated with buying and selling water rights (including the legal enterprise surrounding it) are also substantial. Thus economic risks go hand-in-hand with water resources. The national economy is inextricably linked to at least seven water-related risks (Table 1.1). Within one risk sector alone, the U.S. annual flood losses amount to $5.2 billion, and average over 80 deaths per year (NOAA, 2008). This spectrum of risks is one guide for the scope of information needed from IWRSS, as well as to who the stakeholders are.

The landscape has changed markedly in the last few years, however. Increased stresses on water resources and have created new economic opportunities, leading many to call water "blue gold" or the "new oil". Increased stress on water resources creates demand to build new water infrastructure, coinciding with the challenge of renewing decaying water infrastructure. Annual global water infrastructure investments are $500B [*Ashley and Cashman, 2006*], and significant growth is expected in the future. This has spawned rapid investment and growth in water-related businesses (Figure 1.2) involved in utilities, manufacturing and technology development for both domestic and global markets. In economic sectors, there is widespread anticipation that water investments in the 21st century could rival the same opportunities oil offered in the 20th century.

Table 1.1. *Seven water-related risks and a selection of corresponding economic objectives.*

Risks	Economic Objectives
Water Resource Shortages	• Optimization of water allocations for growing communities. • Support productive agriculture • Expand industry and river commerce
Reduction of Water for the Environment	• Manage fish and wildlife habitats, ecosystems
Contamination and Pollution of Water Bodies	• Maintain quality of rivers, lakes, groundwater, wetlands, marshes and estuaries to reduce mitigation costs and support growth and recreation
Flooding Loss	• Minimize impacts including loss of life and property and build community resilience
Drought Loss	• Minimize economic impacts and build resilience
Wetland Loss	• Manage wildlife habitats, ecosystems
Coastal Ecosystem Deterioration	• Support productive aquaculture

Figure 1.2. The rapid growth of Standard and Poor's Global Water Index (GWI) since it's inception in late 2001 illustrates the alignment of industry towards water issues. The 50 constituents of the GWI represent a diversified portfolio of the global water market in two distinct clusters of water related businesses: Water Utilities and Infrastructure and Water Equipment and Materials [Source: *Standard and Poor's, 2009*].

It is important to recognize and anticipate the importance that water resources information provided by IWRSS will have on the future economy, and the expectations this will create. The design of the IWRSS project considers this, and aims at a robust operational framework to provide timely, reliable, authoritative, well-integrated, and well-communicated information about past trends, current conditions, and future states of water resources.

1.1.3 Transitioning to Integrative and Adaptive Water Management

Adaptation to fluctuations in water availability has always been at the core of water management, but increased uncertainties about the impacts of climate changes and other increasing stresses are driving a transition towards more integrated, flexible and adaptable water resources management. Stationarity is the foundational concept underpinning most water resources management systems, including those found in the United States. Stationarity assumes that the mean conditions are unchanging and that natural systems fluctuate within a fixed envelope around that mean. Climate change undermines this basic assumption that historically has facilitated management of water supplies, demands and risks [*Milly et al., 2008*]. The validity of statistical relationships, regulatory rules based on historical conditions, and even of relying on personal experience is no longer intact. It has become increasingly clear that knowledge of the past is not a good guide for understanding the future.

> "Traditionally, hydrological design rules have been based on the assumption of stationary hydrology, tantamount to the principle that the past is the key to the future. This assumption is no longer valid."
>
> *IPCC, 2007*

Adaptive strategies include capturing society's views, reshaping planning processes, coordinating land and water resources management, recognizing water quantity and quality linkages, conjunctive use of surface water and groundwater, protecting and restoring natural systems, and including consideration of climate change. [*IPCC, 2007*]. Limits on adaptation to change in water quantity and quality include [*Arnell and Delaney*, *2006*]:

1. Physical Limits: It may not be possible to prevent adverse effects through technical or institutional procedures.
2. Cost: While it may be physically feasible to adapt, there may be economic constraints to what is affordable.
3. There may be social or political limits to the implementation of adaptation measures (e.g. construction of new dams).
4. Capacity of water management agencies and the water management system as a whole may act as a limit on which adaptation measures (if any) can be implemented. The low priority given to water management, lack of coordination between agencies, tensions between national, regional and local scales, ineffective water governance and uncertainty over future climate change impacts constrain the ability of organizations to adapt to changes in water supply and flood risk.

These limits may exist for local, regional or national reasons, and they influence the type, quality and accuracy of predictive water resources information needed to effectively manage water resources and ecosystems. For IWRSS to be effective, it must engage the spectrum of water and environmental management stakeholders and strive to understand their constraints and needs. In addition to good communication, because water and environmental management is seeking greater *integration* and *adaptability*, IWRSS must be on this same path and share principles of integrated and adaptive management.

1.2 The IWRSS Consortium

The IWRSS Consortium has been established to provide a framework for operational collaboration and innovation. The initial actors in the consortium are the National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers (USACE), and the U.S. Geological Survey (USGS). Together these agencies have missions focused on water science, observation, management and prediction. They share mutual strategic objectives including improving risk management and resilience, developing a comprehensive systems approach and

The fleur-de-lis (iris) is associated with water and traditionally symbolizes unity.

common operating picture for the water resources enterprise, standardizing business practices, improving technical competencies, and broadening coalitions and collaboration. These actors already collaborate every day in the course of routine operations, coordination and planning. The IWRSS project seeks to strengthen collaborations and broaden them to provide the intellectual resources, tools, data and information necessary to meet 21st century water resources challenges. The vision of the IWRSS Consortium is to be the most useful government organization for stakeholders of our nation's water resources and an unbiased, trusted broker of water resources information. Thus IWRSS is an *open coalition*. The IWRSS project is expected to engage the broad community of water interests and collaborate to achieve maximum benefit to a wide stakeholder base. It is intended to capture the strengths of each actor's capabilities, to identify the gaps, and ensure interagency coordination to fill those gaps. The Bureau of Reclamation, U.S. Department of Agriculture, the Environmental Protection Agency and other water resources stakeholders are expected to play important roles in IWRSS.

1.3 IWRSS Stakeholders

The stakeholders for the IWRSS project are consumers of water resources information who can benefit from the new and improved information and integrated service delivery that IWRSS will provide. They require data and information to develop knowledge necessary to make decisions and take actions. Each of the seven risks identified in Table 1.1 has corollary objectives that are associated with various decision-making stakeholder communities. IWRSS stakeholders include decision makers who manipulate water, water and environmental resource managers and planners, emergency managers and responders, public-sector information consumers with a variety of commercial and private interests, and "internal" stakeholders involved in the enterprise collection, analysis, prediction and delivery of water information and services.

Each of these groups includes a wide array of agencies, departments, organizations and individuals. For example, decisions as to how, where and when water is manipulated in the United States are chiefly the result of the working and interaction of twelve major networks of decision makers. These are [*White, 1973*]:

1. farmers and suburbanites who develop their own domestic supplies;
2. ranchers and Bureau of Land Management offices who improve stock water on grazing lands;
3. farmers, irrigation districts, Bureau of Reclamation offices, and legislators;
4. farmers and drainage districts who drain agricultural lands;
5. freight carriers, TVA, and USACE offices and legislators who improve waterway transport;
6. municipalities and franchised companies providing municipal water;
7. municipalities disposing of urban waste;
8. private companies supplying their own water and disposing of their own waste;
9. municipalities, levee districts, TVA, and USACE offices and legislators controlling flood flows;
10. private and public hydroelectric power producers;
11. municipal, state and federal operators of water-based recreation;
12. farmers, Forest Service and Soil Conservation Service [*sic*] offices carrying out watershed management.

Each of these networks involves individuals or offices having primary responsibility for making decisions about water management or projects that manipulate the flow of water. Each is affected by supporting activities of other people or agencies. Thus to be fully engaged with just the water manipulation stakeholder community, IWRSS must reach out to farmers and ranchers, irrigation districts, drainage districts, levee districts, municipalities, legislators, and a half a dozen federal agencies.

Similarly, water and environmental resource managers and planners consist of a wide array of local, state, regional and national entities with responsibilities for the development, management, conservation or protection of natural resources. A few examples include soil and water conservation districts, watershed protection districts, departments of natural resources and environmental conservation, fish and wildlife services, and forestry management services. Emergency managers and responders also include a wide array of entities at multiple scales, with interests ranging from local response to floods, to situational awareness for national security. Internal IWRSS stakeholders are typically both consumers and producers of information. They include actors at all geographic and organizational scales across the IWRSS Consortium, including NWS River Forecast Centers, USACE District offices, USGS State Water Science Centers, and national centers and laboratories.

These few examples reiterate the important point that water resources affects a broad spectrum of interests who clearly have a stake in new and improved water resources information and service delivery. The IWRSS project recognizes this, and its design facilitates early consideration and engagement of the spectrum of stakeholders to identify needs and ensure that information products and services have wide benefit.

1.4 Overview: IWRSS Project Design

The overarching objective of the IWRSS project is to demonstrate a broad integrative *national water resources information system* to serve as a reliable and authoritative basis for adaptive water-related planning, preparedness and response activities from national to local levels. The project seeks to make intersections between relevant systems more seamless, synthesize information better across systems to improve services and service delivery and improve the overall quality of information, and provide new information and services to better support the needs of water resources stakeholders.

The following sections provide a brief overview of the IWRSS project design. Details are found in subsequent chapters.

1.4.1 Design Process

The IWRSS project was conceived in 2007 during a NWS workshop on improving information exchange, technical capabilities and service delivery for cold regions hydrology. The workshop included participants from other agencies and customers. Part of the discussion was focused on improving the integration of nationally produced snow information, products and services (NWS National Snow Analyses) into river forecast and management operations. The National Snow Analyses (NSA) are a comprehensive set of high-resolution gridded data sets describing current snowpack conditions across the nation; they can be considered as an operational pilot project for the IWRSS goal of producing new high-resolution national gridded water resources information. While successful in their own right, they had not been well integrated with operational river forecasting systems, so a number of ad hoc approaches had emerged to use the information. Customers emphasized the need for continuing to produce nationally consistent information, but pointed out that it did not stop with snow information. Well-integrated data and information products describing the gamut of water resources were necessary. The group was encouraged to move in this direction and find ways of smoothing out intersections between nationally produced information and regional river forecasting. This was the impetus for the IWRSS project. It was immediately clear that no single agency could accomplish this alone – a consortium was needed.

The project was then designed through a series of workshops and meetings with participants from NOAA, USACE and USGS to develop a shared vision (Appendix 1). Operational goals were identified with crosscutting implementation themes to address the goals. Teams met to refine each of the crosscutting themes. The participants in these activities included management and staff of field offices and national centers, regional and national program managers, laboratory directors and technical directors. Most of these participants are both actors and stakeholders in IWRSS, and have both producing and consuming roles. The design has been informed by the broad experience of all of the participants, as well as by external customer groups to whom these elements have been presented. The design draws extensively from agency strategic plans and recommendations, including the NWS Integrated Water Science Plan, NOAA Strategic Plan, and the USACE Campaign Goals. The design is a blueprint; collaborative demonstration and implementation of the design elements are intended to be opportunistically driven and executed.

1.4.2 Project Design

The Consortium union of water science, observation, prediction and management missions uniquely assembles key capabilities necessary to achieve IWRSS objectives and goals. Each agency brings intellectual resources, modeling tools, data, integrative systems and research and development capabilities to the table. USGS brings historical water-budget analyses, water-use statistics, surface water and ground water observations, ground water modeling capabilities, geographic data sets and high-resolution Earth imagery. USACE brings water management, hydrologic and hydraulic models and data, surface water observations, and substantial eGIS expertise. NOAA brings weather and climate forecasts, river forecasting models, and a proven operational framework for national high-resolution water resources modeling and prediction. This collaborative union is necessary to meet 21st century water resources challenges.

To meet the overarching goal of demonstrating an integrative national water resources information system (actually a system-of-systems), the project has three major operational goals: 1) Integrate services and service delivery, 2) Increase accuracy and lead time of river forecasts, and 3) Provide new "summit-to-sea" high resolution water resources information and forecasts. These are interconnected by three crosscutting implementation themes: 1) Human Dimensions: Stakeholder Interactions and Communications, 2) Technical: Information Services, and 3) Operational Science: Summit-to-Sea Modeling and Prediction Framework. Tasks for implementation are structured around these three crosscutting themes.

The conceptual framework for the IWRSS project is forged from the original objective of better integrating the National Snow Analyses with regional forecast operations within the NWS. It transforms the NWS National Operational Hydrologic Remote Sensing Center (source of the National Snow Analyses) into an IWRSS support center, potentially with Consortium participation, to produce core national gridded water resources information in concert with regional offices, and provide centralized functions in support of regional operations and interactions. The support center is structured for enhancing regional interactions, including the placement of some of its staff in regional offices to facilitate communications and focus on regionally relevant support. Existing regional and local offices (NWS River Forecast Centers and Weather Forecast Offices, USACE District offices and USGS Water Science Centers and field offices) continue their current river observation, science, forecasting, management and service roles and gain national science, technical and operational support and collaboration for the new business area of integrated water resources analysis and prediction.

In one perspective of the conceptual framework, the combined multi-agency array of national, regional and local offices can be considered as nodes in a communications network, through which the project can gather information about stakeholder needs, exchange information, provide backup functionality and necessary redundancy, and deliver integrated services. The goals and themes of the project involve developing integrated water resources communications and stakeholder engagement capabilities using this existing network, developing technical interoperability and data synchronization capabilities between different systems that are in use on the network, using the interoperable network and systems to provide enterprise Geographic Information Systems (eGIS), geo-Intelligence, and a Common Operating Picture, and exploiting the service-oriented architecture of the framework systems to facilitate the implementation of advanced modeling capabilities and production of new gridded water resources information.

Developing and using this framework, implementing new capabilities, and incorporating all into operational workflows at national, regional and local levels and across organizational boundaries is managed through regional demonstration projects. *Core regional capabilities* for river forecasting and management exist through the NWS Community Hydrologic Prediction System (CHPS) and the USACE Corps Water Management System (CWMS). *Core national capabilities* for high-resolution modeling exist through the NOHRSC's operational systems used for the NSA pilot. Expanding on the NSA pilot, the IWRSS support center will produce a first-order suite of new, consistent national gridded water resources analyses and forecast products using a small set of common models. It will also work with the Consortium to develop first-order technical capabilities needed to enable system interoperability and data synchronization within and between the national and regional systems. Higher-order capabilities (outcomes) can then be built on these core first-order capabilities, and will be developed and demonstrated in selected large regional watersheds. Higher-order outcomes to be demonstrated regionally include:

1. Integrated Water Resources Services
    a. Substantial stakeholder engagement, enhanced internal communications
    b. Integrated Data/Service/Product Delivery – Single National Portal
    c. Training and Outreach, Improved Risk Information and Communication
2. System Interoperability, Collaborative Tools and Workflow
    a. CHPS/CWMS/National Interoperability
    b. Data Synchronization
    c. Incorporation of common models used nationally into regional application
    d. Toolkits for access/analysis and collaborative operational workflow
3. Common Operating Picture
    a. Geo-intelligence, Enterprise GIS for Water Resources and Hydrologic Prediction

4. Integrated, Sustainable Consistent Water Resources Modeling and Forecasts
    a. Implementation of National Integrated Gridded Water Resources Forecast System
        i. Basic short-term ensemble water budget forecasts at 1 km^2 resolution for U.S.
        ii. Advanced modeling for demonstration areas – transition best to national
        iii. Advanced regional river and flood forecasting models, including linkage to coastal/estuary and groundwater.

Each high-order outcome encompasses an array of specific elements. For example, the first outcome includes the participatory process with stakeholders to identify and understand needs, and includes the implementation of a transparent front for water resources information. The second outcome includes implementing interoperable system communications elements in CHPS, CWMS and the national support center's operations system (GIS/RS), and it also includes conducting long-term reanalyses of national modeling information to assess biases and provide guidance necessary to use this information in river forecast models and forecast workflow. The Common Operating Picture involves technical tasks associated with data synchronization as well as development of geospatial datasets and visualization capabilities. Outcome four includes sharing pre-staged dam break models across organizations as well as operating national high-resolution land-surface models. As major elements of these outcomes are matured at the demonstration watersheds, they will become available for implementation elsewhere.

1.4.3 Research and Development

Each of the Consortium agencies possesses strong capabilities in water-related research and development (R&D) in both science and technology, housed in several laboratories, science centers, and research groups. The project provides a mechanism and framework to coordinate these efforts and guide future R&D investments. The IWRSS project management activity will include a twice-yearly Consortium R&D meeting to review relevant on-going and planned research activities. External groups with activities closely related to IWRSS, such as the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) would be invited to participate. To facilitate coordination across multiple agencies, a common framework for identifying science and technology readiness levels will be considered for IWRSS, following the broad practice of the technical acquisitions community.

The project is designed to provide an implementation framework that can facilitate moving research to operations (R2O). There are two main aspects to this. First, the class of models used for high-resolution gridded analyses and forecasts is more readily able to use new types of observations or information than regional river forecast models that depend on long-term calibration, and the focus of IWRSS is on the broader water resources realm – not just on river flow. Because these models will be used at the national level and in the regional demonstrations in a robust, interoperable environment, there will be significantly more opportunities and available approaches to introduce new capabilities into the water resources prediction framework. Second, as part of the interoperability and data synchronization framework, the IWRSS support center and regional demonstrations are intended to have sufficient capacity to provide central data backup and continuity of operations functions. This benefits R&D by providing convenient access to operational data for development and simulation testing.

Moreover, it provides a test bed with both a central location and specific watersheds for multi-scale testing and implementation of new data, tools and techniques.

Similarly, each of the Consortium agencies is involved with development and operation of water data collection and observing systems. The integrative nature of IWRSS will be useful for identifying gaps in water resources data collection and will help guide future investments in observing systems.

1.5 Programmatic Framework

The IWRSS project design has drawn from an extensive array of planning instruments to identify and align with broadly held goals and objectives. During the past year, several events have clarified the programmatic framework even further.

In August of 2008, the senior administrators and under-secretaries of five agencies[4] signed a memorandum authorizing expanded inter-agency collaboration in work to adapt water program management to reflect changing climatic conditions, charging senior officials to cooperate in work including: sharing of information, consideration of research priorities, and cooperative implementation of projects (Appendix 2).

NOAA's leadership has identified water resources as one of its highest priorities through recent strategic plans and annual guidance memoranda. This was recently validated by an October 2008 decision by the NOAA Executive Council to transform NOAA's Hydrology Program into an Integrated Water Forecasting Program, with goals to accelerate delivery of products and services demanded by customers, align agency-wide capabilities to address user needs in a unified and consistent fashion, implement a National Integrated Water Resources Gridded Forecast System by 2013, and improve NOAA forecasts of water resources, floods and ecosystem health.

USACE leadership also identified water resources as one of four priorities in October 2008, with a goal to deliver enduring and essential water resources solutions through collaboration with partners and stakeholders. Two specific objectives within this goal are to: 1) deliver integrated, sustainable water resources solutions, including implementation of integrated watershed practices, and 2) implement collaborative approaches to effectively solve water resources problems, in a framework involving more collaborative regional planning and greater interaction with stakeholders.

The USGS strategic science plan for 2007-2017 emphasizes priorities of new, comprehensive focus on terrestrial, freshwater, and coastal/marine ecosystems, influence of climate change on the water cycle, and conducting a water census of the United States.

Lower level strategic plans were widely consulted, and the participants in the IWRSS planning process have first-hand familiarity with field-level operational needs as well as planning roles within their agencies. Thus the IWRSS design is well informed and adheres closely to programmatic objectives.

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[4] National Oceanic and Atmospheric Administration (NOAA), U.S. Environmental Protection Agency (EPA), U.S. Army Civil Works (i.e. USACE), U.S. Dept. of Agriculture, and U.S. Department of Interior.

1.6 Expected Outcomes and Value Propositions

From a stakeholder's perspective, the three operational goals and crosscutting themes described above do not mean much. These are organizational constructs that help frame and manage the project. The outcomes that are important to stakeholders are more tangible. They will make a difference to day-to-day operations, applications, decision-making and actions. The three goals are addressed by three crosscutting implementation themes, each with a set of tasks. The tasks in turn lead to four tangible outcomes (below). Thus the project design has traceability between the operational goals, the implementation tasks, and the outcomes important to stakeholders. As stakeholder engagement increases, the outcomes, tasks and goals will be refined, always with traceability in mind. The following are the initial value propositions for the IWRSS project.

Outcomes

1. Integrated Water Resources Services
2. System Interoperability, Collaborative Tools and Workflow
3. Common Operating Picture
4. Integrated, Sustainable Consistent Water Resources Modeling and Forecasts

1.6.1 Integrated Water Resources Services

Customer satisfaction with federal water resources information and services will increase as a result of concerted efforts to engage stakeholders, better understand their challenges and needs, and incorporate this understanding throughout IWRSS operations.

Customer satisfaction will also increase as a result of integrated data, service and product delivery. IWRSS will strive towards the appearance of a single national portal for water resources information using consortium collaboration, effective web services and high-accessibility delivery mechanisms, and industry standards and protocols, especially for geospatial data. For information consumers, including commercial customers who add value to water resources information, satisfaction will increase because information acquisition effort/costs will decrease. Obtaining and using comprehensive water resources information will be simpler.

IWRSS will help meet corporate goals to improve risk information and communication and build community resilience through provision of comprehensive water resources information and a focus on outreach and stakeholder participation.

1.6.2 System Interoperability, Collaborative Tools and Workflow

Internal operating efficiency will increase, and risk will decrease, as a result of improved interoperability and reduction in effort, tools and applications necessary to exchange data and information. IWRSS-enabled interoperability will enhance continuity of operations by facilitating and providing mechanisms for backup, beneficial redundancies and failover.

IWRSS interoperability efforts and a focus on developing collaborative operational workflow will result in faster implementation of new tools across the enterprise, with an associated reduction in implementation costs.

Internal stakeholder satisfaction will increase as a result of improved operational communication, coordination and collaboration.

1.6.3 Common Operating Picture

Capacity to protect life and property during flood events and other hazards will be improved by increasing forecaster's access to relevant information through eGIS, sharing critical geo-intelligence across geographic and organizational boundaries, and providing state-of-the-art geospatial processing and analysis toolkits for operational systems.

Employee satisfaction and the ability to attract new members to the workforce will increase with the implementation of a Common Operating Picture and state-of-the-art geospatial processing and analysis tools. IWRSS will increase corporate competitiveness for the Nation's young geospatial and water resources talent.

Satisfaction of Congress and Corporate leadership will increase because a Common Operating Picture enables rapid, authoritative situational awareness of the state of the Nation's water resources with easy ability to drill-down to local scales and details.

1.6.4 Integrated, Sustainable Consistent Water Resources Modeling/Forecasts

Customer satisfaction will increase with the delivery of a new suite of high-resolution digital water resources information that is nationally consistent and provides both the big-picture and local details.

Customer satisfaction will increase with the assurance that a well-designed and supported framework is in place to produce integrative water resources information reliably and authoritatively, and that risks of this information not being available when needed are reduced.

New science and technology will be implemented faster, with reduced cost, as a result of implementing a centralized national hub with interoperable capabilities that are well-connected with regional capabilities, providing both national and regional testing capabilities, and avoiding monolithic architectures that limit flexibility.

1.7 Summary

The following two chapters introduce the project, describe the vision, objective and goals, and discuss the approach for the project design and implementation. The next three chapters describe each of the three crosscutting themes in detail; here are found the specific elements and capabilities that IWRSS will focus on. The next two chapters describe the plans for the national IWRSS operational support center and the regional demonstration projects. The CONOPS is summarized from a system or user point of view in Chapter 9, and the business concept is discussed in Chapter 10.

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Chapter 2 The IWRSS Vision, Goals and Themes

The IWRSS project is intended to demonstrate a foundation – a benchmark – for a broad integrative national water resources information system, to serve as a reliable and authoritative basis for adaptive water-related planning, preparedness and response activities from national to local levels. Three broad goals within the project are to integrate service and service delivery, increase accuracy and lead-time of river forecasts, and provide new "summit-to-sea" high-resolution water resources information and forecasts. This requires intra- and interagency collaboration to couple weather and climate forecasts, link terrestrial models (land-surface, hydrologic, groundwater, and hydraulic) and link these with marine/estuary models, and improve the flow of data and information within and across organizational boundaries. It requires stakeholder participation, which has a large role to build social capital for the system and to ensure effective response to the growing needs of customers and stakeholders. This chapter describes the vision for IWRSS, its three operational goals, and three crosscutting themes for collaborative implementation.

2.1 The IWRSS Vision and Goals

The vision of IWRSS is to be the most useful government organization for stakeholders of our nation's water resources and an unbiased, trusted broker of water resources information. Throughout the polydisciplinary fabric of water resources, stakeholders require knowledge to fulfill their responsibilities to make decisions and take actions. This is the driver for the IWRSS project. The purpose of IWRSS is to usefully and effectively support the knowledge base with data and information needed to assess confidence and risk, consider alternatives, and make actionable decisions. Thus the IWRSS vision involves an iterative participatory process of a) actively engaging stakeholders across levels and sectors to understand what information is needed and how it is needed, b) providing it reliably, consistently and authoritatively, and c) working with stakeholders to help them use the information effectively and identify needed improvements. This spiral development model incrementally builds capability towards a 100% design and ensures that IWRSS remains well connected to stakeholder needs throughout its evolution. Because the stakeholder's world is complex, changing and full of uncertainty, to be most useful IWRSS must be integrative, adaptive and help reduce uncertainty. Realizing this vision requires operational innovation and collaboration spanning the missions of water science, observation, prediction and management.

With this vision, the overarching objective of the IWRSS project is to demonstrate a broad integrative ***national water resources information system*** to serve as a reliable and authoritative basis for adaptive water-related planning, preparedness and response activities from national to local levels. Since this necessarily involves an array of consortium and constituent systems used for various aspects of water resources and environmental science, observation, prediction and management, the objective is actually to demonstrate an integrative system-of-systems. The project seeks to make intersections between relevant systems more seamless, synthesize information better across systems to improve services and service delivery and improve the overall quality of information, and provide new information and services to better support the needs of water resources stakeholders.

Operational Goal 1
Integrate Services and Service Delivery

Operational Goal 2
Increase Accuracy and Lead Time of River Forecasts

Operational Goal 3
Provide New "Summit-to-Sea" High-resolution Water Resources Information and Forecasts

More specifically, three operational goals of the IWRSS project (left) represent key areas where significant advances are necessary to achieve project objectives and outcomes.

2.1.1 Operational Goal 1: Integrate services and service delivery

This goal has both an inward (consortium operations) and outward (constituent applications) component.

The inward component is concerned with developing a Common Operating Picture (COP) by improving interoperability between systems, exchanging data and information seamlessly between systems and actors in the consortium, and making a significant leap-forward in the realm of geospatial information accessibility, visualization and interpretation. By ensuring that all of the actors in the water resources enterprise can access consistent, reliable and timely operational information within their normal workflow, a COP provides critically needed situational awareness, helps prevent a fragmented knowledge base and thus reduces uncertainty. One specific activity within this goal is to develop reliable interoperability and data synchronization mechanisms between two major systems used for operational water management (Corps Water Management System, CWMS) and for river and flood prediction (the National Weather Service's Community Hydrologic Prediction System, CHPS) to help achieve a COP, provide back-up and continuity of operations capabilities, and support a national water resources information system. This is a principally a systems-level activity, involving mainly technical, policy and security aspects necessary to make systems communicate with each other. Another specific activity within this goal is to implement enterprise Geographic Information System (eGIS) capabilities within the water resources analysis and prediction operations framework (particularly for NOAA, who is farthest behind in this area) by exploiting the interoperability and data synchronization capabilities of the COP and leveraging the significant eGIS capabilities and experience of USACE. These activities combine to enable a sophisticated geo-Intelligence framework for water resources that supports operational situational awareness (especially important during crises such as flood events), improves operating efficiency (thus reduces overhead costs) and can be spun off as a service to other water resources stakeholders.

The outward component seeks a similar COP experience for IWRSS consumers by providing a transparent front for water resources information. Currently, water resources information and services are provided through an overwhelming and inconsistent array of web sites and applications. The same actions to develop interoperability and geo-Intelligence capabilities for the internal COP are applicable to help develop a unified experience for IWRSS information consumers. Together with contemporary web services these capabilities enable the outward appearance of "one-stop-shopping" while not requiring all information to be warehoused in one place.

2.1.2 Operational Goal 2: Increase accuracy and lead-time of river forecasts

This goal is aimed at strengthening collaboration to improve several key themes important to river forecasting. These include flow forecasting and water management (including low flows in particular), flood forecasting, levee and dam failures, river ice, climate and drought mitigation, water supply, coastal environments, geo-intelligence, and research and development. Improved data access and modeling capability are common denominators for all of these themes. One focus of this goal is on exploitation of the fundamental systems-level capabilities gained in Goal 1 within the workflow of specific forecast systems and modeling tools, particularly CHPS, CWMS, the USACE Hydrologic Engineering Center River Analysis System (HEC-RAS), and the NWS National Operational Hydrologic Remote Sensing Center's (NOHRSC) operations system, GISRS. Goal 1 enables improved access to data, and Goal 2 implements this access within key forecasting tools and applications.

By stepping-up collaboration, this goal is also focused on filling information gaps, where one actor has information or tools needed by another. Many examples are available. For one example, the NOHRSC has numerous modular software functions and applications for the manipulation of the large gridded numerical modeling and remote sensing data sets it handles daily. Many of these operational grade tools may have utility in CHPS or CWMS to support geo-Intelligence and distributed modeling, and can be incorporated as needed through the service-oriented architecture. Another ready example is river-ice modeling, where USACE has the modeling skills needed by NWS River Forecast Centers. The enhanced collaborative framework of IWRSS facilitates exporting this capability to the NWS. Each crosscutting theme includes examples of such gaps, and through this goal the IWRSS project will work to identify and appropriately fill them.

2.1.3 Operational Goal 3: Provide new "summit-to-sea" high-resolution water resources information and forecasts

This goal is at the core of the envisioned national water resources information system and in terms of overall synthesis, is the grand challenge for the IWRSS project. This goal is concerned with putting together the development and implementation of high-resolution models, interoperable tools and collaborative workflow that together enable comprehensive description and prediction of the water resources environment at all locations, from the mountain summits to the seacoasts and estuaries. The two-fold goal is to:

1. provide stream-flow forecasts throughout the river and stream network from headwaters all the way to the coasts and estuaries, advancing the current capability where forecasts are only available at selected locations and generally stop short of the coasts, and
2. provide consistent and seamless high-resolution GIS-ready geospatial data and information describing past, current and future soil moisture, snowpack,

evapotranspiration, groundwater, runoff and flood inundation conditions, and the uncertainty associated with this information.

Achieving this goal requires linking of land-surface, hydrologic, groundwater, and hydraulic models with marine and estuary models, and coupling of weather and climate forecasts to drive the models. It requires acquisition and assimilation of all available observations across the spectrum of water resources variables to improve and validate the models. It requires incorporation of historical water budget analyses and coordination of these with high-resolution model reanalyses needed to connect new physically based model information with conceptual calibrated models used for river forecasting. It requires the efficiencies and information access gained by developing interoperability in Goal 1, and the enhanced forecast tools and workflow gained in Goal 2. Marshalling the intellectual resources of the consortium partners and implementing new subject-matter expertise within the consortium is essential.

2.2 Cross-cutting Collaboration Themes

The IWRSS project will demonstrate a new integrated interagency operations approach for the end-to-end water resources forecast process and service delivery. This type of water resources prediction is a new business area and IWRSS is a new model for the way we do business. Part of this model is to strengthen and enhance the numerous intersections that exist between the three operational goals of IWRSS. One example of important intersections: system interoperability and data exchange mechanisms are intrinsically linked to principles of enterprise GIS, and both intersect the needs of a national water resources forecast system and the ways that stakeholders will interact with the system. Ensuring effective connectivity between different elements is a major purpose of IWRSS. To achieve the overall objective, three crosscutting collaboration themes are focused directly on key intersections (right).

> CC Theme 1: Human Dimensions
> Stakeholder Interactions and Communications
>
> CC Theme 2: Technical
> Information Services
>
> CC Theme 3. Operational Science
> Summit-to-Sea Modeling and Prediction Framework

2.2.1 Cross-cutting Theme 1: Human Dimensions

This theme is concerned with establishing and maintaining the participatory process for IWRSS and building the social capital necessary for success. It involves all aspects of stakeholder interactions and communications at both national and regional levels. It includes development and implementation of effective internal and external communications strategies to articulate IWRSS benefits and services, translate between various lexicons used by different agencies and stakeholder groups, report progress, accomplishments and plans, and present information in briefings, conferences and meetings. It includes the development of outreach aids including internal and external IWRSS web site content and information materials.

A major element of this theme is the development and implementation of social science strategies for stakeholder engagement that apply a suite of appropriate social science methods including needs assessments, audience profiles, focus groups and surveys. This includes the development of evaluation metrics to track progress and customer satisfaction throughout the project. Accomplishing the goals of this theme requires leveraging the service and outreach knowledge and capabilities that exist within the consortium (examples from within NOAA include NOAA Coastal Services Center social science tools, best practices from NOAA regionalization, and the network of NWS regional Service Coordination Hydrologists and local Service Hydrologists) and fostering expertise in human dimensions aspects of social sciences.

2.2.2 Cross-cutting Theme 2: Technical Information Services

This theme is concerned with information services and involves all technical aspects of the national water resources information system, including system interoperability and data exchanges, eGIS and geo-Intelligence, integrated information delivery, the acquisition and management of observations and surveillance, and technological research and development. In particular it is concerned with the intersections between these focal areas, and emphasizes the implementation of sound information technology (IT) engineering practices to promote the coordination, integration and facilitation of interagency activities to pursue common goals in water resource management.

Interoperability and data exchange services involve development and implementation of mechanisms whereby the enterprise solutions (consisting of systems, models, data, products and services) of individual water resource agencies can communicate, coordinate and collaborate in a seamless, transparent and timely manner at key points of intersection, as well as mechanisms to enable highly efficient, transparent and automated data exchanges and sharing across agency boundaries. Enterprise GIS services involve implementation and management of a common, comprehensive set of key baseline GIS data layers that are shared by all IWRSS consortium actors. Geo-Intelligence services involve development, implementation and maintenance of high performance tools and procedures that visualize, interpret, model consequences of, create derived products for, generate reports for, and invoke actions or changes in behavior based on forecasted water resources events in a geospatial and temporal context. Integrated delivery services involve the existing and anticipated hardware, software, telecommunications systems, and protocols that facilitate the automated delivery of IWRSS products and services to external stakeholders (the internal stakeholder needs are met by the system interoperability and database synchronization focal area). The observations and surveillance focal area involves the acquisition and management of observational data and metadata, data usage coordination, and data distribution mechanisms. The goal of this focal area is to optimize the value of new and existing observation networks.

Overall, this crosscutting theme aims to ensure effective workflow among the various actors of the enterprise, identify and accommodate policy and cultural differences among the actors, and incorporate best practices in information technology. To meet this goal, the theme engages in integral, ongoing, and crosscutting research and development activities directed towards advancing understanding of and leveraging emerging science (including social science) and technologies.

2.2.3 Cross-cutting Theme 3: Operational Science

This theme is concerned with the physical and social science aspects of developing a well-integrated national water resources information system that is responsive to the needs of stakeholders. It includes the physical science aspects necessary to advance operations in five focal areas: 1) develop and implement the summit-to-sea modeling and prediction framework, 2) provide the historical context and trend information necessary to understand the present and the future, 3) advance water flow and management capabilities, 4) improve the use of observations, and 5) quantify uncertainties and validate analyses and forecasts. A sixth focal area includes the social science aspects necessary to identify and understand specific information needs, relate these needs to the design and function of operational tools that provide the information, and to effectively communicate this information back to the stakeholder.

The physical science aspects of this theme are fundamentally concerned with estimation of past, current and future states of the water budget at high spatial and temporal resolution. This requires appropriate models and techniques, which are available but need varying degrees of work to implement and connect. More importantly, a wide range of subject matter expertise is required to implement and operate these models, appropriately use surface and remotely sensed observations to assess and correct these models, and to produce meaningful information products and services from them. The scope of water resources and therefore IWRSS demands expertise in:

- hydrology and hydraulics (surface hydrology, snow and glacier hydrology, geomorphology, hydraulics, soils, and groundwater dynamics);
- vegetation and agriculture (forest hydrology, agricultural practices, and water-vegetation interactions);
- weather and climate (boundary-layer meteorology, numerical weather and climate modeling, and climatology);
- ecological-hydrological interactions (terrestrial ecosystems, aquatic ecosystems, water quality and biogeochemistry, watershed sustainability, wetlands and marshlands hydroecology, and limnology);
- hydrologic remote sensing (snow cover and water equivalent, soil moisture, evapotranspiration, land surface characteristics and phenology, image processing, optical and microwave electromagnetics);
- applied mathematics, numerical computation and statistics (numerical solvers, algorithm development, optimization, stochastic and nonlinear processes, spatial statistics, topology); and
- geospatial information (geographic information systems, geospatial analysis, cartography, projections and datums, spatial data accuracy).

One of the main purposes of this theme is to gather these intellectual resources to inform the development and implementation of IWRSS and to make them accessible to day-to-day operations.

The social science aspects of this theme are concerned with the expertise necessary to interact and effectively communicate with stakeholders, comprehend their needs, and help design appropriate physical science tools to create needed information. Understanding a stakeholder's needs can require an understanding of the legal, regulatory and economic framework they're operating in, the drivers that motivate them to require information in the first place, and the social and political constraints that shape their need for information. It would generally be a mistake to rely on hard-core physical scientists – we know who we are – to make these determinations. Different skill sets are required to correctly interpret and translate needs.

The operational science theme is focused more on science implementation and integration than on science development, recognizing that there is a large resource of mature science capability readily available. Where science development is needed, either for filling critical gaps or for enabling implementation, this theme is concerned with identifying and drawing from capabilities within and outside of the Consortium, in guiding and coordinating investments in science development. Thus IWRSS is not a research instrument; it is an instrument for operational implementation that aggressively mines and assembles existing capability. This capability comes from Consortium laboratories and science centers that already exist, internal and external test beds, and from academic sources. The design of IWRSS aims to exploit service-oriented architectures and be a fast track for science implementation, using either national IWRSS support capabilities or regional demonstrations as a vehicle. To facilitate this, this theme involves developing a common framework for identifying science and technology readiness levels across organizational boundaries, following the broad practice of the technical acquisitions community.

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Key Points for this Chapter

- The IWRSS project must be flexible to meet stakeholder's needs. The project will follow principles of integrative and adaptive management.
- The project must be opportunistic to succeed in a resource-limited environment. A two-tiered implementation strategy for evolutionary acquisition of capabilities and agile implementation is proposed.
- IWRSS will work to exploit the existing network of national, regional and local offices for gathering, producing and delivering information and stakeholder participation.
- A joint national IWRSS support center will be established to provide central functions and work with regional offices to build and demonstrate capability. An existing NWS national center will be transformed for this purpose.
- Regional demonstration watersheds will be the principal venue for IWRSS implementation.

Chapter 3 IWRSS Design and Implementation

This chapter provides an overview of the organizational, management and implementation concepts that shape the design of the IWRSS project. It explains the basic driver for IWRSS to be integrative and adaptive, as the broad water resources management community strives to respond to change and uncertainty. Given this driver, the multi-agency nature of IWRSS, and the realities of budgets and resources, fundamental strategies for focused but agile IWRSS implementation are described. Key elements of the IWRSS project design are summarized here in terms of major tasks to be implemented. In the three crosscutting thematic chapters that follow, these tasks are covered in more detail, including initial steps necessary to begin development, demonstration and implementation. Then the national, regional and local framework for the project and the main actors and roles are briefly introduced. These aspects of the operations concept are covered in more detail in Chapter Seven. This chapter concludes with a brief consideration of other potential intersections that may need to be considered in the future evolution of IWRSS but are not considered further in this report.

3.1 Integrative and Adaptive Management in Water Resources and for IWRSS

In a water resources management paradigm facing significant change and transition, it is important for IWRSS to itself be well integrated and adaptive. Monolithic, isolated, or rigid solutions are the wrong approach in these circumstances. To operate effectively and provide the greatest benefit to users of water resources information, IWRSS takes its cue from the best practices of integrated and adaptive management (IAM) regimes. Of utmost importance to this approach is social learning through extensive communication, iteration and feedback.

IAM regimes recognize the systems to be managed are complex and adaptive, and build on these strengths to perform well in uncertain environments. Governance is polycentric and horizontal, with broad stakeholder participation. This has been shown to be more effective than centralized systems in allocation of scarce resources in dynamic and uncertain environments. It relies strongly on participatory processes and active stakeholder involvement to build commitment and social capital needed for social learning and to include a wide range of perspectives. Adaptive and multi-level governance regimes integrate bureaucratic hierarchies, markets and network governance. Elements of IAM include [*Pahl-Wostl, 2008*]:

- IAM regimes employ cross-sectoral analysis to identify emergent problems and integrate policy implementation. Implementation of integrative solutions requires cross-sectoral analysis to identify emergent problems and integrate adaptive responses to new insights. *For IWRSS this means developing habits of looking broadly at both needs and (sources of) solutions.*
- Increased uncertainty in water supply, an increase in extreme events, and reduction of natural buffering capacity (e.g. fresh water stored as naturally as snow; limited man-made reservoir capacity) require that adaptation strategies be developed at the transboundary level, addressing issues across multiple scales of analysis and management. Neither top-down nor bottom-up approaches are sufficient – both are necessary. Transboundary cooperation is a key requirement for integrated and adaptive water management. *For IWRSS this means strengthening intersections between geographic and organizational scales, focusing on those human, technical or science elements that are highly integrative or have broad implications and use.*
- Also key is comprehensive understanding achieved by open, shared information sources that fill gaps and facilitate integration. Access to information must be open. Uncertainties must be clearly communicated. A comprehensive understanding of water problems and their solutions is only achieved by open, shared information sources. *This is directly applicable to IWRSS and is embodied in concepts of technical information services.*
- Infrastructure needs to be scaled appropriately with increased use of decentralized technologies and diverse sources of design adapted to the regional context and application. Large-scale infrastructure with long life span provides few opportunities for learning and may easily lead to lock-in situations. Collaborative platforms play a key role in cross-scale linkages – both in terms of geographic and organizational scales – and improve horizontal and vertical interplay. This doesn't imply that such platforms should be entirely formalized in terms of membership, procedural rules, roles and the distribution of decision-making power. Formalization may destroy the characteristics and benefits of open platforms. *For IWRSS this means seeking system interoperability, encouraging more connected and integrative networks, encouraging the use of versatile and scalable high-performance micro-computing systems, avoiding monolithic or closed technological solutions and systems, and developing regionally focused service and support structures and tools within nationally centralized operational facilities.*
- Financial resources should be diversified using a broad set of instruments. Large infrastructure (e.g. supercomputing) reduces flexibility and thus efficiency. Acceptable risks need to be negotiated in participatory processes rather than prescribed. *For IWRSS this means seeking large-scale budget initiatives as well as small-scale funding opportunities, being innovative and entrepreneurial about funding, and working to provide multiple sources of support for IWRSS objectives.*
- Social learning is paramount to IAM. The IAM framework is structured as context, process and outcomes with feedback loops to account for change in a cyclic and

iterative process. Multi-party interactions involve 1) processing of factual information about a problem (content management), and 2) engaging in processes of social exchange (social involvement) to resolve essential elements such as framing of the problem, the management of the boundaries between different stakeholder groups, the type of ground rules and negotiation strategies chosen or the role of leadership in the process. The management of content and social involvement is strongly interdependent and cannot be separated. Communication plays an extremely important role. This leads to an entirely new element of monitoring the quality of the communication process. *These social learning concepts are directly applicable to IWRSS and are integrated into the Human Dimensions framework of IWRSS.*

Increasing the capacity of a stakeholder group to use predictive information effectively to manage problems and challenges (i.e. effectiveness of IWRSS) requires these elements. One cannot expect that design and implementation of integrated and adaptive management regimes will be based in a full understanding of the interaction between regime elements. Some properties are emergent and path-dependent, and will unfold during the implementation process. This is an important consideration for IWRSS and the reason why IWRSS must be flexible; the whole process of transition towards IAM regimes has to be regarded as a kind of adaptive management process as well. Integrative solutions identified today may not be what are needed tomorrow, so IWRSS must have latitude and capacity to change.

3.2 Guiding Strategies for Implementation

IWRSS seeks to fill a need that has been broadly validated by customers, leading science organizations, federal agency leaders, and the White House. The IWRSS design is well informed by Consortium strategic plans and objectives. It brings together an unprecedented set of operational capabilities, is driven by customer demand and focused on strong outcomes through a participatory process, is broad in scope and is aimed at integration and efficiency. Fully implemented, IWRSS would unquestionably mark a revolution in water resources information production, services and delivery, with significant economic benefits. Thus the IWRSS project is a reasonably attractive investment choice to meet water resources goals.

At the same time, the comprehensive vision today cannot define all aspects of the desired end-state. That requires iteration with stakeholders through a participatory process – IWRSS will evolve. So it isn't possible to specify entirely what is to be accomplished through IWRSS, or to declare the total cost of implementing IWRSS capabilities. Moreover, the realities of limited budgets and resources don't favor large new initiatives. The objectives of IWRSS are important enough, however, that the strategy cannot be to wait until some major investment comes along before getting started. The implementation of the IWRSS project must be opportunistic to succeed – "opportunity driven, opportunity executed". Small or large, opportunities can be aligned with the IWRSS design to implement elements of IWRSS gradually, with significant interim benefits. This approach carries a risk of winding up with disconnected pieces that miss the key intersections, and thus fall short of desired capabilities. Mitigating this risk requires a well coordinated and disciplined framework for project management, communication, and implementation, where the 100% design blueprint is always in view and being refined in response to stakeholder needs, opportunities are mapped to design elements, and collaboration occurs during implementation to ensure that pieces fit with each other.

This leads to a two-tiered approach to IWRSS implementation: agile and opportunistic on the ground, structured and disciplined above. At the high level (overall project management and IWRSS design implementation) the IWRSS project will use a basic evolutionary approach to capability acquisition called a spiral development model. In this approach, the desired end-state capabilities described in the initial IWRSS design will be refined through cycles of demonstration, stakeholder feedback and risk management. In each cycle, capability will be developed incrementally based on resource opportunities through a continuous process of re-evaluating capabilities, opportunities, and evolving end-state requirements. At the low level (opportunistic task-level implementation, often involving software engineering), agile development models from the contemporary IT industry will be used. Agile methods are highly adaptive and rely on cross-functional teamwork, collaboration and adaptability to rapidly implement new capability. Agile development teams focus on specific tasks and producing working capability quickly, through iteration and frequent re-evaluation of plans and requirements. Teams have end-to-end responsibility for implementation of a task, and instead of extensive planning and written requirement documentation, work quickly through intensive communication with stakeholders during the development process. Organizational boundaries and hierarchies are not particularly important; it is more important to (temporarily) assemble necessary skills and talents for a given task. Given the need to work across agency boundaries and opportunity-driven resourcing, agile methods will be essential for getting the work done. For IWRSS to succeed with this implementation strategy, what is required more than anything else is a firm commitment to build towards the design as opportunity allows, and the well-coordinated and disciplined framework to keep it together.

With this strategy in mind, the IWRSS design begins with what resources we have or expect to have soon, and focuses on integrative and transformative elements that can make a big impact on achieving objectives. These lynchpin elements include exploiting the national, regional and local framework that already exists, the task elements within each of the three crosscutting themes, and using regional demonstrations to focus implementation and bring it all together.

3.3 National, Regional and Local Framework

Each agency in the IWRSS Consortium has a network of national, regional and local offices with varying purposes. NOAA has national centers and headquarters offices relevant to IWRSS, regional River Forecast Centers and hydrologic services headquartered within regions, and local Weather Forecast Offices. USACE operates laboratories and applied research facilities with national interests and conducts its water management operations at regional Division and then smaller District levels. USGS has a network of national centers and headquarters, regional headquarters, state water science centers, and state field offices.

If considered as a network of nodes in a communications system, the combined multi-agency array of national, regional and local offices within the IWRSS Consortium is potentially a very powerful tool for gathering, producing and delivering information – if it functions as a well-connected system. Certainly many aspect of it already do function well for certain purposes, but this can't be taken for granted for the new business area of integrated water resources prediction. IWRSS needs this network to gather information from local and regional stakeholders about their water resources information needs, exchange information transparently across geographical and organizational scales, provide backup functionality and necessary redundancy for river forecasting functions as well as water resources functions, and to deliver consistent and integrated services.

Exploiting this network better is one lynchpin for IWRSS. The goals and themes of the IWRSS project involve key interrelated tasks necessary to use national, regional and local capabilities to their fullest extent to meet 21st century water resources needs. They include:

- developing integrated water resources communications and stakeholder engagement capabilities using this existing network,
- developing mesh-like technical interoperability and data synchronization capabilities between different systems that are in use on the network,
- using the interoperable network and systems to provide enterprise Geographic Information Systems (eGIS), geo-Intelligence, and a Common Operating Picture, and
- exploiting the service-oriented architecture of the framework systems to facilitate the implementation of advanced modeling capabilities and production of new gridded water resources information.

Developing and using this framework, implementing new capabilities, and incorporating all into operational workflows at national, regional and local levels and across organizational boundaries will be accomplished through regional demonstration projects in conjunction with a national support center. The NWS National Operational Hydrologic Remote Sensing Center (NOHRSC) will be transformed into a national IWRSS operational support center to address needs that can be met centrally. Its purpose will be to produce and provide core national gridded water resources information in concert with regional offices, provide centralized functions and expertise in support of regional operations and interactions, and help build regional interoperability, data synchronization and modeling capability through regional demonstration projects. It will work jointly with the eGIS support infrastructure within the Consortium to deliver common geospatial support services. In close collaboration with the IWRSS support center, local and regional offices responsible for selected demonstration watersheds will be the focus for implementing the IWRSS design elements that are summarized in Table 3.1.

Table 3.1. *Crosscutting themes and selected corresponding functional tasks associated with the IWRSS project design. These task elements are initial core implementation tasks, to be refined during implementation.*

Theme	Task Elements
Human: Stakeholder Interactions and Communications *(Chapter 4)*	Develop and implement communications strategies
	Develop outreach capability
	Develop and implement a social science strategy for stakeholder engagement
	Develop and implement evaluation metrics
	Conduct research and development (social science)
Technical: Information Services *(Chapter 5)*	Develop system interoperability within and across agencies
	Implement enterprise Geographic Information Systems (eGIS) and geo-Intelligence within the operational prediction framework
	Integrate information delivery
	Improve use of observations and surveillance
	Conduct research and development (technology)
Operational Science: Summit to Sea Modeling and Prediction Framework *(Chapter 6)*	Develop and implement a National Integrated Gridded Water Resources Forecast System and associated products and services
	Implement enhanced flow/flood forecasting and water management capabilities
	Leverage water resources science studies and exploit available data and information through innovation and assimilation
	Quantify uncertainties, validate water resources forecasts
	Improve use of observations and surveillance
	Conduct research and development (physical science)

3.6 Other Potential Intersections Affecting Implementation

The design elements of IWRSS produce interoperability, communications, modeling and prediction capabilities that could have strong implications for other agency objectives that are related but not specifically addressed within IWRSS. Two immediate examples are hurricane preparedness and response, and landslides. Both of these could be spin-off applications for IWRSS information (there are no doubt several others) but are not discusses further in this report.

Key Points for this Chapter

- Early progress on internal and external communication is essential.
- Near-term internal elements include developing a short vision document, presenting IWRSS at key meetings, and providing top-down agency-specific communication on IWRSS.
- Near-term external elements include a vision document that relates to stakeholders, meeting with key national level partner groups, and conduct tri-agency briefings to Congress and OMB with stakeholders present.
- A web site for IWRSS is needed immediately for internal and external communications and coordination.
- Begin working on the long-term social science strategy from the beginning of the project, not partway through.

Chapter 4 Human: Stakeholder Interactions and Communications

This crosscutting design theme ensures relevance for IWRSS. In the current practice of river forecasting and management, a set of stakeholder communities is well established and their needs are reasonably well understood. As described in the first chapter, the scope of water resources is broader than this set, and it is important for IWRSS to reach this broader community. This theme provides the mechanisms for IWRSS to make these connections. It addresses the basic driver for IWRSS to be integrative and adaptive, as the water resources management community strives to respond to change and uncertainty. The community is manifest at national, regional and local scales, thus the IWRSS design is multi-scaled and this theme prescribes a flexible framework to reach all scales. The theme includes internal and external communications strategies, outreach capabilities through an IWRSS web site, social science strategies for stakeholder engagement, and evaluation metrics to track progress and customer satisfaction throughout the project. This design leverages service and outreach knowledge and capabilities that exist throughout the consortium and fosters expertise in human dimensions aspects of social sciences.

4.1 Overview: Stakeholder Interactions and Communications

The design of IWRSS products and services must reflect recognition, understanding, and consideration of the environmental, as well as social, cultural, and economic aspects of managing water resources in different parts of the country. The success of IWRSS depends in large part on a solid understanding of the project audience, both internal and external, and their perceptions, beliefs, attitudes and values towards water services. An investment in research to discover this information is a necessary and critical initial step, and one that must inform the design of IWRSS development to ensure that the process used to engage, communicate and deliver services will resonate and change the behavior of participants. This research will include audience profiles of both the participating federal agencies and the national and regional partners they wish to reach.

Chapter 1 defined the stakeholders for the IWRSS project as consumers of water resources information who can benefit from the new and improved information and integrated service delivery that IWRSS will provide. In practice, stakeholders can be anyone with an interest in water resources. Five general categories of stakeholders describe the gamut that IWRSS must consider for its interactions and communications (Table 4.1)

Table 4.1 Categories of stakeholders

Stakeholder Category	Description	Examples
People who live, work, play, or worship at or near a resource	Those whose everyday lives and well-being are directly connected to a resource or issue. This group is essentially made up of the "neighbors" of the issue, and they should be invited to participate because their everyday lives may be impacted.	Residents, resource users, businesses, community/civic organizations, interest groups and nongovernmental organizations (NGOs), government, Native American tribes, and the media
People interested in the resources, its users, its use, or its non-use	Those who assign values to a resource and are concerned about the way that resources are used. This group includes those who extract value from resources, as well as those more interested in conserving or protecting resources. This group should be invited to participate because of the sheer interest in resource or issue.	Businesses, resource users, interest groups and NGOs, community/civic organizations, government, and Native American tribes
People interested in the processes used to make decisions	Those deeply interested in the legal and procedural aspects of an issue. This group includes those who want to ensure that all relevant policies and procedures are observed in reaching a decision. They should be involved because of their ability to derail a process of litigate final decisions.	Interest groups and NGOs, government, the media, residents, and Native American tribes
People who pay the bills	Those whose money is directly or indirectly used to fund resource management through taxes, fees, and other means. This group wants to ensure that money is spent wisely and should be invited to participate because the government is accountable for how it spends public dollars	Residents, resource users, businesses and government
People who represent citizens or are legally responsible for public resources.	Those who have the legal authority and obligation to manage natural resources. Members of this group want to ensure the best final decision is reached and should be invited to participate because it is their duty.	Government

(Source: Meffe and others 2002) [NOAA Coastal Services Center][5]

5 NOAA Coastal Services Center; Introduction to Stakeholder Participation, *Social Science Tools for Coastal Managers,* 2007.

Early identification of stakeholders across all scales and sectors is essential to ensure their needs are well understood and inform the design and delivery of IWRSS products and services. Preliminary efforts are necessary to compile accurate information on known and anticipated stakeholders, and it should be expected that more stakeholders would be identified over time so this information needs to be updated regularly. Once identified, NOAA's Coastal Services Center recommends four questions to be answered for each stakeholder:

1. What are the basic characteristics of the stakeholder (name, contact information, affiliation, position, scope of influence, likely degree of involvement)?
2. Is the stakeholder representing any organized group? If so, what are the characteristics of those groups (mission, membership, key contacts, history, authority, scope of influence, likely degree of involvement)?
3. What is the stakeholder's position on the key issues?
4. What are the stakeholder's interests in the issue (e.g. improving water quality, preserving aesthetics, increasing property values)?

Methods of collecting data for stakeholder analysis will include primary and secondary information sources. Primary sources include direct communication with stakeholders through interviews, surveys, attendance of stakeholder functions, or other data collection methods. Secondary information sources include sources such as web sites, newspapers, public records, organizational publications, reports or other decision-making processes. All stakeholder information should be inserted into a relational database and geospatially attributed for GIS; it should be possible to select an area on a map and identify known stakeholders and their characteristics, make queries to find stakeholders with certain characteristics, and so forth.

This framework, with data collected locally and gathered nationally, provides a powerful capability with which to begin the task of assessing stakeholder needs. Needs assessments can be conducted in many different ways, but start with having good information about who the stakeholders are.

An example of a stakeholder needs assessment already underway is the USACE State-of-the States Water Resources Needs Assessment. This is a concerted effort to identify needs, challenges, gaps and opportunities for enhanced Federal support to States and regional entities for more integrated water resource management. The assessment is conducting a study of State water plans and related documents, as well as interviews with state water officials. The assessment will be looking at common themes and regional trends and needs. The study will report on findings and engage in discussions with State, Federal, regional, and non-governmental representatives and others at three regional conferences and one national conference on how to enhance water planning within and across the States and regionally. The study is expected to initiate a dialogue with these stakeholders about how Federal partners can better support the their key water needs, especially for more integrated water resources planning and management. This example will be important for IWRSS objectives and illustrates some of the approaches further needs assessments might consider.

4.2 *Initial Implementation Tasks*

4.2.1 Develop and implement communications strategies

This element is focused on establishing both internal and external communications strategies. It includes development and implementation of effective communications strategies to articulate IWRSS benefits and services, translate between various lexicons used by different agencies and stakeholder groups, report progress, accomplishments and plans, and present standardized information in briefings, conferences and meetings.

Internal Communications. Internal strategy development is initially focused on early-stage communication within and among participating federal agencies. The internal strategy includes preparation of a vision document, rolling out IWRSS at major internal meetings, and agency-specific top-down communication on IWRSS.

The vision document is intended to articulate IWRSS benefits consistently for participating agencies and customers, and will be used as a marketing piece for internal audiences. Its content will include:

- value propositions for each agency that describe agency-specific benefits for multiple levels within each agency;
- benefits to the nation – highlights of IWRSS' ability to address contemporary priority issues, including hazard resilience, climate change, security/public safety, smarter use and management of water resources, and potential cost savings to the nation;
- explanation of IWRSS as a new integrated interagency operations approach for the end-to-end forecast process and hydrologic service delivery – a new way of doing business;
- definition of the service component of IWRSS appropriate for each agency's lexicon, description of what IWRSS looks like, identification of key intersection points, and necessary agency actions to support IWRSS in both the long- and short-term;
- definition of how IWRSS is leveraging the science, resources and technology among the various participating federal agencies to form a seamless suite of information to our customers.

The internal strategy calls for rollout at major internal meetings to establish buy-in at the management level. Participants need to know what IWRSS is offering and where it's going, and be able to articulate this to customers. Relevant meetings include national and regional manager and leadership meetings, collaboration workshops, and training activities.

Agency-specific top-down communication on IWRSS (e.g. email to all employees, town hall meetings in regions, webinars and e-newsletters) is also necessary to develop an ongoing dialog. This dialog should happen horizontally and vertically so education happens at a level that is relevant to each employee. Ongoing communication should keep employees up-to-date on IWRSS agency investment, progress and accomplishments. Email content would include:

- IWRSS creates intra- and interagency alignment, should make jobs easier
- Clearly state IWRSS as priority to agency
- Opportunity for better service to public
- Promotes internal efficiency (cost-effective)
- Integration of data and services

- Improved responsiveness to and effectiveness in meeting customer needs
- Explain design for national center and regional demonstrations

External Communications. The external communications strategy is focused on customers, stakeholders and partners. Again, it is initially focused on early-stage communications. It includes both national and regional level outreach.

An external vision document is needed that describes benefits to partners and to the Nation (end user). This vision document will focus less on agency propositions, and more on outcomes and the higher level of service to be expected as a result of IWRSS. It will use existing success stories of IWRSS-like projects to make it real and demonstrate results.

Key national level partner groups, "gatekeepers" (critical individuals in partner consortia), other federal agencies, etc. that need to be involved in early stages of IWRSS need to be identified. These may include:

- Flood Emergency Management Agency (FEMA) Floodplain Map Modernization Project
- Bureau of Reclamation
- U.S. Department of Agriculture (USDA)
- USDA Forest Service
- Environmental Protection Agency (EPA) Watersheds
- Advisory Committee on Water Information (ACWI)
- Association of State Floodplain Managers (ASFPM)
- National Hydrologic Warning Council (NHWC)
- International Association of Emergency Managers (IAEM)
- American Water Resources Association (AWRA)

The external vision document should then be distributed to partner groups as a consistent information and marketing tool. IWRSS should be presented at partner conferences and meetings, tailored to focus on those aspects most relevant to their interests.

A national IWRSS Stakeholder's Conference is needed to have a discrete opportunity to inform partners and receive targeted feedback. Sub-regional meetings should also be supported across the country to reach stakeholders at smaller geographic scales, and to begin to sell IWRSS as a way to address water issues more relevant at these scales.

Finally, the IWRSS consortium should conduct tri-agency briefings both to Congress and to the Office of Management and Budget (OMB). This element would be most effective with key partners present.

4.2.2 Develop outreach capability

The IWRSS project is expected to quickly take on many different scales and audiences. A method is needed to disseminate initial documents for consistent messaging, and eventually to track the progress of the project. An IWRSS web site should be established and made open to the public. The content of the web site should be focused on the consortium (i.e. not agency-specific) to demonstrate multi-agency ownership. The web site should articulate the general goals and plan (e.g. the external vision document) and feature regional demonstration areas, the rationale for choosing them, and a schedule for progress (e.g. meetings, products, upcoming workshops, etc.). The site should provide an opportunity for general input, such as a comment box or email to reach IWRSS staff. The site should also provide well-designed short- and long-version PowerPoint presentations for at least three audiences: management, technical, and non-technical. These uniform presentations will help ensure that messaging is consistent.

4.2.3 Develop and implement a social science strategy for stakeholder engagement

The initial strategy for stakeholder engagement involves employing a suite of social science methods to identify stakeholders and assess their interests and needs to inform the IWRSS project during its implementation. A variety of methods are available (e.g. needs assessments, audience profiles, focus groups, interviews, surveys) to be used as circumstances dictate. These methods are part of a social learning process to discover local knowledge about key water resource issues, increase mutual understanding of the problems, challenges, and available information, and develop social capital. This process is essential for understanding how to best manage boundaries between different stakeholder groups, connect partners and stakeholders across demonstration regions, and negotiate future design decisions and strategies.

Longer-term strategies include refreshing needs assessments and continuing the participatory process, but also include increasing the capacity of stakeholder groups to use IWRSS predictive information effectively to manage problems and challenges. This will require several integrative and adaptive elements within IWRSS. Cross-sectoral analysis is needed to identify emergent problems or needs and integrate adaptive responses to new insights. Transboundary cooperation – addressing issues across multiple scales of analysis and management – is a key requirement. Contemporary water resources problems, such as increased uncertainty in water supply, an increase in extreme events, and a reduction in storage capacity, have broad implications at all scales across the multi-disciplinary water resources fabric. IWRSS will be more widely beneficial if it works across boundaries from the beginning and strives towards a comprehensive understanding of water resources challenges and the knowledge needed by stakeholders to address them.

4.2.4 Develop and implement evaluation metrics

The IWRSS project is *outcome-driven*. The project design reflects the *context* of the water resources enterprise, with its complex array of agencies, actors, and science and technical capabilities, and as noted previously, needs to be flexible and adaptive to respond to customer needs in an uncertain world. The design also includes stakeholder *participatory processes* for interaction and communication. *Desired* o*utcomes* will vary geographically, and clear traceability should exist between actions, outputs, and outcomes.

The design is thus structured for multi-party interactions that involve the enterprise context, participatory processes and desired outcomes for water resources stakeholders with feedback loops to account for change and adaptability through an iterative process. This leads to a need for two types of metrics. First, evaluation metrics are needed to track progress towards the outcomes themselves, at both national and regional demonstration scales. Second, there is a need for monitoring the change in quality of the communication process. A social networking study is recommended to track change in coordination and communication as a result of IWRSS. This should be both on a national scale between the lead federal agencies and at the regional scale between the project and stakeholders.

4.2.5 Conduct research and development (social science)

Water resources and social behavior are inseparable. Critical intersections between the physical and social science aspects exist whether or not they are explicitly considered. One category of intersections important for IWRSS has to do with social choices made every day involving use and manipulation of water as a resource. A variety of social constraints shape these choices: legal and regulatory frameworks that specify when, where, how and how much water can be moved or used, economic motivations where choices affect a someone's bottom line, and cultural influences that lead people through choices such as whether or not to conserve water. This category is important to IWRSS because these types of factors can have as much or more to do with the success of water resource management policies and practices than any physical science information. If someone is required or otherwise highly motivated to make a certain choice, new information may not make any difference in the decision-making process. To be most useful, IWRSS needs to possess and foster a solid understanding of the social context affecting stakeholders' decision processes.

The second category has to do with the cognitive aspects of how water resources information is communicated, interpreted and used. People are often very good at making decisions with incomplete knowledge, if the information they have captures important, qualitative differences. Understanding this ability in the context of water resources decision-making is essential for producing useful information. It's particularly necessary to understand what qualitative or quantitative differences are important and how these relate to any firm thresholds or triggers that exist in the decision-making process. The other side of this is that well-intended information is often ineffective for any number of reasons. Examples abound; hurricane forecasts with 100% accuracy still do not prevent the need for some people to be rescued from the roofs of buildings in the ensuing floods. The question of how high to stack sandbags is not directly answered by river stage exceedance probabilities. Red means danger in some cultures, prosperity in others. How should it be used on a map of water availability? Cognitive reasoning processes and cultural influences determine how people perceive and interpret information, which in turn affects whether and how they use it. Understanding these influences is essential for IWRSS to be useful and effective; failure to do this well can render the best information useless. To be most effective, IWRSS must invest in understanding cognitive reasoning processes related to water resources information, and in developing ways to takes these into account in the design and delivery of information.

For this focal area, stakeholder research will play an important role. The dialog with stakeholders must include these aspects to help develop understanding of what they really need to make effective decisions, and this should inform the design of IWRSS products and services. Beyond this, social science research and development will be needed to develop computational approaches that address both qualitative and quantitative aspects of reasoning with respect to water resources. To improve integrative water resources management, IWRSS needs to learn how to better exploit cognitive abilities to make good decisions with incomplete and often qualitative information.

4.*3 Summary of Key Intersections with Current Practice*

Water Resources Web Sites. IWRSS will work towards a transparent interface with stakeholders for water resources science and services. This will lead to some level of standardization of water resources information now provided on various web sites, but does not imply a need for coalescence to a single master web site. An IWRSS web site will be created that most likely will provide nationally and regionally generated information and point to other web services.

Stakeholder Interactions. Early stages of IWRSS will involve service and outreach staff at local and regional offices (e.g. in NWS, these would include Service Coordination Hydrologists and Service Hydrologists). They will be asked to identify stakeholders in their areas and provide baseline information about their knowledge of stakeholder needs. This information will be integrated within a national information system and cross-referenced with other assessments of user needs. In due course outreach materials describing IWRSS will be provided for communication with stakeholders.

External Communications, Meetings and Conferences. When it is appropriate to communicate IWRSS objectives and plans at external meetings and conferences, the message will need to be delivered consistently. Standard talking points and briefing materials will be available for this purpose.

Human Dimensions: Stakeholder Interactions and Communications

Summary of Near-Term Tasks

1. Develop and implement internal and external communications strategies.
    a. Internal
        i. Prepare a short vision document
        ii. Roll out IWRSS at major internal meetings
        iii. Coordinate top-down internal communications
    b. External
        i. Prepare a short external vision document and distribute to key national and regional level partner groups at their meetings.
        ii. Coordinate delivery of IWRSS presentations at key national and regional partner and stakeholder meetings.
        iii. Conduct a national stakeholders conference
        iv. Conduct tri-agency briefings to Congress and OMB
2. Develop outreach capability
    a. Develop web site for external and internal use.
3. Develop and implement a social science strategy for stakeholder engagement.
    a. Conduct an open workshop to develop strategic framework
    b. Form a committed work group that will meet periodically via telecon and face-to-face to refine strategy and work on task 4 below.
4. Develop and implement evaluation metrics
    a. Identify a set of high-level outcomes for the IWRSS project and develop appropriate metrics to track progress towards these outcomes.
    b. As regional demonstration projects take shape, identify key outcomes for each one and develop appropriate metrics to track progress.
    c. Conduct a social networking study to establish baseline metrics for internal, trans-organizational and stakeholder communication. Plan to revisit the study on a periodic basis to monitor the quality of communication.
5. Conduct social science research and development.
    a. Conduct stakeholder research to understand drivers and constraints that affect how information is used and interpreted.
    b. Research and develop qualitative and quantitative computational social science methods to improve interpretation, understanding and use of water resources information and exploit cognitive abilities to make good decisions with incomplete information.

Key Points for this Chapter

- Developing system interoperability between USACE and NWS now is important because USACE is changing its IT infrastructure to two national servers and minimizing the number of lower-level security exceptions.
- System interoperability and seamless data exchange across a mesh-like network involving region-to-region and region-to-national enables critical backup and continuity of operations, central dissemination and management of common data sets, and is the key to moving towards a unified transparent front to external stakeholders.
- System interoperability, seamless data exchange, and enterprise GIS are intrinsically linked and need to be developed and implemented together.

Chapter 5 Technical: Information Services

This cross-cutting design theme is concerned with information services and involves all technical aspects of the national water resources information system, including system interoperability and data exchanges, enterprise GIS (eGIS) and geo-Intelligence, integrated information delivery, the acquisition and management of observations and surveillance, and technological research and development. In particular it is concerned with the intersections between these focal areas and with the human and operational science themes, so relationships between focal areas and themes are described in each of the following sections.

This theme emphasizes the implementation of sound information technology (IT) engineering practices to promote the coordination, integration and facilitation of interagency activities to pursue common goals in water resource management. It exploits service-oriented architecture and web services to integrate models and data, and establishes capability and protocols for trans-organization communication between databases and application systems. The implementation of this theme's focal areas will rely almost exclusively on leveraging existing technologies (e.g., industry standard APIs for database-independent connectivity, socket programming in C/C++, open source tools for datum and map projection transformations, etc.). The focus of this theme is the integration of these existing, proven IT technologies with water resource science and technology to facilitate operations and improve the fidelity of data and information.

Through system interoperability and database synchronization disparate water resource management systems (e.g., CHPS, CWMS, NOHRSC-GISRS, etc) will behave more like a single seamless system. Critical data will be exchanged automatically; operational tasks will be triggered in response to hydrologic events or actions occurring at any node in the IWRSS network. Collateral benefits include regional and national data collectives both within and across agencies and built-in continuity of operations.

Both eGIS and geo-intelligence, especially working in concert with database synchronization, ensures that all IWRSS collaborators are working with the same or compatible, up-to-date, baseline geospatial datasets. They ensure a common operating picture (COP). Everyone will employ the same vertical and horizontal datums. Map projections and other data transformations will be applied on the fly as data moves throughout the IWRSS network. If a critical dataset is altered (e.g. the levee dataset is updated to reflect levee breaks), those datasets will be distributed automatically throughout the IWRSS network.

Geo-intelligence and eGIS also provide a stakeholder context for IWRSS water resource model outputs. Geo-intelligence places model results and forecasts into a broader context, including different stakeholders' points of view. eGIS will enable rapid answers to questions like "What stakeholders are impacted by a given flood stage forecast?", and system resources can be leveraged to automatically notify stakeholders with critical information. Similar capabilities are envisioned for integrated product and delivery and for observations and surveillance. Using advanced telecommunications techniques that are commonly used in other fields, tools will be developed and distributed to help IWRSS collaborators leverage the IWRSS network to deliver products and services to their stakeholders. IWRSS' information services will act as a force multiplier on existing and new surface observation networks.

5.1 Key Applications Systems

There are three principal systems important to IWRSS that share similar features from the system design point of view but perform different functions. The USACE operates the Corps Water Management System (CWMS) for water management functions. The NWS is in the process of implementing the Community Hydrologic Prediction System (CHPS) for river forecasting functions. The NWS NOHRSC operates a unique system called GISRS for handling its distributed modeling, remote sensing and geospatial data processing functions. Each of these systems uses databases to store a wide array of data, and there are several situations where the data possessed by one would be useful to another. Also, each of these systems is comprised of a number of models, tools and functions, and has relatively straightforward mechanisms to exchange these capabilities and implement new ones. There are several opportunities for developing interoperability and facilitating data exchanges between these systems. The three systems are reviewed very briefly below.

5.1.1 Corps Water Management System (CWMS)

The Corps Water Management System (CWMS) is a real-time decision support system for water management (Figure 5.1). CWMS is an integrated system of hardware, software, and communications resources supporting the USACE's real-time water control mission and has been in use since 2001. USACE is responsible for

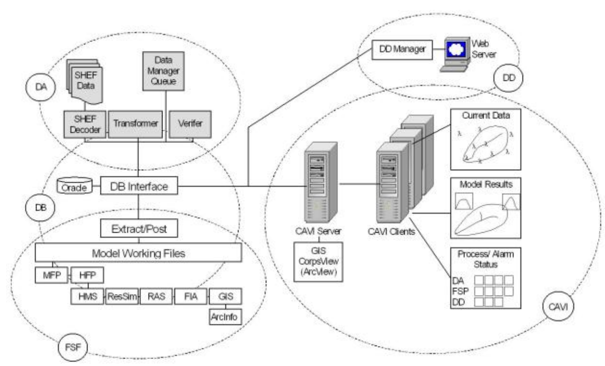

Figure 5.1. The major components of CWMS are shown, including the client-side (lower right) that the user interfaces with, and the server side (everything else) that provides system resources.

round-the-clock monitoring and operation of more than 700 multipurpose reservoirs and flow-control structures and thousands of miles of levees. CWMS software integrates processing from data to water management decisions. CWMS has components for acquiring, storing, visualizing and disseminating data, and watershed modeling components that interact with all of the data management activities.

The CWMS database component stores hydrometeorological data and manages retrieval and display using an Oracle database management system. The data acquisition component collects real-time data from data streams, and decodes, validates and transforms the raw data. The modeling component manages model configurations for watersheds and runs models for operational forecasts.

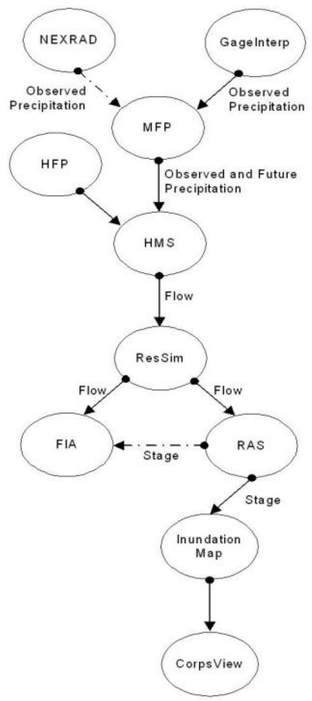

Figure 5.2. Schematic flow diagram showing how discrete model components are linked within CWMS.

CWMS uses a client-server architecture. The CWMS client is the principle user interface to the CWMS software. It retrieves hydrometeorological data for plotting and editing, provides a graphical user interface and graphic displays, retrieves model parameters for editing, and conveys model control requests to servers. The CWMS server provides the system resources to support multi-client access to models and databases, manage hydrometeorological data for clients, manage model parameters and state information, and perform model runs.

CWMS provides a full range of hydrologic and hydraulic modeling software to evaluate operational decisions and compare the impact of various "What if?" scenarios. Watershed modeling in CWMS includes hydrologic and hydraulic simulation models for short-term forecasts and event scenarios. Discrete models are developed outside of CWMS and then linked together to evaluate a variety of scenarios, including future precipitation amounts and timing, reservoir operations, and levee failures (Figure 5.2). Precipitation is analyzed on a grid basis and uses observed data from NEXRAD or interpolated from gages. Future precipitation scenarios use NWS Quantitative Precipitation Forecasts (QPF). The HEC-Hydrologic Modeling System (HEC-HMS) computes runoff on a 2-km grid from observed and forecasted precipitation to produce stream flow hydrographs. The HEC Reservoir Simulation System (HEC-ResSim) simulates reservoir regulation using inflow hydrogaphs and project characteristics such as operating rules and scheduled releases. It computes reservoir storage, release and spillway flow to produce downstream hydrographs. River hydraulics are modeled with the HEC River Analysis System (HEC-RAS). HEC-RAS is used with stream flow hydrographs and channel hydraulic characteristics to analyze river hydraulics to compute water depth, velocity and inundation boundaries. It handles steady-flow or unsteady-flow analysis. It can be used in conjunction with Arc-GIS and an Arc extension, CorpsView, to compute and view inundation boundaries and depth maps. HEC Flood Impact Analysis software (HEC-FIA) is used to compute agricultural and urban damages and project benefits by impact area. It computes damages and benefits between different scenarios and project conditions. It produces "action tables" which list and schedule emergency actions to take during an event based on forecasted stages.

5.1.2 NWS Community Hydrologic Prediction System

The NWS Community Hydrologic Prediction System (CHPS) is designed to support the operational real-time hydrologic/hydraulic model support for the NWS River Forecast Centers (RFC). CHPS is an open source system based on a Service Oriented Architecture (SOA) and is intended to replace the existing NWS River Forecast System (NWSRFS) so that advances in hydrologic and hydraulic sciences can be more readily accommodated. In the initial version of CHPS, the basic modeling systems in use today will be migrated and implemented within the SOA framework provided by the Flood Early Warning System (Delft FEWS) developed by Deltares. The NWS RFCs are responsible for river forecast services at nearly 3000 locations throughout the USA, with the primary function to protect lives and property with forecasts for floods. Secondarily, the RFCs provide services for water supply (seasonal volumes), low flow, flash flood guidance, and probabilistic forecasts (ensembles). CHPS will provide the model support for these services.

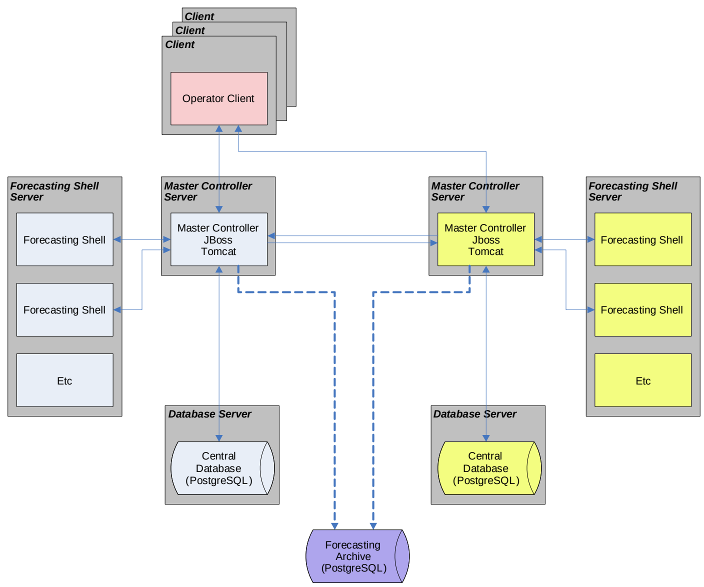

Figure 5.3. The major components of CHPS are the Database Server, Master Controller, Forecasting Shell Server, and Operator Client. The left systems (grey) are the primary systems, and the right (yellow) are standby systems.

The CHPS database server provides the centralized repository for all hydrometeorological data in a Postgres database (Figure 5.3). Data are acquired and imported into the CHPS database from various data sources through workflows that manage the data and perform conversions or transformations as required. The CHPS Master Controller performs as the traffic controller for the data access and model execution. The CHPS Forecasting Shell Server(s) provide the computational resources on which the models are run. With communications through the Master Controller, modeling tasks are coordinated, executed and updated for the clients.

The user interface for CHPS is through the Operator Client, which provides the graphical user interface to display and edit hydrometeorological data as well as the interface to submit model runs and display the hydrologic and hydraulic model results. Additional interactive capabilities are available to monitor and maintain various model states.

CHPS will introduce a different way of handling model-forcing data than has been traditionally performed at the RFCs. Both observed and forecast Precipitation, Temperature, and Evapotranspiration data will be analyzed external to CHPS, with the results provided in a gridded format for ingest by CHPS. Then to accommodate the model expected input, CHPS will perform any necessary areal averaging.

With the initial release of CHPS, the primary models available for use will be the Sacramento Soil Moisture Accounting model (SAC-SMA), SNOW-17, and HEC-RAS with numerous other algorithms or computational models such as Unit hydrograph, hydrologic routing, consumptive use, reservoir, channel loss, time-series manipulation, etc. Utilizing these components, CHPS workflows will provide the continuous stream flow modeling and deliver resultant time series that support the RFC forecast products and services.

5.1.3 NWS NOHRSC Geographic Information System and Remote Sensing System (GISRS)

The NOHRSC Geographic Information System/Remote Sensing System (GISRS) is a geospatial information and modeling system designed for large-scale operational production. It is used by the NOHRSC as the primary engine for national high-resolution distributed hydrologic modeling and remote sensing, including: a) snow energy and mass balance modeling and data assimilation, b) flow direction and accumulation calculation, c) automated basin boundary delineation, d) synthetic unit hydrograph calculation, e) distributed soil moisture modeling, and f) dynamic flood inundation mapping (Figure 5.4). GISRS is an integrated modular system of software, database services, and network communication resources, and is operated on a flexible Linux hardware architecture.

A broad spectrum of science application modules are used to integrate end-to-end production, from the acquisition and processing of raw data, through modeling and analysis processes, through the generation and delivery of products and services used by stakeholders in their forecasting and water management decision making processes. Two unique system-level features enable operational end-to-end orchestration of modular processes in a fully automated and largely self-healing environment: 1) time and space management, and 2) relational systems control through inter-module reporting/messaging facilitated by relational databases. All science applications use these system-level features to manage spatial and temporal attributes and communicate progress and status across applications.

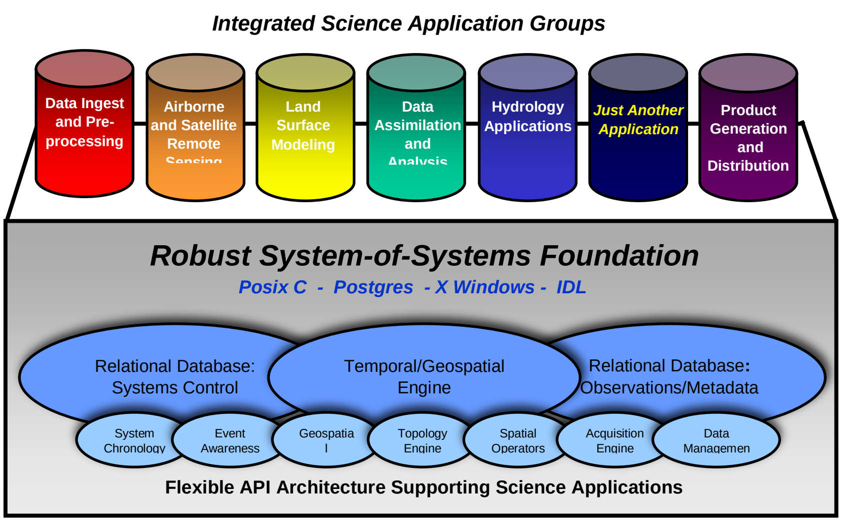

Figure 5.4. The major components of GISRS are shown. Application groups consist of individual GISRS modules performing similar or related functions. All GISRS modules are developed using a common set of Application Programmer's Interfaces (APIs). GISRS modules coordinate with one another through a variety of Postgres databases.

Science application modules are developed using Application Programmer Interfaces (APIs). The GISRS APIs consist of several hundred library functions that allow application programmers to easily embed complex geospatial, temporal, and relational operators within their scientific code. These allow module developers to focus on the science rather than on the complexities of space and time inherent in distributed modeling, and ensure a high degree of standardization among GISRS modules. Standardized modularization and the inter-module reporting/messaging system allow all GISRS applications to become aware of what each other is doing and enables high-level system automation.

The GISRS APIs may be leveraged for IWRSS Information Services in several ways. First, much of the functionality inherent in the GISRS APIs can be ported to complimentary systems (e.g., CWMS or CHPS). Existing GISRS API technology can also be incorporated into IWRSS system interoperability, database synchronization, geo-intelligence, surveillance and observations, and products and services to facilitate standardization across the IWRSS community.

The GISRS database server component serves three functions: 1) it is used to store hydrometeorological point observation data, 2) it is used to store metadata for point, vector, and gridded data, including the physical location of the data on the network (which enables distributed data services), and 3) it is used for inter-module communication via a reporting/messaging system. Each GISRS application reports on the progress that it makes, in both space and time, in the form of relational database records. Subsequent applications can query the database for these reports/messages to synchronize automated production.

5.2 Develop system interoperability within and across agencies

In this design *System Interoperability* refers to reliable mechanisms whereby the enterprise solutions (consisting of systems, models, data, products, and services) of individual water resource agencies can communicate, coordinate, and collaborate in a seamless, transparent, and timely manner at key points of intersection (Figure 5.3). *Database Synchronization* refers to highly efficient, transparent, and automated data exchanges and sharing across agency boundaries. Both have been identified as high-priority goals for IWRSS, and several potential intersections have been identified.

The initial tasks are concerned with developing a set of recommendations and strategies to implement specific system interoperability capabilities and specific data exchanges. The first task is to evaluate and document the need for and the requirements of system interoperability and database synchronization. Existing technical assets (systems, models, data, products, and services) at consortium member's water resource enterprises need to be assessed. From this assessment will come a recommendation of a range of forward-thinking system interoperability strategies. The range of strategies will take into account differences in existing and anticipated enterprise architectures. Necessary technical characteristics and engineering requirements will be documented from this assessment. Similarly, a range of database synchronization strategies, technical characteristics and engineering requirements will be identified and documented. For both, the proposed strategies should a) be readily scalable, b) easily extensible, c) provide for network topology flexibility, and d) minimize the degree of modification required for existing enterprise systems. A gap analysis will then be conducted between the assessments of existing enterprise systems against the proposed strategies.

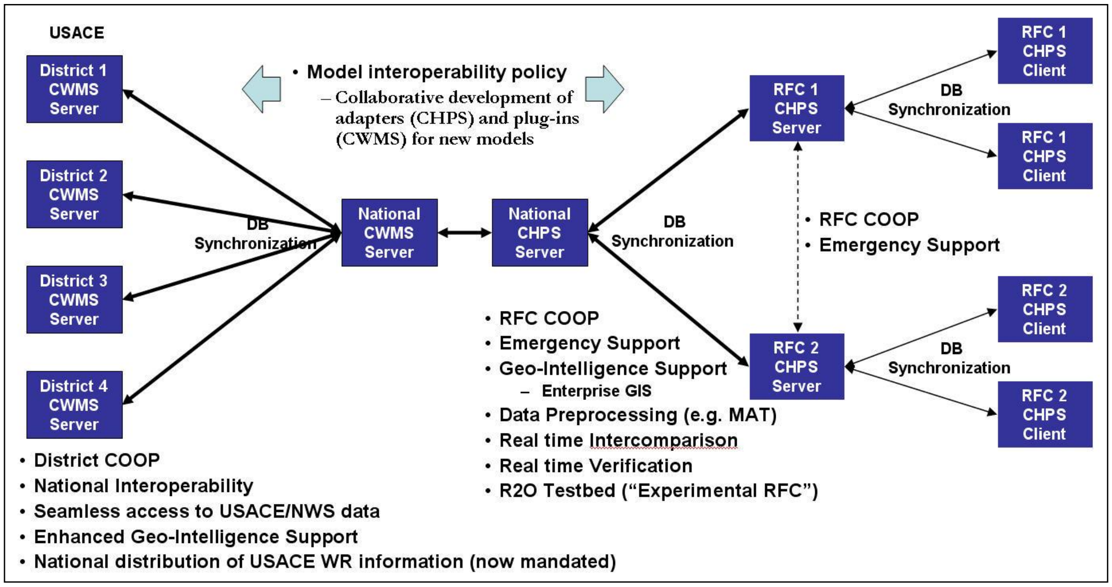

Figure 5.3. Straw diagram showing system interoperability and database synchronization implementation for NWS CHPS and USACE CWMS. By linking between regional nodes and to a central national node, a variety of benefits can be realized (bullets). Although exceptions are still anticipated, USACE is in the process of migrating to two national server centers to serve as the principal hubs for external network communications, making this approach essential for NWS-USACE communications.

In addition to the technical considerations addressed above, both system- and data-related access, privilege, and security needs and constraints will be identified, including firewall access between systems, file- and record-level access to data, and protection of proprietary data. Agency Chief Information Officers (CIO) will be engaged to help address these issues. Relationships between system interoperability and database synchronization with other information services focal areas and crosscutting themes are shown in Table 5.1.

5.3 Implement enterprise Geographic Information Systems (eGIS) and geo-Intelligence within the operational prediction framework

An *Enterprise Geographic Information System (eGIS)* is a platform for delivery of organization-wide geospatial capabilities, including data management, visualization and geospatial analysis. Data management is among the most powerful of eGIS capabilities. It focuses on efficient storage and retrieval of all of an organization's geographic information. It doesn't need to be centralized, but does need a central catalog with knowledge of the data location and access to it, and must follow geospatial data standards. eGIS provides free-flow of information, coordination and management of geospatial information across an enterprise, and will provide IWRSS with a comprehensive set of key baseline GIS data layers that are shared by all IWRSS consortium members, one important key to achieving a common operating picture. *Geo-Intelligence* refers to

Table 5.1. *Relationship with other Information Services Focal Areas and Crosscutting Themes.*

Focal Area / Theme	Relationship
eGIS and Geo-Intelligence Development and Implementation	System interoperability and database synchronization is the mechanism whereby eGIS datasets are distributed among consortium members automatically.
Integrated Delivery of IWRSS Products and Services	System interoperability and database synchronization is the mechanism whereby IWRSS products and services acquire IWRSS data to distribute to external stakeholders. IWRSS products and services is a system interoperability and database synchronization client.
Observations and Surveillance	System interoperability and database synchronization is the mechanism whereby observations, remotely sensed data, and model data are distributed among consortium members automatically.
Human Theme	The human component will research and document interagency interactions and provide system interoperability recommendations that will maximize user acceptance and workflow efficiency.
Science Theme	System interoperability and database synchronization is used by the science component to: • Schedule model execution (managing the time domain), • Facilitate inter-model communication and coordination, • Acquire initial model states and forcings, • Acquire assimilation and validation data, and • Distribute new model states.

high performance tools and procedures that visualize, interpret, model consequences of, create derived products for, generate reports for, and invoke actions or changes in behavior based on forecasted water resources events in a geospatial and temporal context.

5.3.1 eGIS

Initial eGIS implementation tasks focus on assessing needs, inventorying relevant data sets, identifying and adopting standards and documenting requirements. The first task is to identify all static (e.g., elevation) and near-static (e.g., levees) natural and man-made features that affect or are affected by either water resources or water resource related decision making processes and coordinating these with emergency event data. Then these data sets will be mapped into existing IWRSS applications. All IWRSS applications should use a common set of data (i.e. all viewers see the same, up-to-date version) (Figure 5.4). Existing GIS data sets will be inventoried, and then gaps will be identified and documented.

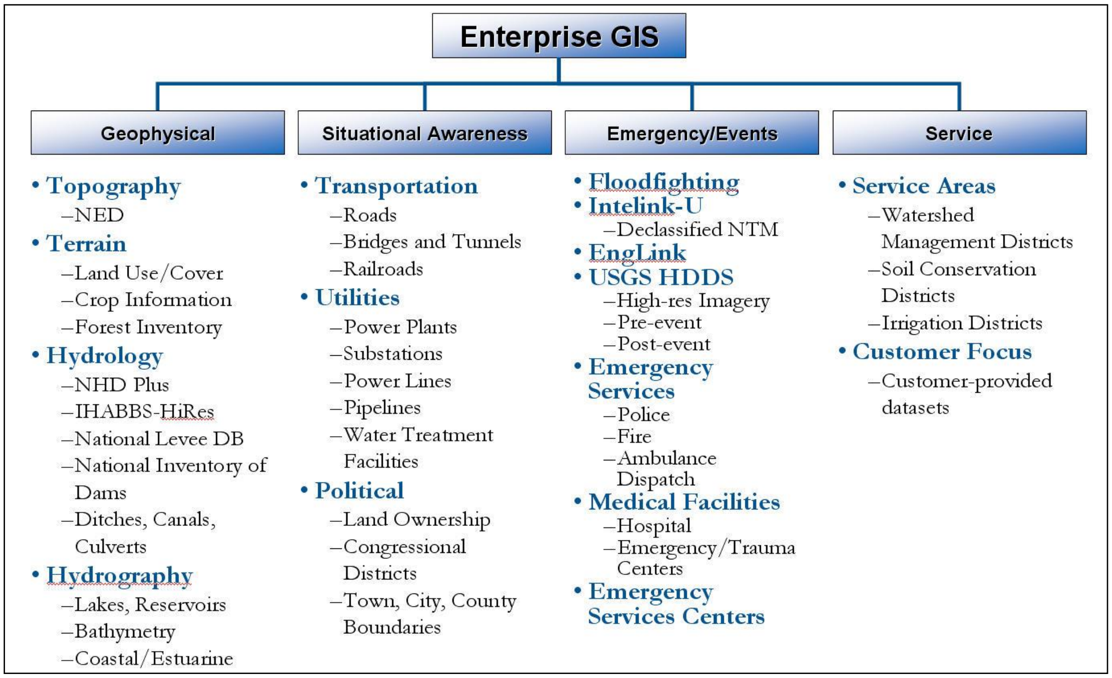

Figure 5.4. Common GIS layers that can be provided through eGIS framework include geophysical data, situational awareness data, emergency data including special geo-Intelligence data during events, and data sets related to service delivery.

The next sets of eGIS tasks are to identify and adopt standards for data representation, location (projections and datums), formatting, organization, metadata, etc. The project will leverage existing data standardizing activities by coordinating with eGIS groups in USACE, USGS and NOAA. IWRSS will also participate in the Open Geospatial Consortium (OGC) to maintain alliance with international standards for GIS data.

Data exchange and management for IWRSS eGIS is closely linked to interoperability and data synchronization issues (Table 5.2). Coordination with the database synchronization focal area is necessary to support on-the-fly reformatting and reprojection. Also, changes made to near-static GIS data sets (e.g. addition of new levee information) should be distributed among consortium members automatically and in near real time. Coordination is also necessary with the IWRSS science component on necessary data formats and representation. The project will recommend strategies for managing data in both the geospatial and temporal domains and document technical characteristics and engineering requirements, and take into consideration relationships with commercial off-the-shelf (COTS) GIS.

Included in this focal area is the pathway for implementing a high-resolution version of the Integrated Hydrologic Automated Basin Boundary System (IHABBS), an internal system used by the National Weather Service for basin delineation. One of the common geospatial data sets for the eGIS framework is the enhanced National Hydrography Dataset Plus (NHD+), which is appropriate for developing high-resolution IHABBS. Furthermore, IWRSS eGIS adherence to standards will respect the ACWI Subcommittee on Spatial Water Data advisory role on basin delineation. Together, these will align NWS basin delineation tools with other sectors of the government.

5.3.2 Geo-Intelligence

Initial tasks here again are concerned with inventorying capability and tools across the consortium as well as COTS solutions, and identifying and documenting gaps. Recommendations will be focused on solutions that allow for sharing geo-intelligence development activities across agencies, including Application Programming Interfaces (API), COTS GIS, open source tools, etc. Technical characteristics and engineering requirements will be documented, in coordination with the focal area on Integrated Delivery of IWRSS Products and Services to provide geo-intelligence tools for IWRSS' external stakeholders.

Part of this focal area includes developing access and use of effective web services to help communicate enterprise situational awareness, geo-intelligence products and data. Examples of existing applications that proved useful during the Midwest floods of 2008 are mini-wiki approaches including Intellipedia, which provides a common geo-intelligence forum for USACE, USGS, FEMA/DHS, and NGA (Figure 5.5)

Table 5.2. *Relationship with other Information Services Focal Areas and Crosscutting Themes.*

Focal Area / Theme	Relationship
System Interoperability and Database Synchronization	eGIS standards for representing space and time will help determine the requirements and specifications of IWRSS databases and data. Geo-intelligence tools will allow database synchronization to reformat and reproject IWRSS dataset on the fly.
Integrated Delivery of IWRSS Products and Services	Geo-intelligence tools developed by internal IWRSS stakeholders will be shared with IWRSS external stakeholders, including COTS extensions and interactive web site tools.
Observations and Surveillance	eGIS standards for representing space and time will help determine the requirements and specifications of IWRSS databases and data.
Human Theme	The human component will research and document external stakeholder requirements of IWRSS products and services. Some of the product requirements may be met by eGIS datasets. Some of the service requirements may be met by IWRSS geo-intelligence tools.
Science Theme	eGIS standards for representing space and time will help determine the requirements and specifications of IWRSS databases and data. eGIS datasets will help parameterize IWRSS models. Geo-intelligence tools (including interpretation tools and derived product tools) will allow internal and external IWRSS stakeholders to integrate IWRSS model data into their enterprises.

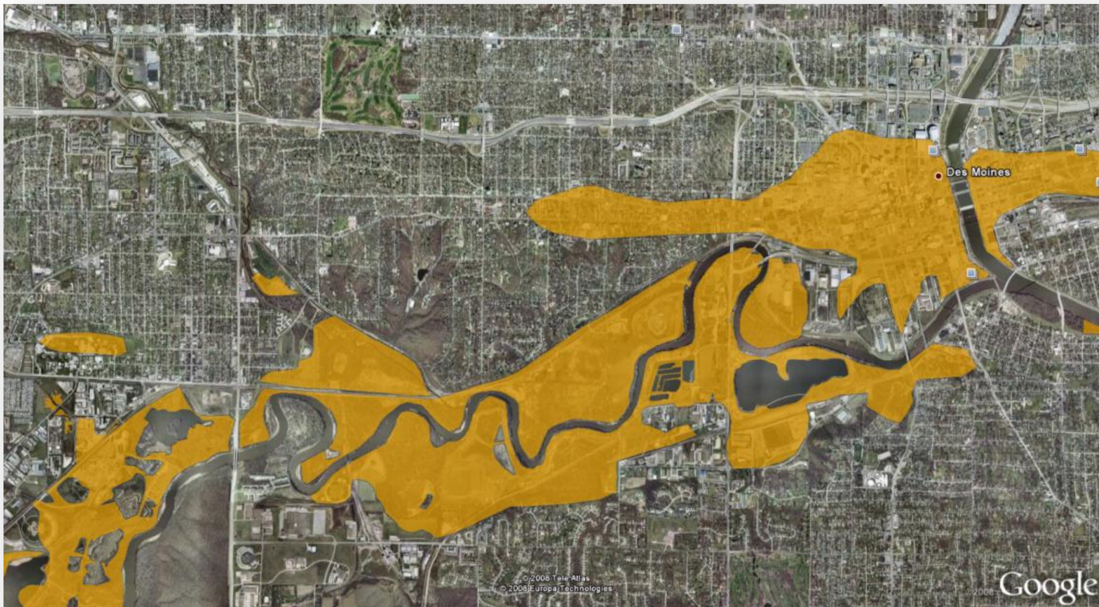

Figure 5.5. High-resolution map of flood extent in the Des Moines, IA vicinity during the 2008 Midwest Floods. Mapped data (shape files) were manually retrieved from Intellipedia twice each day, manually converted to KML files for Google Earth, and emailed to the River Forecast Center for use in flood forecasting operations. IWRSS geo-intelligence elements will greatly streamline the operational accessibility of this type of information.

5.4 Integrate information delivery

Integrated Delivery refers to existing and anticipated hardware, software, telecommunications systems, and protocols that facilitate the automated delivery of IWRSS products and services to external stakeholders (the internal stakeholder needs are met by system interoperability and database synchronization focal area).

Tasks for this focal area begin with researching and documenting existing and anticipated languages, protocols, services, COTS solutions, etc. for delivering products and services over the Internet. Because this arena is marked by rapid change, particular focus here will be on new trends in web services. Legacy products and services and delivery mechanisms that need to be maintained will be documented, and a range of forward looking product delivery and service architecture requirements and specifications to meet a broad range of external stakeholder expectations will be researched and documented. From this will come recommendations for a) a range of delivery mechanisms and strategies, from one stop shopping for national products to regional and local web sites and a national archive, and b) tools and services to assist regional and local stakeholders develop their own web sites and applications, including web services, Really Simple Syndication (RSS) feeds, and APIs. The recommendations will evaluate potential for existing services such as NDFD, USGS capabilities to accommodate IWRSS information – or learn from their best practices. Relationships with other focal areas are shown in Table 5.3.

Table 5.3. *Relationship with other Information Services Focal Areas and Crosscutting Themes.*

Focal Area / Theme	Relationship
eGIS and Geo-Intelligence Development and Implementation	Integrated delivery of IWRSS products and services will share IWRSS eGIS datasets and geo-intelligence tools with external stakeholders.
Observations and Surveillance	Integrated delivery of IWRSS products and services will share observations, remotely sensed data, and model data with external IWRSS stakeholders.
Human Theme	The human component will research and document external stakeholder requirements of IWRSS products and services. It will make recommendations for the range of IWRSS products, the range of IWRSS services, and the range of IWRSS products and services delivery mechanisms.
Science Theme	Integrated delivery of IWRSS products and services will share IWRSS model results with external IWRSS stakeholders.

5.5 Improve use of observations and surveillance

For IWRSS purposes an *observation* is defined as an in situ measurement, reading, or classification of a subsurface, surface, or atmosphere parameter. *Surveillance* is defined as a remotely sensed or modeled estimation or classification of a subsurface, surface, or atmosphere parameter. There are several considerations of observations and surveillance important to the IWRSS project, including the quality of all observation and metadata, coordination of usage of observation data, and distribution mechanisms. A central goal within IWRSS is to optimize the value of new and existing observation networks. IWRSS will also help guide and prioritize the rollout of new observing stations and networks by providing a comprehensive view of what the data will be used for and of the needs of both internal and external stakeholders.

Tasks in this focal area include reevaluation of current observation station metadata strategies, evaluation of current observing system capabilities and identification of critical gaps for water resources. This focal area will recommend and implementation strategy to fill critical gaps with consideration of incorporating remote sensing capabilities. A framework and path for development of remote sensing capabilities within IWRSS will be designed. IWRSS will coordinate with the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) on the development of new water resources sensors for snow, soil moisture, and river and lake elevation and work to leverage new and existing remotely sensed and modeled data sets, including implementation of remotely sensed vegetation phenology and potential evapotranspiration (PET) and exploitation of USGS products and other innovative technologies. Relationships with other focal areas are shown in Table 5.4.

Table 5.4. *Relationship with other Information Services Focal Areas and Crosscutting Themes.*

Focal Area / Theme	Relationship
Human Theme	The human component will research and document more efficient user interactions with observations data including formats, delivery mechanisms, data management mechanisms, and metadata requirements.
Science Theme	Observations and surveillance provides IWRSS models with forcing data, validation data, and assimilation data.

5.6 Technical Collaboration Approaches

Technical collaboration will be a hallmark of IWRSS and will reflect social science influences on the design, development, and implementation of IWRSS' technical and science components. Collaboration should a) increase the overall level of acceptance and adoption of IWRSS concepts and b) identify strategies that enhance workforce/workflow efficiencies among both internal and external IWRSS stakeholders.

Internal collaboration among IWRSS consortium members will work to identify workflow best practices, including determination of how consortium members work together now and how they might work together more efficiently in the future, identification and documentation of gaps, and ensuring that stakeholder acceptance of proposed information services strategies are vetted prior to development and implementation. It will also work to identify and accommodate differences among consortium members' parent agencies in areas such as policies (management, technical, etc), funding mechanisms, and culture.

Similarly, external collaboration with IWRSS customers will work to identify best practices by determining how our customers use our products and services now and how they might use our products and services more effectively in the future, canvassing stakeholders to determine their requirements, identifying and documenting gaps, ensuring that stakeholder acceptance of proposed information services strategies are vetted prior to development and implementation, and adapting customer oriented practices. This focal area will coordinate closely with the activities of the crosscutting theme on stakeholder interaction and communication.

5.7 Conduct research and development (technology)

This focal area will engage in integral, ongoing, crosscutting research and development (R&D) activities directed toward a) advancing our understanding of and b) leveraging emerging sciences (including social science) and technologies. It will work to assess current and planned R&D activities across IWRSS consortium members, identify areas of overlap and potential collaboration, evaluate critical IWRSS R&D needs, and identify and document gaps.

An important task for this focal area is to modify, then adopt, relevant Technical Readiness Level (TRL) standards to facilitate integration of joint IWRSS R&D capabilities by providing a consistent framework for comparison. While not perfect, TRLs provide a common language for ranking the status of a particular science or technology capability, and are widely used in the acquisitions community to identify and evaluate science and technology across multiple lines of development within and between organizations. In the case of IWRSS, lines of development include (but are not limited to) multiple centers, laboratories and field offices in NOAA, multiple laboratories and centers in USACE, multiple centers and field offices in USGS, a large array of academic sources, and several commercial sources. Each line may have its own approach for internal assessment ad oversight of S&T development and implementation, but IWRSS requires the common framework for science and technology acquisition that TRLs provide. A common description of TRLs is given in Table 5.5. Variations are also common to suit specific needs (including science and system readiness) and may also be used for IWRSS. USACE has the capacity and willingness to offer training to the IWRSS consortium on the use or TRL for science and technology acquisition.

Table 5.5. *Common descriptions for Technology Readiness Levels.*

Technology Readiness Levels	Description
1. Basic principles are observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system proven through successful mission operations.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

This focal area will work to map current R&D activities into the TRL framework and recommend a portfolio of specific R&D activities to a) mature relevant science and technology (to advance IWRSS' TRL) and b) develop needed capabilities. This will include R&D elements across basic research, applied science, and advanced technology demonstration. R&D is a continuous requirement in IWRSS focal areas.

5.8 Summary of Key Intersections with Current Practice

Integrated Hydrologic Automated Basin Boundary System (IHABBS). This is an internal system used by the NWS for delineation of basins above forecast points. The software system itself has not been updated for many years, but the system is still used for annual basin updates. Demand has shifted to using high-resolution data sets to improve basin delineation, especially in areas of low relief. Through this theme, IHABBS will be replaced with open tools based on the high-resolution USGS National Hydrologic Dataset Plus (NHD+) data set, which will satisfy NWS requirements and standardize the toolset across agencies.

Interoperability with Changing USACE Systems. Communication protocols between NWS and USACE must change as a result of USACE's transition to dual national server centers. Although local security exceptions will still be allowed, the goal is to minimize these. IWRSS interoperability and data synchronization becomes a key intersection point for science operations and models in this new environment.

Geo-intelligence and eGIS. As the Midwest Floods of 2008 clearly showed, operational river and flood forecasting has a critical need for improved intelligence and enterprise (trans-agency) flow of information, especially during major events. IWRSS will be the mechanism to address this need across agency boundaries and leverage USACE and USGS expertise in this key area. Capability will be delivered through major operational systems, including the spatial viewer (or an enhanced alternative) in CHPS.

Data Archive. The central accumulation of regional model states and parameters through the data synchronization and interoperability elements enables a central permanent archive.

Continuity of Operations. The mesh network created by multi-node data synchronization provides a flexible capability to ensure continuity of operations, through other nodes at regional or national scales.

Common Framework for Assessing Technical Readiness. Current practices have no common means of assessing the readiness or availability of technical components needed for operations. System and component acquisition is conducted ad hoc. IWRSS will introduce greater organization and discipline into the technical acquisition process for water resources.

Technical: Information Services

Summary of Near-Term Tasks

6. Develop System Interoperability Within and Between Agencies
    a. Evaluate and document specific needs and requirements for system interoperability and database synchronization, considering existing technical assets (systems, models, data, products, and services);
    b. recommend a range of forward looking interoperability challenges;
    c. conduct a gap analysis between existing systems and recommendations
7. Identify system- and data-related access, privilege, and security needs and constraints for data exchange and synchronization.
    a. Consider firewall access between systems, file- and record-level access to data, and protection of proprietary data.
8. Implement enterprise GIS and geo-Intelligence within the operational prediction framework.
    a. Identify all static (e.g., elevation) and near-static (e.g., levees) natural and man-made features that affect or are affected by either water resources or water resource related decision-making processes and coordinate these with emergency event data.
        i. Map data sets to existing and expected IWRSS applications.
        ii. Inventory existing data sets and identify gaps.
    b. Identify and adopt standards for data representation, location (projections and datums), formatting, organization, metadata, etc.
    c. Inventory geo-Intelligence capability and tools across the Consortium, identify gaps and develop recommendations.
    d. Develop access and use of effective web services to help communicate enterprise situational awareness, geo-intelligence products and data.
9. Integrate information delivery
    a. research and document existing and anticipated languages, protocols, services, COTS solutions, etc. for delivering products and services over the Internet.
    b. Document legacy products, services and delivery mechanisms that need to be maintained ; research and recommend a range of forward-looking product delivery and service architecture requirements and specifications to meet a broad range of external stakeholder expectations, including apparent "one-stop shopping".
10. Improve use of observations and surveillance
    a. Evaluate current observation station metadata strategies and observing system capabilities. Identify critical gaps for water resources.
    b. Recommend strategies to fill critical gaps with consideration of incorporating remote sensing capabilities
11. Evaluate, adapt and adopt relevant Technical Readiness Level (TRL) standards to facilitate integration of joint IWRSS R&D capabilities and provide a consistent framework for comparison.

Key Points for this Chapter

- The immediate science goal for IWRSS is to operationally "breadboard" the IWRSS design concept:
  - start bringing the right people together;
  - assemble key science components;
  - make necessary connections (data flow, application adapters and plug-ins, etc.);
  - begin early production to provide experience and examples;
  - begin developing the workflow between actors;
  - engage more stakeholders in the process to begin refining product and service requirements.
- IWRSS is not a research instrument; it is an instrument to fast-track operational implementation that aggressively mines and assembles existing capability, then guides investment in the development of new capability.

Chapter 6 Operational Science: Summit to Sea Modeling and Prediction Framework

A principal objective of IWRSS is to operationally produce a seamless, integrated suite of high-resolution analytical and predictive water resources information for land surfaces, rivers, lakes, estuaries and coasts that supports water resources decision-making at local, regional and national scales. This calls for:

1. high-resolution forecasts at all locations (i.e. summit-to-sea), not just at selected forecast points on rivers;
2. high-resolution analyses (historical and current) and forecasts throughout the water cycle, including: a) precipitation b) snow water storage, c) soil moisture and temperature, d) evapotranspiration, e) runoff, f) groundwater and aquifers, g) river flow (including low flows), which in turn must support analyses and forecasts of g) water quantity, h) water temperature and i) water quality;
3. short-term, mid-range and long-range forecasts extending from hours to seasons;
4. evaluation of water budget forecast skill against historical analyses;
5. improvements in river flow forecasting and water management capability;
6. operational linkages between river flow forecasts and coastal/estuary conditions;
7. uncertainty information throughout, and
8. consistent, integrated products and multi-scale service delivery to help a wide range of stakeholders use the information effectively.

This theme is concerned with both the physical and social science necessary to accomplish these tasks. It includes the physical science aspects necessary to advance five focal areas: 1) develop and implement the summit-to-sea modeling and prediction framework, 2) provide the historical context and trend information necessary to understand the present and the future, 3) advance river prediction and management capabilities, 4) improve the use of observations, and 5) quantify uncertainties and validate analyses and forecasts. A sixth focal area includes the social science aspects necessary to identify and understand specific information needs, relate these needs to the design and function of operational tools that provide the information, and to effectively communicate this information back to the stakeholder.

This chapter first describes the general approach towards science implementation and development for the IWRSS project, then describes the six science focal areas identified for IWRSS implementation, where there are immediate opportunities to make a leap forward towards IWRSS goals.

6.1 Approach to Operational Science Implementation

Through the auspices of a federated consortium and the specific elements of the human and technical crosscutting themes, the IWRSS project provides a collaborative and integrative framework to gather and assemble the various capabilities necessary to move aggressively towards the science objective above. One key premise for IWRSS is that a consortium is necessary to accomplish the objective – no single group or agency has all of the tools and expertise necessary. The project is enabled by a willing consortium, which is expected to grow. A second key premise is that substantial science capability is readily available off-the-shelf to make substantial early progress towards the objective. Several suitable elements have been identified through the course of IWRSS planning. Models, tools, data and information are available. They are not perfect, but they're sufficient to get started on producing baseline comprehensive high-resolution water resources information. Another important enabler is the replacement of the NWS River Forecasting System with the service-oriented architecture of CHPS, which greatly facilitates collaboration with other systems and applications within the IWRSS framework.

The immediate science goal for IWRSS is to operationally "breadboard" the IWRSS design concept: start bringing the right people together, assemble key science components, make necessary connections (data flow, application adapters and plug-ins, etc.), begin early production to provide experience and examples, begin developing the workflow between actors, and engage more stakeholders in the process to begin refining product and service requirements. This approach will establish a baseline capability in the shortest time, which can then be enhanced through focused science development and stakeholder input, using both national IWRSS support infrastructure and regional demonstrations as vehicles.

Thus IWRSS is not a research instrument; it is an instrument to fast-track operational implementation that aggressively mines and assembles existing capability, then guides investment in the development of new capability. Existing capability comes from several Consortium laboratories and science centers, internal and external test beds, and from academic and possibly commercial partners. Through a spiral development model and a national-regional demonstration framework, it provides a viable and rich environment for testing, developing and implementation of new capabilities. To facilitate this, this theme involves developing a common framework for identifying science and technology readiness levels across organizational boundaries, following the broad practice of the technical acquisitions community. The IWRSS project management activity will include a twice-yearly Consortium R&D meeting to review relevant on-going and planned research activities and where possible align them with IWRSS. External groups with activities closely related to IWRSS, such as the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) will be invited to participate in these reviews to help them understand where federal water resources operations are headed and look for synergies in R&D. Such effort is necessary for IWRSS to ensure that initial baseline capabilities are improved quickly to address more complex challenges ahead.

Three aspects of the IWRSS project design will help in moving research to operations (R2O). First, IWRSS is focused on the complete water budget, and the class of models used for high-resolution gridded analyses and forecasts is generally more flexible and less reliant on long-term records of historical observations than conceptual river forecasting counterparts. New observational data, model components and tools can be tested and implemented more easily with these models. Second, because these models will be used at both the national level and in the regional demonstrations in a robust, interoperable environment, there will be significantly more opportunities and pathways available to introduce new capabilities into the water resources prediction framework. Third, as part of the interoperability and data synchronization framework between regional demonstrations and the national support center, centralized data archive functions will be provided in IWRSS. With sufficient off-line capacity, this data accessibility can enable a convenient proving ground to simulate regional operations and test new procedures, either at a national or regional scale, or both.

A fourth and very important factor that will help IWRSS become a successful engine for R2O is the track record within the Consortium. Two of the USACE partners in IWRSS are part of the USACE Engineer Research and Development Center (ERDC): the Cold Regions Research and Engineering Laboratory (CRREL), and the Coastal and Hydraulics Laboratory (CHL). In four of the past seven years the ERDC has won top honors for Army Large Research Laboratory of the Year in recognition of its high R2O success rate. The IWRSS project will work to leverage the management skills and experience that lead to these honors.

6.2 Develop and implement a National Integrated Gridded Water Resources Forecast System and associated products and services

The first operational science focal area is to develop and implement a national integrated gridded water resources forecast system, and the products and services associated with this. This involves describing the past, present and future state of principal water budget components. Current river forecasting methods share this same fundamental basis, but for IWRSS this information is needed at high-resolution at all locations. High-resolution gridded estimates of water budget components will provide raw materials to produce information stakeholders need to make water-related decisions.

6.2.1 Scope of Water Budget and Modeling Needs

One of the three key concepts defining water resources (see Chapter 1) is water availability: the location, spatial distribution, and natural fluctuations of water. Water availability is described in well-defined science terms by the components of the water budget. By principles of continuity the terms of the water budget must balance, so for a simple water budget at a point:

$$P = Q + E + \Delta S \qquad \text{Eq. 6.1}$$

where: P = Precipitation
Q = Runoff
E = Evapotranspiration
ΔS = Change in storage in snow, soil, or groundwater.

Thus inputs equal outputs plus a change in storage; precipitation either runs off, evaporates or is transpired by plants, or is stored as snow or in the ground. Elaborating a bit further for a small area (grid cell) or catchment gives a more complete picture of water availability:

$$P = I + AET + Q + \Delta SW + \Delta SM + \Delta GWS + GWR \qquad \text{Eq. 6.2}$$

where: P = Precipitation
I = Vegetation Interception
AET = Actual Evapotranspiration
Q = Surface runoff
ΔSW = Change in snow water storage
ΔSM = Change in soil moisture
ΔGWS = Change in groundwater storage
GWR = Groundwater runoff.

Thus over an area, any precipitation that occurs is either intercepted by vegetation canopies (where it may evaporate, or later fall to the surface), evaporates or is used by vegetation, runs off and departs the area on the surface or in channels, infiltrates into the soil or percolates to the ground water table, where it may depart the area underground (Figure 6.1). Each of the terms in *Equation 6.2* is further elaborated in practice using atmospheric, hydrologic, hydraulic and groundwater models to describe the processes at work and represent the state of each term at a particular point in time. For example, the evapotranspiration term represents first-order links to ecological systems and involves additional terms describing the atmospheric boundary layer, vegetation canopy structure characteristics, and soil water availability. Many commonly used models represent these processes. These models in turn require a variety of forcings to drive them, data to parameterize them, and observations to correct and validate them. Tools and expertise are needed for all of these purposes.

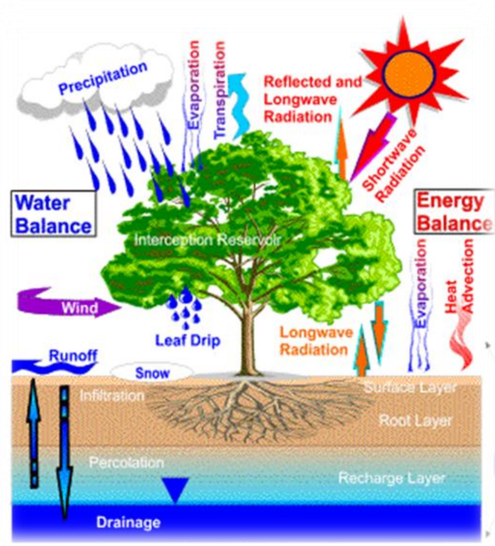

Figure 6.1. Physical process elements of the water budget that must be modeled in IWRSS.

For IWRSS, most of these water budget terms are to be modeled on a high-resolution tessellation, which is most commonly a uniform grid but may also be irregular polygons (a.k.a. coverages) for efficient work at high-resolution (e.g. individual hill slope or catchment scale) for regional demonstrations. These grids or coverages for each variable in the model describe the location and spatial distribution of water fluctuations, forming the core of the water resources

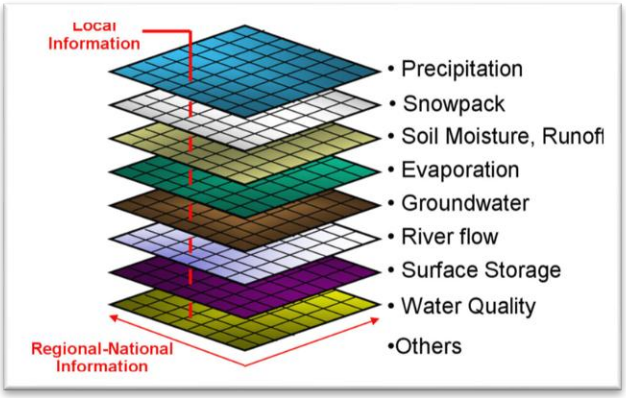

Figure 6.2. Conceptual suite of high-resolution national gridded water resources analysis and prediction products. High-resolution grids provide national, regional and local views.

availability information IWRSS will provide (Figure 6.2). The grids themselves are an important and useful data set, and from them a wide array of local, regional or national information products can be readily derived, extracted, or summarized.

Measures of uncertainty are required for each variable. To provide such measures in strict scientific terms can be quite challenging, but this is an important area for stakeholder participation and input. Ultimately the measures need to be meaningful for the stakeholder, and science has a particular talent for describing uncertainty in esoteric terms that do little to convey how much confidence the user should place in the information. In many cases even qualitative information may be sufficient, but the important point is that IWRSS will work through its social science framework to help determine effective metrics.

Each element of Figure 6.2 actually represents a family of related products needed to describe the variable, as illustrated by the National Snow Analysis (Figure 6.3). In each case, there are multiple state variables and fluxes at multiple depths or heights (e.g. depths in the soil, layers in the snowpack, heights of vegetation canopy, etc.) that are produced by the models and are important either in their own right or for model diagnosis. The suite of model outputs from this type of model is typically extensive, and at high resolution involves large data volumes.

The IWRSS objectives associated with a summit-to-sea modeling and prediction framework require integration of several capabilities, including spatially distributed land surface models, groundwater models, and estuary models, techniques for uncertainty estimation, verification of gridded analyses and forecasts, observations for verification and assimilation, appropriate methods for data assimilation, and relevant data and information storage, delivery, and archive mechanisms. Implementable solutions for all of these are available for assembly or within reach, but embarking towards this objective is a very large and complex task and requires a substantial commitment. In many cases, models describing fundamental domains of the water budget (e.g. surface water and ground water) are not yet well integrated, or include most of the necessary components but are weak in one or more key areas. There is significant overhead associated with setting up, pre-processing and operating the necessary high-resolution models even for a small region, and economies of scale are an important consideration. Therefore the spiral development model will be important here to continue and extend existing national capability, integrate models as needed, carefully determine what capabilities are needed regionally, and then implement capability regionally through the demonstration projects.

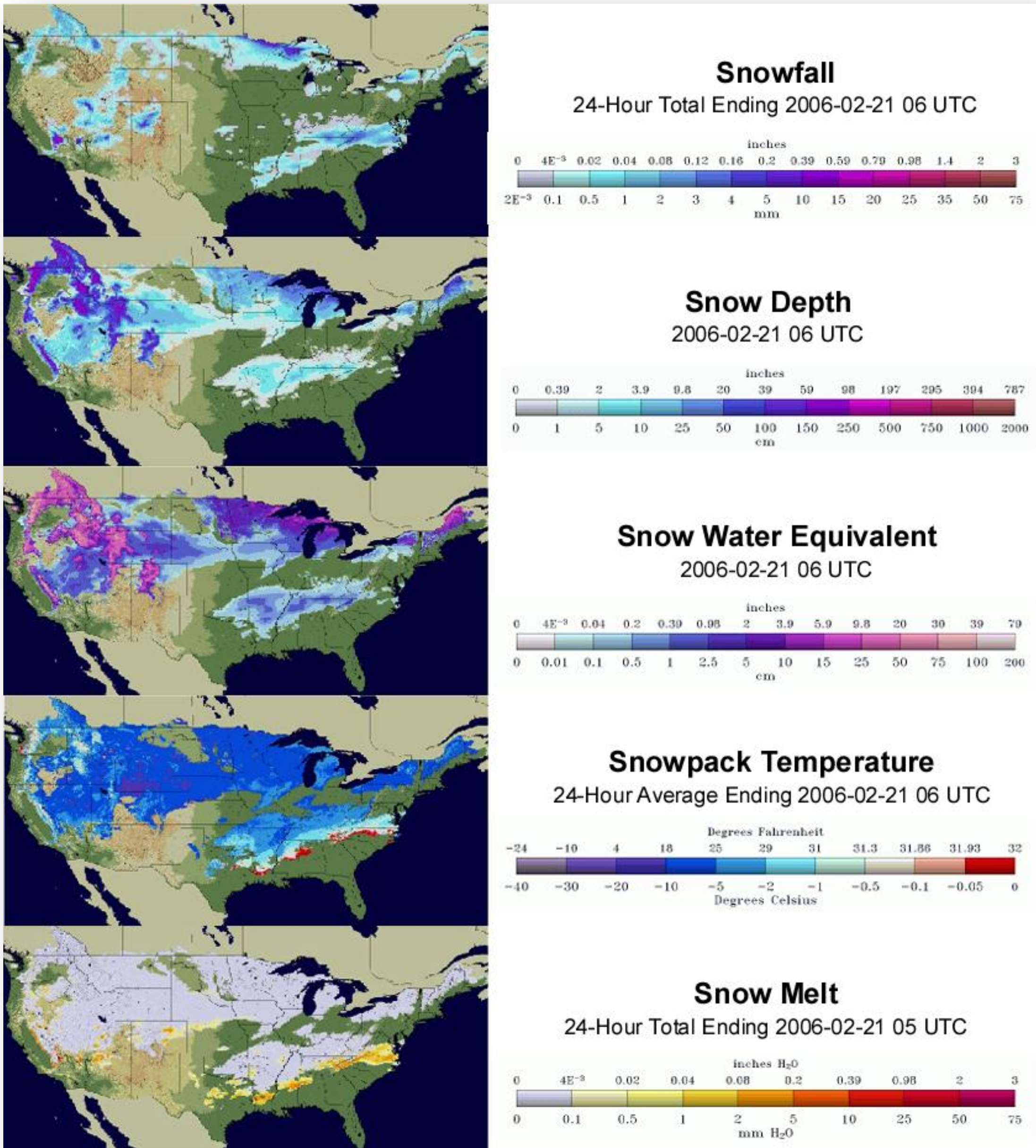

Figure 6.3. For each general water resources variable shown in Figure 6.2, there are several state variables and fluxes needed to fully describe the variable. These examples from the NWS National Snow Analyses depict the state of the nation's snowpack for one hour at 1 km^2 spatial resolution, and are based on all available ground, airborne and satellite snow observations assimilated into a land surface model that represents snow energy and mass balance. Similar operational procedures and data assimilation are required for each of the general variables shown in Figure 6.2.

6.2.2 Available Models and Forcings

A goal for this focal area is to operate a set of multiple models to exploit the different strengths of individual models and provide a measure of uncertainty via the range of outputs the models produce. The initial set of distributed land-surface model candidates for IWRSS implementation include the NOHRSC snow model (NSM) operated now for the National Snow Analyses, the NWS Hydrology Laboratory Research Distributed Hydrologic Model (HL-RDHM) which is a semi-distributed model being implemented regionally in NWS River Forecast Centers and nationally at the NOHRSC, the USACE Fast All-Season Soil Strength (FASST) model which uniquely includes river ice and soil mechanical properties, and a set of four land-surface models: the NCAR Common Land Model (CLM), the Community Noah Land Surface Model (Noah), the MOSAIC model, and the Variable Infiltration Capacity Model (VIC) . The latter four are incorporated in a package called the Land Information System[6] (LIS). They are commonly used by the broad land-surface modeling community and benefit from community development and support. The Noah model is used by the NWS and by the Air Force Weather Agency as a land-surface submodel for numerical weather prediction. A version of the USGS MODular three-dimensional finite-difference ground water FLOW model (MODFLOW) will also be implemented for operational groundwater modeling in IWRSS. One candidate version, GSFLOW, is already coupled to surface channel flow to provide information on low-flow conditions. All of these models are reasonably mature but will eventually require refinements to tailor them for IWRSS needs. More information and references for individual models is given in the glossary.

There a several options for providing numerical weather data to run these models for analyses (e.g. now-casts), short-term, mid-range and long-range forecasts. The National Snow Analyses use physically downscaled analyses and short-term forecasts from the Rapid Update Cycle (RUC) and North American Mesoscale (NAM) Weather Research and Forecasting (WRF) models, and these will be convenient starting points for analyses and short-term forecasts for IWRSS modeling at both national or regional scales. The Global Forecast System (GFS) can be used to extend forecasts to approximately seven days. Downscaling GFS is somewhat less straightforward than for the RUC and NAM because its spatial and temporal resolution decreases over time, but can still be accomplished. Long-term model forcings will come from the Climate Forecast System (CFS), but these will first require concerted regional skill assessments through NWS NCEP collaboration, historical water budget analyses and model reanalyses.

6.2.3 Model Reanalyses

Conducting long-term historical reanalyses of the water budget using the models to be used for analysis and prediction in IWRSS is a critical task needed for several purposes.

One purpose for reanalyses is to provide knowledgeable guidance for using current and forecast high-resolution gridded water information in regional river forecast models. River forecasting requires objective procedures to update state variables based on the long-term relationship between the forecast model simulation and the gridded model simulation. The procedures must account for biases between the two modeling systems or their forcings. Average long-term differences can be the result of different input data, inexact calibrations, varying algorithms and other factors. Typically in order to establish the relationship between the values

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[6] Source: http://lis.gsfc.nasa.gov/Overview/index.shtml

used for updating and the model values to be adjusted, a sufficient period of overlapping values is required in order to avoid a biased update. For this project at least several years of overlapping data from the high-resolution gridded models and the regional river forecast model will be required. The overlapping data sets must be analyzed to develop appropriate guidance for updating the regional river forecast model. The regional demonstrations will be the venue for performing these reanalyses and developing the guidance for updating the river forecast models.

A second purpose for reanalyses is to evaluate the historical skill of the models that are used for current analyses and forecasting. For this purpose the reanalyses should be closely coordinated with historical water budget studies planned by the USGS see (3.4.3 below), which will provide important forensic information to assess the ability of current models to represent what has already occurred. This is a critical step towards understanding appropriate levels of confidence for different situations and conditions.

Together with the detailed USGS water budget studies, the reanalyses data sets will be useful in their own right for providing historical water resources information. They may be used simply for historical context, for evaluating trends, or for reforecasting techniques and design studies, where current conditions are compared to similar conditions in the past to understand what happened when these conditions occurred previously. Thus the reanalyses data sets are not just an internal diagnostic product. IWRSS must also take these data sets into consideration for integrated information and service delivery. As illustrated by Figure 6.3, the volume of data and information will be very large when multiple state variables at high spatial and temporal resolution, multiple models, and extended time periods are involved. As an example, the National Snow Analyses main operations system recycles about 8 Terabytes of disk storage every few days, just for snow information. Key tasks necessary to prepare for reanalyses are to carefully evaluate what information needs to be retained from the historical model runs, and carefully plan the storage and data delivery service that will be required to support this very large data set. The USGS EROS Data Center should be considered for this purpose, given their substantial capability and experience in handling very large data volumes.

Other key questions to resolve prior to execution of the reanalyses are the choice of historical forcings to be used, how to handle data fusion and assimilation, and practical issues of freezing the versions of the land surface model used in the reanalyses. The NWS North American Regional Reanalysis (NARR) is widely considered to be the best atmospheric forcing data set for this type of work, but has a well-known bias associated with snow (melts too fast), especially in the west. The IWRSS reanalysis will need to carefully consider the impact this bias may have on the reanalysis objective of determining biases between contemporary analyses and forecasts and the calibrated river forecasts models. The data assimilation question is more problematic; most of the observations used in contemporary assimilation of land surface models, including most of the remote sensing observations, are either incompletely or unavailable for the past. In most cases it won't be possible to perform a reanalysis that fully represents the contemporary operation of the land surface model and data assimilation framework, which will reduce the effectiveness of the bias assessment and regional river forecast model guidance resulting from the reanalysis. The last question is about a requirement (whether there is one, and how to handle it) to operate a version of the land surface model and data assimilation framework "frozen" in the form used for the reanalyses, to ensure that the bias adjustment guidance remains valid. This can generate a conflict between supporting the need for providing guidance for regional river forecasting and providing the best possible water resources information as model capabilities improve.

6.2.4 National, Regional and Local Modeling

Models are nothing more than a way of organizing information to help us understand, explain and predict processes and behavior. They should be thought of as tools in a toolbox – there are different tools for different purposes, and several different tools are usually necessary to accomplish a complex job well. Relying on a single model or modeling approach for water resources results in a narrower view of water availability and increases risk of missing or overlooking important information. Thus multiple models and modeling approaches will be used within different aspects of the IWRSS project.

Modeling needs for IWRSS relate to specific objectives and span a wide range. At one end, there is a need for nationally consistent analysis and prediction of fundamental water budget components such as snow, soil moisture, and runoff. At the other end, there are needs for highly specialized modeling tools to address unique, site-specific issues of concern to stakeholders – how river ice affects a particular reach of a river, how agricultural practices in a single watershed district will affect water quality downstream, how close salt water will encroach towards a freshwater intake on a river during low flows. In between, there is a large need for regionally consistent tools for river and flood prediction and water management. There is considerable diversity in physical drivers between regions, however, which necessarily requires different regions to focus on different modeling needs. Hurricanes and storm surge may be the dominant driver in one region, while rain-induced snowmelt may be the dominant driver in another. All three scales – national, regional and local – need to be addressed coherently, but different approaches are needed at each scale to accomplish specific goals. The general technical approach of IWRSS (e.g. interoperability, data synchronization, etc.) is designed to support and facilitate the use of a wide range of available modeling tools suitable for different scales by providing ample mechanisms for crosstalk and interplay.

High-resolution land-surface models, implemented nationally, can provide a great deal of water availability information useful at regional and local scales. As illustrated in Figure 6.2, one can "drill down" through a vector of all of the water budget information at a single grid cell to provides local information, or examine clusters of grid cells comprising catchments or watersheds. The comprehensiveness, richness and consistency of this information make it very versatile. Where necessary, this information can be sharpened regionally or even locally by employing the same type of model over smaller domains at higher resolution. The IWRSS concept of operations includes making this type of model accessible for regional and local use. For this focal area, a key role of the regional demonstration is to learn about the behavior of these models in an operational setting, develop effective mechanisms to use the output of these models within the regional river and water resources forecasting framework and workflow, and as necessary incorporate the models (or parts of them) into regional systems. Because of the high overhead of operating these models (partly a large preprocessing and computational load, partly a lot of complexity and moving parts to worry about in an operational implementation) IWRSS will begin by implementing these models at the national IWRSS support center to begin generating a core suite of products and provide a basis to explore these models together with the regional centers. As learning occurs at both scales, the modeling will be implemented nationally and/or regionally as required. A range of scenarios to be examined for national and regional implementation include operating the models at higher resolution at the regional scale, operating the models with different forcings nationally and regionally to create broader ensembles, and operating the models nationally and providing only the output to regional centers to allow them to focus on other tasks. As part of the regional effort, this focal area will explore USACE innovations in high-resolution modeling that use a very high-resolution polygonal mesh framework to efficiently increase the effective resolution of land surface models without the overhead of fine resolution grids. To facilitate interpretation and use of multiple models in the operational forecasting environment, the development of a comparative analysis toolkit has been identified as a first-order necessity. The toolkit will function within the CHPS/CWMS environment and will contain tools to allow rapid assessment of the differences between outputs of different models. Through the interoperability and data synchronization elements of the technical theme, regionally produced model state information can be gathered nationally, where grid-to-grid and grid-to-polygon difference fields can be automatically produced and returned to the regions as a data service (see second spin-off service below) to feed the comparative analysis toolkit.

There are two important "spin-off" services of this focal area. First, all of the candidate land-surface models for national application are stand-alone systems that are assembled from a series of functional "packages", where each package describes specific physical processes in different ways. For example, one model employs a particular snow package X, another employs a different snow package Y, and so forth. In most cases, packages are functional blocks within the model codes. The group of models considered here provides several different choices of sub-models describing processes for snow, soil moisture, evapotranspiration, and runoff. While working on this focal area, IWRSS will actively look for opportunities to disaggregate these components from their "parent" models, and develop necessary adapters and plug-ins to make them individually available for use in CHPS and CWMS. This effort will greatly expand modeling capability and flexibility within these key systems, and expedite progress towards being able to run regional multi-model ensembles.

The second service to be spun-off from this focal area is centralized pre-processing and downscaling of weather forcings. The national-scale implementation of land-surface models involves substantial overhead for acquisition and pre-processing of numerical weather observations, analyses and forecasts. Data from an array of sources are ingested, downscaled to high-resolution, quality controlled, and reformatted in preparation for use in models. Modeling applications at all scales require these same tasks to be performed, so this focal area will work to provide this service centrally through contemporary catalogue and content delivery mechanisms such as Unidata's Thematic Real-time Environmental Distributed Data Services[7] (THREDDS). Local modeling applications can tap into this service as needed. Within the NWS CHPS framework, for example, pre-processed national surface air temperature grids delivered through a common service can be "finished" locally for CHPS-specific applications, with a substantial reduction in local pre-processing demands. USGS State Water Science Centers have a similar need for a pre-processing service to provide a full suite of weather forcing parameters to support a variety of modeling purposes, as do a variety of other partners and stakeholders such as CUAHSI.

6.2.5 Coastal and Estuary Modeling

The physical interface between terrestrial and marine waters is critical for several reasons. River flow is routinely altered as it approaches the coast by tidal effects and salt-water intrusion. Storm surge causes more complex alterations. Marine circulation is altered by the influx of less-

[7] See Glossary for more information on THREDDS.

buoyant fresh water from rivers. There are significant ecosystem consequences of these effects for both the terrestrial (river) and marine components.

Three-dimensional models describing the circulations of near-shore and estuary waters are operated by NOAA's National Ocean Service (NOS) and the USACE Coastal and Hydraulics Laboratory. Projects are underway to expand the coverage of these models, particularly the ADCIRC model, with objectives to include the full extent of the national coastline. Bringing this information together with the terrestrial component is a key task for the IWRSS project. Eventually, coupled modeling systems may be employed. First-order tasks, however, are to use the technical capabilities brought by IWRSS to significantly improve communication of marine information to the river forecasting community and vice versa, and begin working towards coupled systems by identifying intersection points between the different frameworks where information needs to be exchanged routinely, and developing prototype methods for using the information. At least one IWRSS regional demonstration will offer opportunities to work on this task.

6.3 Implement enhanced flow/flood forecasting and water management capabilities

This element is concerned with a number of operational intersections involving flow forecasting and water management, flood forecasting, levee and dam failures, river ice, climate, drought mitigation, water supply, coastal modeling, geo-intelligence and enterprise GIS, and research and development. Several of these are primarily concerned with developing interoperability between the NWS Community Hydrologic Prediction System (CHPS), which the NWS is currently implementing at River Forecast Centers, and the Corps Water Management System (CWMS), which is in use at many USACE District offices. The two systems have many similarities but serve different functions; each has tools and information useful to the other, and both architectures allow for new tools and information to be readily incorporated. IWRSS will work to implement interoperable databases with these systems, system incorporation of national gridded water resources analyses and forecasts products and inundation map products.

Early opportunities for immediate IWRSS demonstration include sharing of dam failure modeling capability through systems integration and interoperable databases, and implementation of river ice modeling and forecast capability. To eliminate time-consuming model set-up during threatening events, USACE has prepared dam failure models that can be downloaded when needed, initialized with reservoir stage information, and operated for scenario analysis. IWRSS interoperability development will enable NWS access to these prepared models and routine updates of reservoir stage information. USACE has also developed river ice modeling and forecast tools that, coupled with gridded degree-day information available from the NWS National Operational Hydrologic Remote Sensing Center (NOHRSC), can enable river ice modeling at NWS field offices. IWRSS will work to implement this capability as well.

Collaboration on drought and climate issues is included in this element. The focus here is on identification of system-level gaps and identifying sound approaches to fill them. Evaluation of the regional and local scale skill of climate models is an essential step before IWRSS can reliably use this information to provide long-range predictions.

6.4 Leverage water resources science studies and exploit available data and information through innovation and assimilation

The significant challenge of producing summit-to-sea water budget analyses and predictions demands aggressive exploitation of available information. This of course applies to observations, which are discussed in the following section, but it also applies to other types of readily available information that is less commonly used in modeling environments. Three specific sources of information that will be important to IWRSS are described below: historical water budget studies conducted through the USGS Water for America initiative, USGS water use statistics, and USDA agricultural crop progress data. It is important for IWRSS to seek other useful information sources and strive to find ways of exploiting them.

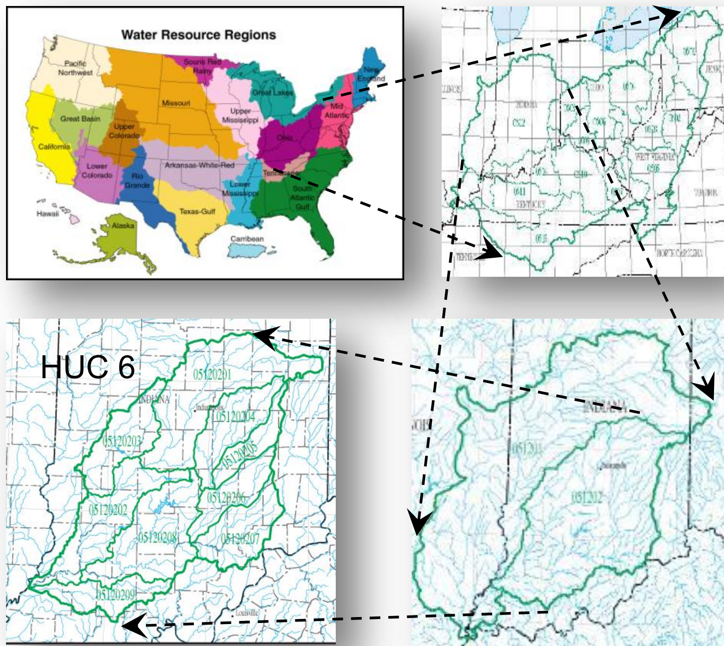
6.4.1 USGS Water for America

As discussed previously in Section 6.2.3, information describing the historical water budget at different scales is critically important for several reasons. One part of producing such information involves conducting model reanalyses through a historical period, as described in that section. The other key part is to conduct comprehensive water budget studies at the scale of moderately sized watersheds to analyze the modeled information together with other information sources, identify important trends, and place the model reanalyses results into proper context. The IWRSS project will leverage and benefit from the USGS Water for America (WFA) initiative, which plans to complete period-of-record water budget analyses for all HUC 6 watersheds over next 10 years.

A pilot project for WFA was conducted in the Great Lakes region, providing a comprehensive view of the historical water budget from 1955 to the present. The study provided extensive analyses of surface water trends, long-term changes in groundwater dynamics, and other related factors that provide context for IWRSS water budget nowcasts and forecasts. For a hypothetical example, an IWRSS forecast of extended dry conditions may be similar to a period many years ago, but groundwater conditions may have been quite different then, so different low-flow results should be expected in the forecast. The WFA studies provide the information needed to make such an assessment. Moreover, the intensive analysis of WFAS forges a path for some difficult technical aspects of IWRSS, such as interbasin transfers, water withdrawals and consumptive use. The synergy between WFA and IWRSS is two-way. By beginning operational production of water budget analyses and forecasts, IWRSS carries knowledge gained by WFA into the future, extending the period of record.

Implementation of the WFA initiative is planned on a regional basis. WFA nationwide study activities will be organized around the 21 Water Resource Regions established in USGS Circular 1223 and will be conducted at the six-digit hydrologic unit code (HUC-6) level (Figure 6.4). Within each HUC-6 watershed, the studies will focus on accounting for system gains and losses, including precipitation, infiltration, recharge, streamflow (runoff and baseflow), evapotranspiration, ground water and surface water withdrawals return flows, consumptive use and interbasin transfers. The studies will examine trends in major water budget components.

The implementation plan calls for six to seven regional (HUC-2) water budget studies to be started every three years, completeing the nation in 10 years. Priority regional study areas for first-tier implementation of WFA studies have been identified but not finalized. They include Alaska, California, Upper Colorado, Souris-Red_rainy, Upper Mississippi, Arkansas-White-Red, Mid-Atlantic, and South-Atlantic Gulf. Within selected regions, nine Focus Area Studies (smaller study areas, starting three every three years) are planned to concentrate on the themes of groundwater – surface water interaction and ecosystem flows and habitats. These focused studies may also look at the issues of water quality's influence on water availability, changing land use, and effects of current and future demand.



Water for America is an independent intiative within the USGS, however the historical context these studies would lend to the IWRSS project is quite valuable and is an important consideration for establishing IWRSS regional demonsration projects. The results of the historical water budget studies should be physcially consistent with the results of the model reanalyses conducted for IWRSS. In fact, the WFA studies themselves require a significant amount of modeling, and there may be opportunities for modeling collaboration to help ensure consistent results. There is opportunity to coordinate the selection of WFA study areas and IWRSS regional demonsration areas to facilitate collaboration.

Early tasks involve coordination between the selection of study and demonstration areas and developing specific plans and methodologies to coordinate the historical water budget studies with the model reanalyses. The reananlyses workgroup should include WFA management and relevant state water science center representatives in early methodological discussions.

6.4.2 USGS Water Use Statistics

Understanding water use and its effects on the water budget and water availability is a challenging task but is fundamentally necessary to reach IWRSS objectives. There are two main aspects important to IWRSS: one focused simply on better understanding of water availability and use in the overall context of operational analyses and prediction, and another focused on providing a first-order accounting of water use in the water budget.

First, to have a better sense of the motivations of stakeholder and constituent groups, the drivers for water availability, and of who holds the risks when water is scarce, it's important to possess at least a fundamental understanding of how and how much water is used at various scales. Second, the natural water budget as described by equations 6.1 and 6.2 and most hydrologic and land-surface models neglects consumptive use, which in many areas constitutes a large proportion of available water. In hydrologic models that empirically relate stream flow to forcing terms, water withdrawals and use are often accounted for implicitly through the calibration process, where they may be incorporated into other parameters or left as a residual uncertainty. In full water budget models like those prescribed for IWRSS, some aspects of water use may be accounted for indirectly if enough information about land use and practice is incorporated into the modeling framework. For example, use of water for irrigation agricultural may be accounted for in the soil moisture and evapotranspiration terms if enough is known about the crops and irrigation practices and this is represented within the model, or if accurate measurements of these terms are available to assimilate into the model. In most cases, neither the model representation nor the observations are sufficient. In the IWRSS framework of gridded high-resolution water budget analysis and prediction, a geospatial estimate of water use is needed.

The most comprehensive assessment of water use in the U.S. is provided by the USGS National Water-Use Information Program, which has responsibility for compiling and disseminating the nation's water-use data. The USGS works in cooperation with local, State, and Federal environmental agencies to collect water-use information. USGS compiles these data to produce water-use information aggregated at the county, state, and national levels. Every five years, data at the county level are compiled into a national water-use data system. Although the resulting data and statistics are not exhaustive, the compilations are one of the few sources of information on water use across multiple scales. Reports provide information on eight categories of water use—public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power.

For purposes of providing general information and context to inform the IWRSS project, the USGS compilations are an excellent resource. A straightforward task for the IWRSS project will be to mine recent compilations (2005 will be released soon, and previous years are readily available) and produce a set of national GIS layers for the IWRSS eGIS framework. Derivatives of these, such as maps showing trends or changes, can also be easily produced. In the context of other eGIS information, water budget analyses and predictions, and derivative products, the geospatial water use information will be useful.

For purposes of accounting for water use within operational water budget analysis and prediction, this data set has less direct utility because of the coarse temporal resolution, but with qualitative inference about underlying temporal patterns of usage, may still provide useful insights for routine operational purposes. This potential utility will be examined within the IWRSS analysis and prediction framework. At a minimum, this information may support a qualitative assessment of uncertainties in the water budget analyses and predictions.

6.4.2 USDA Crop Progress and Condition

The land-surface schemes used in the gridded high-resolution models for IWRSS generally contain representations of different land cover types including various agricultural crops. Parameterizations for these schemes are typically static, and follow a simple prescribed seasonal pattern. This is often sufficient for research purposes, but for operational prediction deviations from prescribed patterns can have important consequences. The same is true for empirical models calibrated to long-term average conditions. For example, a cold and wet spring preceding the 2008 Midwest floods delayed planting and emergence of crops, most notably corn. By early summer, corn crops were two-to-three weeks behind their normal progress. Less rainfall was lost to interception and evapotranspiration; consequently runoff was faster and higher than usual for this time period. Forecasters at the NWS North Central River Forecast Center had difficulties achieving similar runoff in the forecast models because the models were calibrated for conditions with more mature crops. Fortunately, for many agricultural regions of the U.S. crop progress is closely monitored for economic reasons and data are readily available weekly.

During the growing season, the U.S. Department of Agriculture Agricultural Statistics Service provides weekly reports and data listing planting, fruiting, and harvesting progress and overall condition of selected crops in major producing states. Crop progress and condition estimates are based on survey data that are collected each week from early April to the end of November. The Crop progress and condition surveys are non-probability surveys that include a sample of more than 5,000 reporters whose occupations provide them opportunities to make visual observations and frequently bring them in contact with farmers in their counties. Based on standard definitions, these reporters subjectively estimate progress of farmers' activities and progress of crops through their stages of development. They also provide subjective evaluations of crop conditions.

With county-level granularity, the crop progress and condition reports describe the topsoil (upper six inches) and sub-soil moisture (qualitatively), the general crop condition, and crop progress percentages (in terms of phenological stages). Information is provided for corn, soybeans, cotton, sorghum, barley, oats, wheat, rice and peanuts. Combined with basic knowledge of crop water use at different stages of development, these data provide IWRSS with a more dynamic capability than relying only on static vegetation parameterizations. A task for IWRSS is to collaborate with USDA to work towards a convenient data feed that can support weekly national mapping of crop progress for input to water budget models.

6.5 Improve use of observations and surveillance

As with other modeling frameworks, the premise for using observations in IWRSS is to achieve the best possible analyses of current state conditions, which then serve as initial conditions for forecasts. Data assimilation schemes seek to update current states in the model with observations, balancing the inherent uncertainties in the model state variables, which stem from imperfect weather forcings and model physics, with the inherent uncertainties in the observations, which are also imperfect. A variety of sophisticated approaches are commonly used for data assimilation.

One of the principal advantages of the high-resolution land surface models prescribed for IWRSS is that as a general class, they are very conducive to assimilation of observations. The geospatial nature of the models, particularly as high-resolution grids, is well suited to incorporation of remote sensing observations, and with high-resolution, individual grid cells are more easily related to surface observations at point stations. An advantage of using the LIS models in particular is they benefit from broad community support, much of which is focused on improving methods of data assimilation. Consequently, these models employ multiple schemes for assimilating a wide variety of observations, and these capabilities are regularly improved.

Ideally, a rich, comprehensive and accurate set of observed data would be available for updating each of the terms of the water budget. This is unfortunately not the case. Observation qualities differ for each of the terms and vary both spatially and temporally. Sophisticated data assimilation schemes often expect a regular data set with well-known error characteristics. This is sometimes the case for remotely sensed data but rarely the case for surface observations. Consequently, operational data assimilation covering the gamut of the water budget requires a broad-minded multi-sensor data fusion approach, where a range of assimilation schemes are employed in response to the type and quality of available information. The goal is to use as much information as possible, and not neglect information when it fails to meet ideal expectations.

6.5.1 Surface Observations

One thrust for IWRSS will be to aggressively seek out surface observations of key water budget terms. This was the approach taken for the National Snow Analyses, where over a period of a few years, concerted regional efforts resulted in an increase in nationally reported snow water equivalent observations from about 800 sites to over 4000 sites. This required dedicated effort by NWS regional offices to seek out and engage existing measurement networks and make sure that observations already being collected were entered into the national system, and collaboration by NOHRSC to show that the data were being used. Reasonably extensive surface observations are readily available for precipitation, snow water storage, groundwater and river flow, although the quality and coverage vary. With a few regional exceptions, soil moisture observations are quite limited. A key task for IWRSS will be to gather as many of these observations as possible, working through the national support center and network of regional and local offices.

IWRSS will need to take advantage of unconventional and qualitative surface observations to help constrain model states. For example, the weekly crop progress and condition reports noted in the previous section include descriptive characterizations of the topsoil and sub-soil moisture states on a county-by-county basis. Subjective and qualitative, the characteristics are described in fundamental categorical terms (e.g. dry, wet, etc.) and in terms of impacts on crops (e.g. plant stress levels). While these don't lend themselves easily to conventional data assimilation schemes, in an information-poor regime these data will be very valuable. A task to be worked through the operational analyses process in IWRSS is to learn how to effectively use this information. It may be that derivative water budget products, such as maps of modeled water stress, will be important tools for enabling comparison to qualitative observations.

6.5.2 Satellite Surveillance

Remote sensing provides information on precipitation, snow cover, snow water equivalent, soil moisture, soil moisture deficits, vegetation type, vegetation structure, vegetation phenology, evapotranspiration, groundwater, water temperature, and water quality. Each of these topics is essentially a sub-discipline of remote sensing science; volumes of work have been produced on each of these, and any given remote sensing conference or journal is likely to provide recent research results for each topic. A surprisingly large number of satellites currently provide this information, and in the coming decade more are planned that will substantially improve water resources observations. A variety of airborne assets are also available.

This is a major focus area for IWRSS and will require a significant increase over current efforts. The reason this is true is straightforward. Current river-forecasting techniques very effectively use observed stream flow as a model constraint. When the objective function is singular and well observed (i.e. stream flow at a gage), a wide variety of models can be trained to fit that function. In the case of the objectives for IWRSS, the objective function non-singular and poorly observed – it is diverse and highly under-constrained. The objective function is the space-time series of all water budget terms at all locations. Most or all of the remote sensing capabilities noted above will need to be exploited to help constrain IWRSS models. Gathering or producing this information, and making it available for national and regional modeling within the IWRSS framework will be one of the purposes of the national IWRSS support center.

In addition to exploiting currently available satellite information, IWRSS needs to focus on preparations for two future fronts. The first is the GOE-R satellite, which is expected to be launched in 2015. This satellite marks a radical departure from previous geostationary satellites, which had only a panchromatic (i.e. "black and white") band in the visible portion of the spectrum. That configuration allowed basic snow cover mapping but provided little additional information useful to water resources. The GOES-R Advanced Baseline Imager (ABI) is a multi-spectral sensor with several bands in the visible portion of the spectrum, enabling it to measure sub-pixel fractional snow cover, snow albedo, a variety of vegetation characteristics including ET, stress and phenology, and variables related to water quality. The sensor characteristics are similar to the current NASA Moderate Resolution Imaging Spectrometer (MODIS) satellite, but the major difference is that GOES-R is geostationary and provides imagery several times each hour throughout the day. This has large implications for water resources observation. For example, one of the problems that has made use of satellite-derived ET observations difficult is that they are only provided once or twice a day from polar-orbiting satellites like MODIS. Depending on local conditions at the particular time of the satellite overpass, the observed ET may or may not be representative of ET throughout the day. With GOES-R, it will be possible to observe ET hourly or even every 15 minutes, providing a powerful tool to observe diurnal patterns and constrain models. Because the time frame for GOES-R and full implementation of IWRSS summit-to-sea modeling coincide, efforts within the IWRSS project should be focused on exploiting this new sensor.

The second future front for IWRSS to prepare for is a suite of three planned experimental satellites dedicated to observing water resources variables. While these satellites are considered experimental, this is a semantic distinction that just means there is no guarantee that the satellite data will be available after the few years of the experiment. It's essential, however, to demonstrate use of the data these satellites collect in operational applications, otherwise it's exceedingly difficult to make a case for an operational version of the satellite. An extensive planning process over the past ten years has culminated in three planned water resources satellites. The first is designed to measure soil moisture. The second will measure river and lake stage, and the third will measure snow water equivalent. What is unique about these is that for the first time, these sensors will be optimized for the water resources measurements of interest. This is in contrast to today's situation, where spaceborne observation of soil moisture and snow water equivalent is based on very low-resolution sensors that were optimized for ocean observation. None of these sensors will replace the need for surface observations, but will provide important augmentation. It will be important for the IWRSS project to engage in these satellite missions, steer their requirements to help meet operational needs, and prepare to use the observations when they become available.

6.5.3 Airborne Surveillance

Four airborne surveillance focus areas are important to IWRSS goals. The first is operational collection of snow water equivalent and soil moisture observations through gamma radiation detection. The second pertains to high-resolution digital elevation data collection through airborne Light Detection and Ranging (LIDAR) techniques. The third pertains to airborne reconnaissance of relevant water resources events and phenomena. The fourth pertains to guiding development of new airborne observation capabilities.

The NWS has relied on airborne snow water equivalent observations for over 30 years and operates two aircraft for this purpose. The measurement technique is based on attenuation of naturally occurring terrestrial gamma radiation (emitted from radio isotopes found in soil) by water in the snowpack. The attenuation rate is well known (it is a function of the atomic mass cross-section of water) and well behaved (almost linear). The phase of water is unimportant, thus the technique is equally useful for snow water equivalent and for soil moisture. The NWS routinely flies fall soil moisture surveys in selected regions to observe antecedent soil moisture conditions going into winter. Due to the general paucity of soil moisture observations, one task for IWRSS will be for the NWS airborne program to begin collecting summer soil moisture observations to support modeling and data assimilation.

High-resolution digital elevation data collected with airborne LIDAR instruments are extremely valuable for several applications. Many communities and state and federal agencies are moving quickly to obtain these data for areas of interest. All three IWRSS Consortium agencies are actively engaged in collecting LIDAR data, either using their own sensors or contracting the work out to commercial vendors. These data are required for flood inundation mapping, but are also important for many other water resources applications, including observation of hydraulic cross-sections adjacent to rivers, and for supporting high-resolution local and regional modeling. The important task for IWRSS to perform is to provide a coordinating framework that helps identify available LIDAR data, guide investment in new data collection, and make LIDAR data accessible for IWRSS interests. This task does not fall solely on IWRSS; the problem of rapidly increasing but poorly coordinated LIDAR data collections is becoming widely recognized and other efforts are underway to try to organize these activities. It is simply important for IWRSS to be engaged in this process, represent project interests, and work to improve accessibility and use of these data for IWRSS applications.

The third focus area pertains to airborne reconnaissance activities for important water related events or phenomena. Through a number of mechanisms and organizational entities, a wide array of aerial reconnaissance information is collected ad hoc in response to floods, river ice jams, levee breaks and similar water-related phenomena. This includes professional-grade photogrammetric imagery, a proliferation of oblique digital photography and video (static web-cams, bridge-cams, and the like could also be considered in this context), and a variety of anecdotal observations. Much, or perhaps most of this information goes unused in science applications due to lack of awareness that is exists, lack of time to search for it, or lack of operational applications or tools to help use the information effectively. Moreover, much of this information is short-lived and ephemeral, and its real value may come later during calibration or validation activities. Because IWRSS is broad in scope and provides a certain organizational framework, a useful task for IWRSS to perform is to institute guidelines and procedures for collecting, distributing and archiving such information, so that this information can become better integrated within the overall knowledge base for a given area. This task overlaps significantly with the technical information services theme, but emphasis here is on making better scientific use of the information. There are many ways this might be accomplished, and while this is not the highest priority for IWRSS it is nonetheless worthwhile.

The fourth focus area is concerned with guiding development and application of new airborne sensing capabilities to support water resources analysis and prediction. As with LIDAR data and photoreconnaissance, many capabilities exist but just aren't currently used for water resources applications due to a variety of reasons, few of which have to do with lack of capability. Moreover, a large research and engineering enterprise is concerned with developing new airborne sensing technologies, and often the focus of this enterprise is on observing water resources. It would be helpful for IWRSS goals if these activities were informed about IWRSS needs and engaged with IWRSS to try and meet them. Airborne platforms don't provide the coverage that satellites offer, but can be implemented much faster and targeted to specific needs. Given the importance of water resources and the need for observational data, it's appropriate for the IWRSS project to engage in activities related to new airborne sensor development and work to guide investment opportunities to benefit operational goals. There are frequent opportunities for advancing sensors for light aircraft, heavy aircraft, and unmanned aerial vehicles. A task for IWRSS is to work to engage these opportunities.

6.6 Quantify uncertainties, validate water resources forecasts

Contributing to the knowledge base and decision-making capability of stakeholders requires measures of uncertainty associated with the information and products IWRSS delivers. This topic sometimes seems like a Holy Grail – a critically important but somehow unattainable goal. The important point for the IWRSS project to consider with respect to uncertainty metrics is to not let perfect get in the way of the useful. Scientists generally want to see rigorous quantitative estimates of error and uncertainty, and that is indeed the goal for IWRSS. But it is important not to forget that customers and stakeholders often will be satisfied with something less than this, a solid qualitative assurance of the level of confidence in the information. For IWRSS what is most important is that the measures of uncertainty are relevant to the decision-making process used by stakeholders. A root-mean-squared-error (RMSE) of less than 2% volumetric soil moisture is an admirable science goal and an accurate reflection of absolute uncertainty, but it doesn't necessarily inform decision-making. A more meaningful expression for a farmer interested in reducing fertilizer runoff may be a categorical "Go", "No Go", or "At Your Own Risk" expressed geospatially and based on sound reasoning and an understanding of the influence soil moisture has on runoff potential. So, first and foremost, the stakeholder communication component of IWRSS must be employed to help identify these needs. This example also serves to illustrate the point that more than one uncertainty metric is needed, and a certain degree of reasoning is likely necessary to help translate quantitative metrics into information useful to consumers. Thus the quantification and expression of uncertainty will be major activity area in IWRSS; it cannot be relegated to something to be done at a later time. IWRSS will focus on a goal of applying conventional scientific measures, but as quickly as possible additional measures will be incorporated that involve reasoning and understanding of stakeholder needs.

A significant problem for IWRSS in this regard is the under-constrained objective function of estimating space-time series of all water budget terms at all locations. The relatively few observations that are available are needed for updating model states and improving current analyses. There is very little independent information available to provide a quantitative handle on uncertainty. Under these circumstances conventional measures tend to rely on less informative methods, such as assessment of spatial or temporal variance, comparison of differences between models (either absolute or probabilistic), or evaluation of residual differences at point locations after assimilation of observations. These are only partial descriptions that reveal one or more aspects of the uncertainty, but are far from being absolute or comprehensive. Some computationally intensive methods, such as Monte Carlo simulation, may provide this utility for small areas but are not practical for routine regional and national operations. Therefore a significant task for the IWRSS project will be to identify a suite of appropriate metrics to implement. This will be addressed in part through the efforts of a working group focused on this activity

Validation of water budget analyses and forecasts is closely related to quantification of uncertainty, and suffers from many of the same problems. Here the focus is more on developing consistent metrics to gage the skill and performance of analyses and forecasts post facto. This is a somewhat simpler problem because future observations can be used (not quite independently, but more so) to evaluate current forecasts. The goal for IWRSS here is to establish automated validation procedures that routinely assess and map skill for different forecast periods. The skill metrics and evaluation procedures have to be initially developed, but then implementation and automated validation is straightforward. Posterior analysis of geospatial and temporal trends in skill may be useful metrics for describing uncertainty.

6.7 Conduct research and development

As stated in at the beginning of this chapter, IWRSS is not a research instrument per se. There are numerous mechanisms and facilities already in place to conduct general and applied research. The IWRSS project is instead an operational instrument designed to address the needs of a wide range of water resources stakeholders, and to accomplish this, aggressively mine and assemble existing capability. The breadboard concept, borrowed from electrical engineering, is an approach to assemble necessary capabilities as directly as possible to create an operable system and begin learning about it – what the problems are, what's missing, what needs to be improved, and how to make components work together. This forms the baseline for spiral development, through which additional existing capabilities can be introduced to the system, or new investments in research and development can be targeted to address specific needs. In this sense IWRSS provides an organizational framework for the development of new science capabilities.

6.7.1 Sources for Research and Development

Several Consortium laboratories and science centers, internal and external test beds, academic and possibly commercial partners are potential mechanisms for research and development to support IWRSS goals. Within NOAA, the NWS Office of Hydrologic Development (OHD) Hydrologic Science and Modeling Branch includes research groups focused on hydrometeorology, hydrology, hydraulics, hydrologic ensemble prediction, and hydrometeorological design studies. The NOAA Hydrometeorological Testbed (HMT), a field-oriented program designed to test new observing systems and models, is managed through the Environmental Systems Research Laboratory (ESRL) in Boulder, CO, where there is significant atmospheric science and technical expertise. Within USACE, the Engineer Research and Development Center (ERDC) consists of several laboratories and research centers across the country, each focusing on different major thematic areas that include fisheries, aquatic ecosystems, limnology, snow and ice, coastal systems, hydraulics, and information technology, among others. The USGS has national and regional research facilities specializing in water resources topics, and each state has a State Water Science Center with significant R&D

capabilities. Thus without even considering academic or commercial capabilities, it is clear that the IWRSS project can acquire much of its R&D needs close by.

Examining one of the USACE ERDC labs in detail reveals the depth of science and engineering resources that IWRSS can draw from for its R&D needs. The Cold Regions Research and Engineering Laboratory, in Hanover NH has a total on-site staff of 262 with 120 scientists and engineers. Of these there are 34 PhD scientists and 48 Masters scientists. Programmatically, about 44% of CRREL's activity is focused on USACE civil works, and 30% is focused on geospatial research and engineering. Some of CRREL's major programmatic areas include hydrology and hydraulics, water resources geospatial applications, terrain processes and properties, environmental fate and transport geochemistry, and biogeochemical processes in Earth materials. CRREL also houses the USACE Remote Sensing and GIS Center of Expertise, which provides mission support to all aspects of the USACE at project, program and agency levels. This group conducts geospatial research and development, is responsible for a variety of USACE geospatial water resources applications including CorpsView, CorpsMap, the National Levee Database, and the Corps Water Management System GIS, and is responsible for USACE division and district eGIS implementation. For the terrestrial side of IWRSS, CRREL is an especially important and diverse asset. Other facilities noted above are similarly strong in their respective areas.

One academic program of particular relevance to the IWRSS project is the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI). Consisting of NNN partner universities and institutions, CUAHSI provides a nexus for academic research in hydrology and water resources. Of particular interest are three CUAHSI programs: 1) the Hydrologic Information System, which is incorporating state-of-the-art techniques for distributed information services, 2) the Community Hydrologic Modeling and Prediction System (CHMPS), which is a research analogue to CHPS and CWMS and is a potential source for new models and tools for these operational systems, and 3) the WATERS project, which is a field-oriented watershed testbed framework to focus integrative synthesis studies. IWRSS is already coordinating with all three of these programs to move towards a paradigm where the overall operational framework is similar to the overall academic research framework, creating a parallel pathway where operations can easily draw from the research community.

6.7.2 Pathways for Transitioning Physical Science Research to Operations

Thus within this framework, there are three principal mechanisms to coordinate and facilitate the transition of research to operations. First, the collaborative organizational framework of IWRSS provides a communication and organizational structure for individual research and development facilities to engage at multiple levels on specific projects or activities. This mechanism leverages normal R&D processes by inventorying R&D activities, aligning them with IWRSS needs, and promoting collaboration. Second, within and close to the IWRSS Consortium there are multiple testbeds available to facilitate extensive testing in near-operational conditions. These include NOAA's Hydromet Testbed, focused primarily on advancing observational capability, and the CUAHSI WATERS project for comprehensive and integrative field-testing of new models, observations, and data assimilation systems. Third is the offline IWRSS testbed environment of the national IWRSS support center, enabled by centralized operations and national accumulation of regional data sets and modeling parameters. This environment provides an offline simulator for IWRSS operations that can serve as a final proving ground for operational transition, simulating either national or regional operations and providing feedback and training opportunities.

6.7.3 Social Science Research and Development

Social science development is needed to understand and properly link policy and institutional frameworks in the IWRSS project. This need is two-directional. First, a variety of policy and regulations often has as much or more impact on water resources and availability than natural causes. Therefore it's insufficient for IWRSS to focus only on modeling and prediction of the natural aspects of water resources. Water demand profiles and functions, regulatory policies, effects of commodity pricing, and behavioral effects stemming from uncertainties (hydrologic, climate, commodity pricing, demand) must ultimately be identified, understood, and properly represented in the physical models. Second, it is important to make sure IWRSS products and services adequately support policy instruments, and don't inadvertently miss the target. Three examples illustrate this need:

- Many communities maintain drought plans which affect water use policy and practice when put into effect. Such plans contain logic and parameters used to trigger the plan. IWRSS products and services must be cognizant of drought plan trigger logic and provide information consistent with this logic, otherwise the products and services won't be useful for this purpose.
- Stakeholders have their own objective functions. An example is to minimize the number of times a city has to go to a spot market for water, thus minimizing cost. For IWRSS to support this objective, it requires understanding of what the city's decision thresholds are, the lead times for key decisions, how the stakeholder will use the information provided by IWRSS, and where this fits into the decision process.
- The hydropower and other energy sectors (and others) use hydro-economic optimization models to integrate essential hydrologic, economic and institutional components of a river basin in order to explore both the hydrologic and economic consequences of various policy options. Many of these models are formulated as large-scale nonlinear optimization problems, seeking to maximize net benefit from the system. These models would benefit from incorporation of information about uncertainty inherent to availability of water, but stochastic formulations of these models require uncertainty to be described in specific ways. To be useful to these interests, IWRSS would need a basic understanding of these models and their information requirements, as well as an understanding of the stakeholder's operating framework and how they use these models in decision-making.

In all three examples, social science is needed to develop understanding of the objective functions of stakeholders, and then use the understanding to tailor products and services to support those objective functions. This focal area must ensure that IWRSS supports anticipatory decision-making and increased resilience through awareness and understanding of decision thresholds and processes.

6.7.4 Coordination of Research and Development

The spiral development model described in Chapter 3 provides the basic framework for science research and development in IWRSS through an iterative approach of demonstration, iteration with stakeholder needs, development and implementation. For the same reasons described in the previous Chapter on IWRSS technology, a common framework is needed for identifying science and technology readiness levels across organizational boundaries. Part of the IWRSS R&D coordination effort will involve developing an appropriate framework along the lines of Table 5.5, recognizing that for science purposes somewhat different criteria are needed than for technology. Once implemented, this framework will essentially provide a catalog of capabilities available for operational implementation, thus supporting goals of operational flexibility and adaptability, as well as a clear indication of where investment is needed to meet operational goals. With appropriate metadata, this service could be extended to indicate model and data compatibility and provide a search system to locate compatible tools that are ready, or near ready to meet immediate or anticipated needs. Finally, the IWRSS project management activity will include a twice-yearly Consortium R&D meeting to review relevant on-going and planned research activities and where possible align them with IWRSS. External groups with activities closely related to IWRSS, such as the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) will be invited to participate in these reviews to help them understand where federal water resources operations are headed and look for synergies in R&D.

Initial tasks for R&D coordination include an acquisitions workshop focused on providing information and training on different approaches for systematic identification of science and technology readiness levels, followed by the formation of a cross-agency team to adopt or adapt an acquisitions framework for IWRSS. Either in conjunction with this workshop or as a separate activity, the first of a twice-yearly series of trans-agency science review and coordination meetings will be held. These meetings will focus on reviewing current and planned water resources R&D activities so that agencies can work to coordinate and collaborate. These meetings will be scheduled to support current year and out-year budget planning, approximately in July and January.

6.8 Summary of Key Intersections with Current Practice

The science scope of IWRSS is broad and has many intersections with current practices. A few of these are noted below.

National Snow Analyses. The operational products and services that now comprise the National Snow Analyses will be expanded into a full suite of water resources variables, with both analyses and forecasts. Initial focus will be on providing a multi-model ensemble of short-term forecasts, eventually extending to mid-range and long-range forecasts as resources permit.

Remote Sensing. Current focus on satellite-derived snow cover observations and airborne measurement of snow water equivalent will be expanded to include a broader suite of satellite-observed water resources variables, such as ET, and airborne observations of soil moisture.

Reanalysis and Guidance for Empirical River Forecasting Tools. It is expected that the empirical models currently used for river forecasting will remain as essential tools for some time to come. The model reanalysis framework described above will provide the basis for quantitative assessment of biases necessary to use new high-resolution gridded products in forecast systems based on historical calibration. Analysis of the reanalysis products will result in guidance for how to appropriately update the empirical models.

River Forecasts. The high-resolution land surface models to be used nationally and regionally produce predictive estimates of runoff and channel flow. They are generally designed for natural systems and do not yet have all the tools necessary to handle reservoir operations, diversions and withdrawals. As far as river forecasts are concerned, the chief purpose of these models is to provide spatially distributed estimates of water budget variables, lateral inflows at all points (grid cells) along channels, and first-order stream flow estimates for unregulated river reaches. Additional river forecasting capability can be easily added with time and resources, but this is a key area where exploration of workflow and modeling needs through regional demonstrations is important.

River Forecasting Tools Gap Analysis. Through the organizational framework of the Consortium, gaps in current river forecasting tools will be mutually assessed and cross-walked with R&D plans within the Consortium agencies. Following an initial assessment, R&D efforts will be coordinated on a regular basis to work to fill gaps as necessary.

New Models, Tools and Utilities. Standard practice in IWRSS will be to make models, model components, analytical tools, and utility functions available to CHPS and CWMS by including necessary adapters and plug-ins, thereby expanding CHPS and CWMS functionality. One function of the national IWRSS support center will be to serve as a clearing house for these tools, using a catalog and metadata system to organize available components based on their function and purpose, compatibility, and data needs.

River Ice Modeling. Operational river ice modeling will become available nationally for the first time. Through the interoperability elements of the technical theme, historical information from the USACE National Ice Jam Database will be integrated within the river ice modeling tools.

Dam Break Modeling. Pre-staged dam break models provided by USACE will be made available on demand as a seamless service within CHPS. Reservoir data needed to operate these models will be provided as a routine feed through the technical data synchronization element.

Comparative Analysis Toolkit. Through elements of both the science and the technical themes, geospatial tools will be developed for use in CHPS and CWMS that facilitate comparative analysis of model output for both grid-to-grid and grid-to-polygon analyses. These tools have been identified as a first-order necessity to enable examination of different model results in the forecasting workflow.

Experimental Ensemble Forecast System (XEFS). This developmental system to provide ensembles of river forecasts will be a key intersection point for IWRSS. One way for river forecasting to use the information provided by IWRSS will be to treat IWRSS forecasts as additional ensemble members in the XEFS framework.

Model Forcing and Preprocessing Data Service. The suite of nationally downscaled model forcings used to run the national scale water budget models will be provided commonly as a new data service, including short-term, mid-range, and long-range forcings. The web service will be available to the CHPS and CWMS systems as well as USGS Water Science Centers. Additional specialized pre-processed data products will also be provided through this service, such as Mean Temperature Grids needed as input to CHPS river forecasting models.

Sharing the Water Resources Workload. Water resources are inherently a regional and local matter, but as well there are national interests in synthesis, reporting and prediction. Overall the demands are high and the burden is significant. Thus IWRSS is designed to provide strong national support to help with the regional and local workload. National support will focus on common modeling, tools and information needs, and work closely with regional and local centers to provide support functions and allow these centers to focus their attention on the job of engaging and serving regional and local stakeholders. IWRSS is designed flexibly to allow regional variations of how this is accomplished.

Chapter 7 National IWRSS Operational Support Center

The preceding chapters describe goals, themes and elements for providing integrated water resources science and services operationally across geographic and organizational scales. Much of the focus of this is on delivering well-integrated services at regional and local scales, where the majority of stakeholders' interests lie. Regional demonstration projects are the mechanism that IWRSS will use to accomplish this goal. Regional projects will focus on end-to-end demonstration of IWRSS objectives, implementation of relevant tools, and the development of workflow necessary to accomplish these objectives. There is also a need at the national level for synthesis and reporting, coordination and integration, providing regional support, and performing centralized tasks where consistency or economies of scale are important factors. A national IWRSS operational support center is planned for IWRSS to accomplish these functions. The role, functions and structure of this support center are presented here to set the stage for discussion of the regional demonstration projects and the overall concept of operations, which follow in the next two chapters.

This chapter describes the purpose and major functions of the operational support center, the subject matter expertise and staffing relevant to meeting its objectives, a straw organizational structure for the center, and considerations for moving forward.

7.1 Purpose and Major Functions of the National IWRSS Operational Support Center

As was noted in the preface, the IWRSS concept of a national operational support center is something altogether different than most traditional centers. In the integrative framework of

IWRSS, it is conceived as glue, as an agent for synthesis and integration, and as a virtual extension of regional capabilities through provision of shared services and common functions that help to transcend boundaries. It is clear that many, if not most water resources information needs require an array of capabilities and flexible, adaptive approaches to providing and using information. At the same time, there is a definite need to transcend boundaries and provide information consistently everywhere to all. Consider the State of Colorado; it has obvious interests and a legal obligation to consider its water resources comprehensively as a state, but in an accident of geography, it straddles four major drainages and consequently is served by four NWS River Forecast Centers and four USACE Districts, with different boundaries. IWRSS needs to be able to overcome this easily and provide consistent, seamless high-resolution gridded products for the entire State and beyond. Thus the idea in IWRSS is to create a flexible, adaptive system for water resources information, where some services and functions are centralized and shared and others are specific to regional centers, allowing adaptive self-organization and workflow between the support center and various regional centers to respond to different water resources issues and needs regardless of organizational or geographic boundaries.

The purpose of the national IWRSS operational support center (hereafter referred to as the Center) is therefore two-fold. First, there are national tasks to perform, which include centralized operational data processing, modeling and prediction tasks where national consistency or institutional economies of scale are important, national coordination and integration, and national synthesis and reporting. The second purpose, intrinsically related to the first, is to provide shared services and regional support. The conceptual design and organization of the Support Center is structured for enhanced regional interactions and communication, including the placement of some of its staff in regional offices to facilitate communications and focus on regionally-relevant support, and using contemporary communication tools to establish virtual presence whenever its helpful. Thus the two principal functions of the Center are operations and support, and the two main scales of emphasis are national and regional. Specific functions are described briefly below.

7.1.1 Operational Water Resources Modeling and Prediction

The Center will implement and operate a suite of national high-resolution land surface models and data assimilation systems, as described in Chapter 6, to produce a basic set of gridded water budget analyses and predictions nationwide. This will include periodic reanalyses to provide historical information and support calibration and guidance for regional models. These products, as well as downscaled forcings and derivatives, will be distributed through both internal channels and open web services and will serve as a first order water resources product suite. Through interoperable systems, data synchronization, coordination and workflow to be established through regional demonstration projects, these first-order products may be enhanced by regional centers using a variety of mechanisms ranging from providing anecdotal comments and guidance to providing alternative modeled fields or updates to be assimilated into the national framework. In the other direction, tools and toolkits will be developed and integrated within operational regional forecast systems to facilitate comparative analysis of regional and national model results and generate guidance for regional forecasting.

7.1.2 Shared Data Services

Using data synchronization capabilities and advanced information services, the Center will gather and permanently archive key data and information from regional centers, including model states, model parameters, model forcings, and forecasts to support national comparative analyses, modeling, and prediction, support automated verification of forecasts, provide operational archive and backup services, and support training and off-line simulation.

In the other direction, the Center will provide consistent centralized data pre-processing services to support regional modeling, such as temperature and other model forcing grids, water resources surveillance and geo-intelligence products, and enterprise GIS data sets through standard data and web services.

7.1.3 Regional Support

IWRSS will require considerable mix of subject-matter expertise to support day-to-day operations (described in following sections) and attend to a range of issues, and for economies of scale will establish this as a centralized shared service available to support both the Center and regional centers through enhanced and deliberate communications and interactions. Almost the entire staff of the proposed Center organizational structure, including science, technical and analytical components, have explicit operational roles, will be tasked to support both national and regional needs, and will routinely engage with regional facilities. One entire branch of the Center will be physically detailed to regional assignments corresponding to regional demonstration projects to ensure the Center's presence in the region, foster coordination and integration, and directly help with regional activities.

The Center will work hand-in-hand with regional centers involved in regional demonstration projects to develop effective operational collaboration and workflow. In these projects and with Consortium partners it will support development and implementation of high- and very-high resolution modeling capabilities for regional and local application, including two-way interactions needed for coordination and assimilation. Cost-effective telepresence measures, including high-definition video-over-internet, net meetings, chat tools, and weekly or bi-weekly conference calls will be enacted in these projects as a routine, everyday way of communicating and doing business, building on collaboration established between the NOHRSC and some RFCs and best practices identified during the Midwest Floods of 2008.

Center staff with stronger regional support functions will work time periods in synch with regional offices to accommodate regional needs and ensure timely service and support.

7.1.3 Coordination and Integration

The Center will facilitate organizational coordination and integration by developing a shared vision of operations and service, and developing a new business model with a shared leadership system across the Center and regional facilities, structured around delivering well-integrated water resources science and services through a nationwide network instead of around institutional structures and hierarchies. By using existing regional structures within the agencies, and providing a central facility to transcend boundaries and promote integration, IWRSS has a much better chance of success.

The Center will serve as a central hub for developing social networks across regions for communicating water resources issues, needs, and best practices. It will also provide a central catalog for available geospatial data sets, interoperable tools, models and utilities, and other relevant capabilities to facilitate locating and acquiring these resources.

7.1.4 Synthesis and Reporting

The above functions will make the Center a natural hub for synthesizing water resources information needs, requirements, and solutions, and for reporting out on a regular basis. Because effective communication is paramount to the success of IWRSS, the Center will produce a bi-monthly electronic newsletter to communicate to others about progress on regional demonstration projects, water resources success stories and best practices, new tools and information, and other important news. The newsletter will include regular features from each agency, and will regularly highlight stakeholders around the country.

On a more formal level, the Center will be responsible for regular agency reporting on project progress and performance metrics.

7.2 Necessary Expertise and Staffing

A broad range of science capabilities and subject-matter expertise is necessary to accomplish summit-to-sea water resources modeling and prediction. This is revealed in the preceding chapters – implementation and operation of advanced models, processing and application of remotely sensed data, advanced technical and information services, new social science applications – essentially every aspect of IWRSS involves specialized knowledge and capabilities. Scientists, analysts, forecasters, software engineers, IT support staff and administrative support staff are needed to operate a summit-to-sea water resources modeling and prediction system and attend to a range of associated issues.

Physical science expertise is needed in:

- hydrology and hydraulics (surface hydrology, snow and glacier hydrology, geomorphology, hydraulics, soils, and groundwater dynamics);
- vegetation and agriculture (forest hydrology, agricultural practices, and water-vegetation interactions);
- weather and climate (boundary-layer meteorology, numerical weather and climate modeling, and climatology);
- ecological-hydrological interactions (terrestrial ecosystems, aquatic ecosystems, water quality and biogeochemistry, watershed sustainability, wetlands and marshlands hydroecology, and limnology);
- hydrologic remote sensing (snow cover and water equivalent, soil moisture, evapotranspiration, land surface characteristics and phenology, image processing, optical and microwave electromagnetics);
- applied mathematics, numerical computation and statistics (numerical solvers, algorithm development, optimization, stochastic and nonlinear processes, spatial statistics, topology); and
- geospatial information (geographic information systems, geospatial analysis, cartography, projections and datums, spatial data accuracy).

Social science expertise is necessary to interact and effectively communicate with stakeholders, comprehend their needs, and help design appropriate physical science tools to create needed information. Understanding a stakeholder's needs often require an understanding of the legal or regulatory framework they're operating in, the economic connections and drivers that motivate them to require information in the first place, and the social and political constraints that shape their need for information.

These science capabilities and resources will need to be readily available to support IWRSS operations ranging from modeling to stakeholder interactions. Some may not be needed on an everyday basis and can be consulted or borrowed from existing resources – that is one of the reasons for forming a consortium – but many of them will have to be routinely involved in day-to-day operations. While expertise covering most of the gamut needed for IWRSS exists somewhere within the Consortium and is available on an occasional basis for advice and guidance, the bulk of the new operational workload of summit-to-sea water resources prediction requires new resources covering the same gamut of expertise.

7.3 Conceptual Organization and Expertise of the National IWRSS Operational Support Center

To understand the various roles and functions of the national IWRSS operational support center, it is useful to develop a conceptual ("straw") organizational structure and consider the expertise and staffing necessary to address IWRSS objectives. This is done here, and is not an exact prescription but rather an exercise to identify the knowledge, skills and abilities that will have to be present in some capacity. For this purpose the exercise is relatively unconstrained – keep working carefully through the processes and services that must be performed, adding expertise and staff as necessary until it makes sense operationally and all the necessary bases are covered. In the actual implementation of the Center, some roles may be combined, some may be borrowed from elsewhere within the Consortium as needed, and some may be filled from outside of the Center construct. This unconstrained exercise results in a Center with a diverse staff of approximately 100. This size is consistent with other national centers and laboratories in NOAA, USACE and USGS; in fact it is comparatively smaller than many. For present purposes this can be considered a design end-state. In the following sections, this end state is described in detail to explain the various tasks and roles to be performed. Following this, considerations are given for how IWRSS can proceed towards this end state in a stair-stepped fashion as resources allow.

Given the two primary functions of the Center, operations and support, the conceptual organizational structure is a hybrid adaptation of two real organizational structures: 1) The NOAA/NWS National Centers for Environmental Prediction, which provide national scale operational modeling and prediction functions, and NOAA/NOS Coastal Services Center (CSC), which provides a variety of support and services aimed at coastal zone management. CSC has been very successful at providing regionalized support through two central facilities using innovative management and organizational techniques, including locating center staff in regions of interest. This specific model is followed here as well. Other innovations would be encouraged to promote interaction, integration, and collaboration, including joint staffing from the Consortium, rotational assignments, visiting scientists, and similar mechanisms.

The design structure for the Center has a Direction and Administration component and three operational Divisions: 1) Water Resources Services Division, 2) Integrated Information Services Division, and 3) Analysis and Forecast Operations Division (Figure 7.1). The Water Resources Services Division has four branches: a) Regional Water Resources Services h, b) Water Resources Management Services, c) Water Resources Geospatial Services, and d) Water Resources Science

Services. The Integrated Information Services Division also has four branches: a) Production Management and Systems Integration, b) Data Coordination and Digital Services, c) Applications Development, and d) Information Technology. The Analysis and Forecast Operations Division has two branches: a) Integration and Analysis, and b) Forecasting. These divisions and branches are described in detail below.

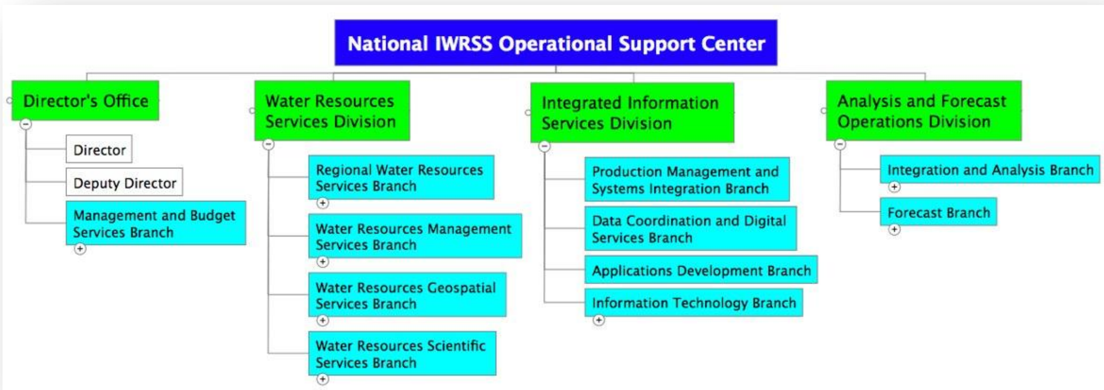


Figure 7.1. Conceptual organizational structure for national IWRSS operational support center.

7.3.1 Director's Office

The Director's Office (DO) is responsible for general management, administration, strategic and operational planning, partnership building, program evaluation, and budget oversight for the Center. The DO ensures that the Center pursues activities that integrate its efforts with partners, are consistent with its stated mission, and are responsive to customers and the parent agency(s).

Management and Budget Services Branch

Administrative staff associated with the DO would be housed in single branch and would include the Deputy Director, management analyst and administrative support, finance, planning and policy, and acquisition and facilities.

7.3.2 Water Resources Services Division

The Water Resources Services Division is a shared services division, providing day-to-day operational support to both the Center and regional facilities. It promotes interaction across organizational and geographic boundaries and provides expertise and services directly to stakeholders.

Regional Water Resources Services Branch.

The Regional Water Resources Services (RWRS) Branch works in-region to create an informed and inspired water resources community that has a comprehensive understanding of water resources management issues, uses best thinking and practices, and makes the best social and economic decisions through the sharing of resources. RWRS helps provide convenient and timely access to accurate and reliable information, as well as technology and training, and helps connect the Center and other NOAA programs to partners and users in each region. RWRS staff work in regional centers and facilitate the flow of information and provide a variety of operational support functions.

The RWRS staff would be detailed to regional field offices involved in the regional demonstration projects, either belonging to the Consortium agencies or possibly with major external stakeholders. The RWRS would engage regional internal entities including NWS Hydrologic Service Division Chiefs in each NWS region, NOAA Regional Teams, River Forecast Centers, and Weather Forecast Offices, USACE Districts and Divisions, and USGS Water Science Centers. Externally, the RWRS would engage customers, stakeholders and partners within the region. The general profile of the RWRS staff would be a water resources specialist, with expertise in one or more areas of specific interest in the assigned region. The size of the RWRS branch would be a function of the number of regional demonstration areas. The branch would be headed by a group of branch chiefs from other branches in the Center representing key areas of regional interactions, with direct input from the host location, which collectively would ensure regional performance and awareness.

Water Resources Management Services Branch.

The Water Resources Management Services (WRMS) division links the water resource management community with information, products, and services that contribute to effective resource management and decision-making. Necessary expertise includes communication and outreach, meeting planning, education and training, and applied social science. WRMS works with water resources managers to build their capabilities to understand and successfully engage their communities, use adaptive management strategies, and develop partnerships by providing technical assistance and training. WRMS facilitates sharing new ideas and lessons learned by bringing the water resources management community together through meetings, conferences, and trade publications. These efforts result in water resource managers who are able to apply best practices that integrate social, economic, and environmental aspects of water resource management.

The chief of this branch should have expertise in water resources management and familiarity with social science concepts. The branch would consist of three main elements: Human Dimensions, Learning Services, and Communications.

Human Dimensions Element. This element would include focal points for stakeholder interactions and customer service, as well as expertise in legal, policy and economic aspects of water resources. A Stakeholder Interactions Group consisting of a social scientist/communications specialist, outreach and public affairs specialist, and an inter-agency liaison would support a Customer Service Desk and provide first-line interaction with internal and external stakeholders, coordination of communications and outreach with other agencies within and outside of the Consortium, and either respond to or direct external queries to appropriate staff. This element would also include two water resources management specialists. A legal and policy specialist with expertise in water law, water rights, allocation, regulatory frameworks, and agency authorities would provide subject matter expertise and guidance to all aspects of IWRSS, with particular emphasis on stakeholder interactions at all levels. A water resources economics specialist with expertise in hydro-economics methodologies, tools and applications would work with stakeholders, IWRSS planners and coordinators and management, and development activities to identify and assess the economic value of water resources information and work to ensure high-value benefits. These two specialists would have major roles in the regional demonstration projects, providing knowledgeable linkages to the legal, policy and economic aspects of the projects to help improve understanding of the stakeholder's concerns and constraints.

Learning Services Element. This function of this element would be to develop and provide IWRSS-related training directed towards external water resources managers. The purpose of this element is to engage the water management community at all levels, but particularly local and regional levels, and provide training to help them manage more effectively, especially in the context of using IWRSS products and services. This would include training focused on using IWRSS products and services, use of geospatial tools for water resources applications, integrative and adaptive management techniques and best practices, and other aspects of water management as deemed appropriate. Training would be implemented through on-line modules, seminars, workshops and conferences. This element would also connect and coordinate with internal institutional training for agency staff to help develop and provide effective water resources training for internal use. Within NOAA, this element might, for example, augment the geospatial training for coastal managers provided by NOAA's Coastal Services Center with additional courses focused on geospatial water resources applications. This element would require one or more education specialists with expertise in building environmental literacy, teaching techniques, and development of effective training materials.

Communications Element. This is a technical element to support Center communications needs through documentation, document management, graphics, production of web content, production of bi-monthly newsletters and other related functions. This element requires one or more communications support specialists.

Water Resources Geospatial Services Branch.

The Water Resources Geospatial Services (WRGS) branch houses the Center's data development and mapping, data integration and analysis, and geospatial product development capabilities. WRGS supports IWRSS enterprise GIS and Geo-Intelligence needs at project, program and agency levels. Scientific and technical capabilities include remote sensing, geographic information system (GIS) analysis, environmental and land cover characterization, hydrologic GIS applications, basin delineation and watershed modeling, geospatial training, and decision-support tool development. WRGS develops and provides access to broad-based information and technology tools for hydrology, water resource and emergency managers. It's important to reiterate here that USACE CRREL houses the USACE GIS/Remote Sensing Center of Expertise, which provides these types of functions for all levels of USACE with a staff of about 30.

The WRGS branch chief would be a geospatial intelligence specialist with expertise in GIS, remote sensing, and water resources applications. The branch would contain three major elements: 1) eGIS and Geo-Intelligence Integration and Development, 2) Hydrology and Water Resources Applications, and 3) Remote Sensing.

Enterprise GIS / Geo-Intelligence Integration and Development Element. This element would be responsible for the development, implementation and integration of eGIS and Geo-Intelligence functionality for IWRSS. It would provide and maintain enterprise geospatial content for eGIS, ensure interoperability of geospatial data, ensure compliance with federal and international geospatial data standards, and provide advanced informatics and scientific data visualization capabilities. This element would require specialists in geospatial data, geospatial interoperability and standards, and informatics. Also required for this element are analytical GIS specialists and software engineering support for eGIS integration and development tasks.

Hydrology / Water Resources Applications Element. The focus of this element is on development of functional geospatial applications that can be added or plugged into existing systems. This element would be responsible for development and implementation of all manner of geospatial applications for hydrology and water resources, including building new analytical capabilities such as model inter-comparison tools, development of extensions and toolkits for COTS software such as Arc, and integration of capabilities within the CHPS/CWMS environments. This element would require one or more GIS specialists and GIS software engineering support.

Remote Sensing Element. This element contains both airborne and satellite remote sensing components. The NWS Airborne Snow and Soil Moisture Surveying Program would be housed within this element. The Program consists of four pilots who are NOAA Corps officers; the senior pilot serves as the Chief Pilot and provides a number of administrative functions including liaison to NOAA's Aviation Operations Center and other fleet services. The satellite remote sensing component would provide expertise and staffing necessary to acquire and process satellite data and imagery and deliver the array of satellite-based data products. Specialists are required to provide theory, practice, and retrieval expertise for optical (visible, near-infrared and thermal) remote sensing, microwave remote sensing, and electromagnetic radiative transfer. One or more image analysts are required, and software support is required for operating and maintaining data streams, implementing retrieval algorithm codes, and supporting processing software.

Water Resources Science Services Branch.

The Water Resources Science Services (WRSS) Branch supports the IWRSS enterprise across all boundaries and ensures that high scientific standards are met within the Center and throughout the enterprise. The WRSS branch is responsible for developing appropriate methods and procedures for all of the Center's operations and services. The branch engages, collaborates with, and leverages science expertise and capacities throughout NOAA, other Federal agencies, and the academic community. The branch actively engages with customers and stakeholders to provide expertise when needed and to effectively translate user needs into applications and products.

The WRSS branch chief would be a senior scientist in hydrologic or water resources sciences. The branch would consist of 5 elements: 1) Hydrology and Hydraulics, 2) Vegetation and agriculture, 3) Weather and Climate, 4) Ecological and Hydrological Interactions, and 5) Applied Mathematics and Statistics.

Hydrology and Hydraulics Element. Recognizing the extensive expertise in this area within the Consortium, this element focuses on those specific aspects that will require particular attention in the operations of the Center and are generally less-well covered elsewhere within the Consortium.

- *Surface Water Hydrology.* Expertise in rainfall-runoff processes, land-surface modeling, and hydrometeorology is needed to support land-surface modeling and prediction, work and interface with other groups within the Consortium such as the hydrology group in NOAA/NWS Office of Hydrologic Development or various locations within USACE.

- *Snow and Ice Hydrology.* Expertise in energy and mass balance of seasonal snow packs and glaciers, water flow through snow and firn, surface, englacial and subglacial drainage of glaciers, and river ice processes is needed to support seasonal snow cover modeling and prediction, modeling and prediction of glacial influences on Alaskan water resources and runoff, work with Consortium partners (e.g. USACE and NRCS) on snow issues, and work with USGS on glacier issues.
- *Geomorphology/Hydraulics.* Expertise in unsteady flow, sediment transport, debris flows and landslides is necessary to support implementation of advanced hydraulic modeling for channel flow and ensure that the IWRSS modeling and prediction framework supports stakeholder interests in debris flows and landslides. This expertise will work closely with the NOAA/NWS/OHD hydraulics team, USGS and USDA.
- *Soils Science.* Expertise in soil science, soil-water interactions and soil hydraulics is needed to support soil moisture modeling, analysis and prediction, to work with USDA and other partners to improve characterization and application of soils information.
- *Groundwater Hydrodynamics.* Expertise in groundwater flow and transport characterization of porous and fractured media and geophysical characterization of aquifers is needed to support groundwater modeling, analysis and prediction and integrate ground and surface water interactions, especially for low flows. This expertise will work closely with USGS.
- *Urban Hydrology.* Expertise in hydrology of disturbed soils, storm water runoff, urban retention and storage, and urban flow diversions is needed to support services in urban and developed areas, including flooding events. This expertise will work closely with urban stakeholders in regional demonstration projects to support local scale high-resolution modeling and help relate IWRSS products and services to local urban environments.

Vegetation and Agriculture Element. This element includes expertise necessary to contend with the wide array of natural and anthropogenic vegetation influences involved in land-surface modeling and prediction and to work with stakeholders on vegetation and agricultural aspects of water resources management.

- *Forest Hydrology.* Expertise is needed in forest-water interactions (especially canopy interception), forest management practices, and effects of wind, fire, insects and disease on forest ecosystems to support modeling and prediction in forested environments, including phonological and disturbance effects on forest-water interactions. This expertise will work with USDA and other partners to improve characterization of forest processes in models, and work with water resource managers dealing with forested environments to understand use and limitations of IWRSS information in these areas.
- *Agricultural Practices.* Expertise is needed in common dry land and irrigated agricultural processes and practices including crop cultivation and production, crop rotation, nutrient management (including fertilization), water management (including irrigation), tillage, pest control, livestock production, and gazing. This expertise will support land-surface modeling and prediction in agricultural environments, including

seasonal crop phenology and water use effects on interception, ET and runoff. This expertise will work with USDA, state agencies, and regional and local entities to improve representation of agricultural practices in models, and support regional and local demonstrations of high-resolution modeling capabilities to inform agricultural and water management practices.

- *Water – Vegetation Interactions*. Expertise is needed in evapotranspiration, plant physiology and stress, and plant water use, including remote sensing and modeling of ET, to support modeling and prediction in vegetated environments. This expertise will work with USGS and USDA on land cover and vegetation characterization at national and regional scales.

Weather and Climate Element. This element includes expertise necessary to support downscaling of weather and climate forcings for models, develop and support climate-scale predictive capability for water resources models, and design and execute IWRSS reanalyses on a recurring basis. Specialized expertise is needed in climate science, including familiarity with climatological analysis techniques, climate modeling and forecasting, and meso- and micro-scale numerical weather modeling. This expertise will support all weather and climate aspects of IWRSS and ensure rigorous operational practices are followed, and will work with stakeholders to build understanding of uncertainties in long-range forecasting and effects of climate change on water resources.

Ecological – Hydrological Interactions. This element supports the extensive intersections between ecological systems and water resources. It guides and builds capability for predicting water quality parameters, and works with stakeholders on ecological aspects of water resources.

- *Terrestrial Ecosystems.* Expertise is needed in terrestrial species and habitat, biogeochemistry, and hydrodynamic processes to support IWRSS interactions with the terrestrial ecology community. This expertise will work with EPA, USGS and others to identify and develop necessary functionality, and to ensure that IWRSS products and services address terrestrial ecosystem management needs.

- *Aquatic Ecosystems.* Similar expertise is needed in aquatic species and habitat, aquatic biogeochemistry, and hydrodynamic processes to support interactions with freshwater and marine ecology communities. This expertise works with the USGS, NOAA National Ocean Service, EPA and others to support determination of requirements, design and development of water quality and ecosystem-relevant prediction capability in IWRSS.

- *Water Quality and Biogeochemistry.* Expertise in water quality, point and non-point pollution, nutrient cycling and water quality modeling is needed to support modeling and prediction activities and interaction with ecology, regulatory and restoration communities. This expertise supports stakeholder participation in design and development of water quality prediction capability. It works with USGS, EPA and USACE on this task.

- *Watershed Sustainability.* Broad expertise is needed in riparian and watershed ecosystems and relationships between ecology, hydrology, morphology, and anthropogenic influences. This expertise supports broad interaction across many communities, in particular the river basin management community. It supports design and development of water quality prediction capability. It works with science and regulatory agencies, watershed districts, and others to ensure that IWRSS products and services address information and decision-making needs for sustainable watersheds.

- *Wetlands, Marshlands and Lakes.* Expertise is needed in limnology, and wetland and marshland hydrophysical processes to support modeling and prediction of lake, wetland and marshland effects on water resources, availability and quality. This expertise also supports design and development of water quality prediction capability. It works with EPA, state departments of natural resources, and others to improve representation of these features in models and to ensure IWRSS addresses management needs.

Applied Mathematics and Statistics. This crosscutting element requires above-average (i.e. above the normal skill set of most scientists) expertise in applied mathematical, numerical computation and statistical techniques including numerical methods, advanced solvers, advanced stochastic and nonlinear methods, and spatial statistics to support IWRSS-wide modeling, ensemble prediction and verification. This expertise will work with the NOAA/NWS/OHD ensemble prediction team and Consortium model and software developers, and will support science staff with advanced numerical capability.

7.3.3 Integrated Information Services Division

This second of three divisions houses all aspects of the Center's information technology, interoperability, data synchronization, data bases and archiving, and related software engineering tasks. It consists of four branches: 1) Product Management and Systems Integration, 2) Data Coordination and Digital Services, 3) Applications Development, and 4) Information Technology.

Product Management and Systems Integration Branch.

The Production Management and Systems Integration branch (PMSI) is a small gate-keeping branch headed by a senior software engineer. It supports the implementation and monitoring of all modifications to the operational production software suite to ensure the reliability of IWRSS real-time data processing, analysis, forecast, and product generation services. PMSI serves as the technical transition between the research and development of all aspects of the IWRSS computing algorithms and their operational implementation. PMSI is responsible for final checkout of new applications software prior to operational implementation and its maintenance after implementation. Standards enforcement ensures that proper procedures are followed and standards are applied for any new or modified algorithm. The branch consists of a small group of senior software engineers dedicated to performing these functions.

Data Coordination and Digital Services Branch.

The Data Coordination and Digital Services (DCDS) branch ensures production and distribution of IWRSS digital products and services through all relevant channels, including: Internet, AWIPS, NDFD, Direct Ship and others. The DCDS branch develops, operates and maintains IWRSS web services, including interactive web content, data cataloguing and delivery services. The DCDS branch develops, operates and maintains IWRSS databases, including national archive, RFC backup, Center development and operational databases.

Necessary expertise includes database administration, web services specialists, system-specific (e.g. CHPS, CWMS, AWIPS, NDFD) specialists, and software engineering support with expertise in these areas.

Applications Development Branch.

The Applications Development (AD) branch provides software engineering development and maintenance support to all Divisions of the Center. The AD branch designs, develops and implements new codes within the Centers operational systems, and integrates relevant Center models, analysis, and utility software tools into the NWS Community Hydrologic Prediction System (CHPS). The AD branch ensures compliance with international, federal and agency coding standards and protocols. The branch chief would be a senior software engineer, and the branch would consist of entirely of general-purpose software engineers with diverse capabilities.

Information Technology Branch.

This branch provides Shared Infrastructure Services (SIS) including system administration and other user support services on a 24-hour basis for IWRSS computing and communications systems. These systems include local and wide area networks, high-performance computing systems, servers and workstations, personal computers, NWS systems used within the center, ancillary devices such as graphics plotters, and the interfaces among all of the above. The SIS group is responsible for the overall planning, design, development, implementation, and assessment of IWRSS computing and communications capabilities as well as for the facilities and infrastructure that support the relevant technology. This responsibility includes coordinating network and communications issues between the Center and other parts of NOAA as well as between the Center and other agencies.

The SIS group also provides support to the Center in the following areas:

- The acquisition, development, and use of special tools for monitoring information systems
- The availability of training and documentation for current and future information processing systems
- The review and evaluation of concept studies which guide the Center in the development, implementation, and operation of information systems
- The preparation of requirements initiatives and other information resources management documents necessary for the acquisition and administration of software and hardware systems
- System acquisition and contract management
- The recommendation, formulation, and preparation of policies and procedures needed to provide system security, control, and accountability as required by the Center and/or Federal rules and regulations.

The SIS group generates and promulgates standards relevant to the development environment that supports the design, preparation, and integration of application software, with particular emphasis on the use of such hardware within an operational environment.

The Information Technology branch has two main elements. Shared System Services requires IT administration expertise for primary operational systems, development and backup systems, and general purpose office systems. Also required for SIS is systems-level software engineering support. The second element is an IT technician staff to provide 24x7 systems administration support to maintain operational status of critical systems and software.

7.3.4 Analysis and Forecast Operations Division

This third and final division is focused on operational production of water resources analyses and forecasts. It consists of two branches: 1) Integration and Analysis Branch, and 2) Forecast Branch.

Integration and Analysis Branch

The Integration and Analysis (IA) branch is responsible for integrating observations with models and preparing analyses of conditions for the present time. These products would be issued twice daily (preliminary and final) for preceding 24-hour period using the IWRSS modeling system and data assimilation framework and coordination with regional centers.

The IWRSS analysis system would be driven with outputs from NOAA's Rapid Update Cycle (RUC2), North American Mesoscale Model (NAM), and Q2 QPE. The analysis products would include surface and sub-surface water storage and flux patterns, moisture deficits and surpluses, and stream flow for the current time, based on observations accumulated over the preceding 24 hours, and a depiction of areas where significant change has occurred over the preceding 24 hours. In addition, discussions would be written on each shift and issued with the analysis packages that highlight the meteorological and hydrological reasoning behind the analyses across the continental United States and Alaska.

The IA branch requires hydrologic and water resources knowledge, skills and abilities contained within a group of regional analysts. Two or more analysts would be dedicated to each of four regions: Eastern, Central, Western, and Alaska, and would work overlapping shifts that cover both the relevant modeling and observation times (fixed according to GMT) and the normal operating hours of the region. The IA branch analysts would perform very similar functions as the analysts that now support the NOHRSC's National Snow Analyses, but in this case there would be more analysts to cover the broader gamut of water resources and to provide dedicated regional support. Each set of regional analysts would be the primary focal points for routine operational interaction with regional centers on matters concerning observations, diagnosis and interpretation of local and regional conditions, and special situations and events, and would also serve as dedicated regional liaisons for the forecasting branch (see below). The goal of this branch would be to function as remote arms of the regional center, collocated in one place to ensure geospatial consistency and efficiency.

Forecast Branch

The Forecast (FC) branch consists of three groups: 1) Short-term Forecast Group, 2) Medium-Range Forecast Group, and 3) Long-Range Forecast Group. The forecast groups would not be dedicated to individual regions (otherwise a large number would be needed to cover all time scales and regions), but would instead work through the regional analysts of the IA branch for coordination.

The Short-term Forecast Group would be responsible for preparing forecasts for the time period of 1 through 72 hours. These products would be issued twice daily (early and final) using guidance derived from the IWRSS modeling system and from NWS River Forecast Centers via CHPS and the regional analysts of the IA branch. The short-range forecast products would include surface and sub-surface water storage and flux patterns, moisture deficits and surpluses, and stream flow for 1-72 hours, and a depiction of areas where significant changes are expected within the forecast period. In addition, discussions would be written on each shift and issued with the forecast packages that highlight the meteorological and hydrological reasoning behind the forecasts across the continental United States and Alaska. This group would consist of a chief forecaster and three supporting forecasters. Forecasters would all be working from the same information, but would divide responsibilities to focus on different water budget components in conjunction with the different forecast products noted above.

The medium-range forecast group would be responsible for preparing forecasts for days 3 through 7. These products would also be issued twice daily (preliminary and final) using guidance derived from the IWRSS modeling system, forced by the NWS medium range forecast model (GFS) and from NWS River Forecast Centers via CHPS. The medium-range forecast products would include 1) surface and sub-surface water storage and flux patterns, 2) daily storage and flux anomalies, and 3) probability of moisture deficits and surpluses. This group would also consist of a chief forecaster and three supporting forecasters, working in a similar way.

The long-range forecast group would be responsible for preparing forecasts out to 90 days. These products would be issued weekly using guidance derived from the IWRSS modeling system, forced by NWS long range outlooks and climatological information. The long-range forecast products would include 1) surface and sub-surface water storage and flux patterns, 2) daily storage and flux anomalies, and 3) probability of moisture deficits and surpluses. This group would have the same composition as the other two forecast groups.

7.4 Computing Environment

As a pilot project for IWRSS, the National Snow Analyses have demonstrated that high-resolution, spatially distributed, primarily 1-D modeling and short-term prediction can be accomplished on high-performance micro-computing systems. This is supported by the experiences of many others who operate similar high-resolution land-surface models over continental and global domains.

The NOHRSC's current computing environment is highly scalable and consists of a small Linux cluster built several years ago using high-performance microcomputers. Eight dual-processor servers are used for full-physics computation of snow energy and mass balance for a five-layer model at a temporal resolution of one hour and a spatial resolution of 1 km^2. The model is run twice for each hour in six-hour blocks, and each hour requires about six minutes. The system gains high efficiency through innovative geospatial tiling and attention to bandwidth across key system components. Rapid improvement in computing capacity and value has improved the picture considerably. During the winter of 2007-2008, the NOHRSC model was run for half of Alaska on a single new server with four processers.

The NOHRSC is currently collaborating with NASA on operational implementation of the LIS framework; in this case a single new high-performance machine or small cluster is expected to handle multi-model (full land-surface models) ensemble forecasts for all of Alaska, and a moderate cluster is expected to handle the continental U.S. Thus it is evident that for purposes of bread boarding a national summit-to-sea modeling and prediction system, much progress can be gained quickly on relatively simple COTS computing systems that are very scalable for national to regional needs. Experimentation will be required to identify necessary system size and capabilities, but experience suggests that a moderately sized cluster will be sufficient for initial national implementation, and a small number of high-performance machines (possibly just one in some cases) at regional centers will be sufficient to perform high-resolution modeling in the regional demonstration projects.

Where more attention will be needed is in mass storage. With high-resolution multi-model ensembles outputting multiple gridded variables, IWRSS will likely produce greater volumes of data in a day than traditional river forecasting generates nationwide in weeks or months. As noted previously, even the National Snow Analyses, which only focus on only one water budget variable, recycle about eight terabytes of storage every few days. Routine operational production of a full water resources suite will require significant high-bandwidth mass storage. Several off-the-shelf solutions are available for purposes of initial bread boarding of the system.

Eventually, there may be supercomputing applications for IWRSS, but this capability is not expected to be necessary anytime soon. The LIS models have been configured for parallel computing, and the academic research community is pushing the envelope by simultaneously calculating Muskingum flow routing on all NHD+ reaches (averaging a kilometer or two in length) in the country using a very large supercomputer.[8] For now, however, the IWRSS project can get started on much more accessible computing systems, building on scalable architectures as necessary.

7.5 Considerations Proposed for Moving Forward

The unconstrained national IWRSS operational support center is an exercise to identify key expertise and staffing necessary to provide the envisioned operations and support functions to meet IWRSS objectives. The principal point to keep in mind is that water resources involve all of these subject and skill areas, and IWRSS will routinely encounter issues in each area. As the Center or regional facilities encounter these issues, expertise not found at the Center will need to be found elsewhere.

As discussed in Chapter 3, the IWRSS design is based on opportunity and spiral development. A certain initial operating capability and associated expertise is necessary to begin, and then this can be further developed as capability increases in the future. Ramping up to initial capability levels, and strategic positioning for future opportunities for growth and development is therefore the most important near-term task for moving forward.

A transformation of the NOHRSC, with its experience in developing and operating high-resolution land-surface models for the National Snow Analyses, as well as its geospatial experience in remote sensing and GIS, is intended to provide an initial seed for the Center. The NOHRSC has already committed to serve this function and work to strengthen regional collaboration. With its current staff of 12, however, the seed is small and there is neither sufficient expertise nor technical support to advance very far towards IWRSS goals. Moreover, the NOHRSC has little space to grow.

In lieu of a large opportunity for rapid growth, the national support center will need to ramp-up capability and grow through innovation and collaboration. One such opportunity on the table is to locate the Center at the USACE Cold Regions Research and Engineering Laboratory[9] (CRREL) in Hanover, NH (Figure 7.1). Although it still maintains considerable expertise in snow and ice, CRREL has diversified over the past 10 years and is now principally focused on

[8] Personal communication, Dr. David Maidment, University of Texas.
[9] USACE ERDC CRREL: http://www.crrel.usace.army.mil/

terrestrial science. CRREL is a highly capable laboratory with 120 scientists, many of whom work in subject areas close to IWRSS, and is part of the USACE ERDC, which has received top honors for research to operations success in the Army. CRREL has offered space for immediate IWRSS needs and future growth of the IWRSS Center, and would provide immediate opportunities for USACE collaboration. CRREL houses the USACE GIS/Remote Sensing Center of Expertise, which is responsible for developing and supporting enterprise GIS in USACE, and it plays a major role in development and support of CWMS. One of CRREL's counterparts in ERDC is the Coastal and Hydraulics Laboratory[10], providing another important collaboration linkage for IWRSS. By establishing the Center at this facility, it can leverage USACE capabilities, realize benefits quickly, and be positioned for future growth.

Figure 7.1. The USACE ERDC Cold Regions Research and Engineering Laboratory (CRREL) in Hanover NH includes 172,000 ft^2 of facilities on 31 acres.

This arrangement is attractive to the NOHRSC, which has enjoyed a long and productive working relationship with CRREL on cold region hydrology. The National Snow Analyses snow model was transitioned from CRREL's research to NOAA operations, and now CRREL functions as the distribution point for inserting National Snow Analyses products into CWMS, CorpsView, and other USACE decision support systems. The NOHRSC is in the process of implementing its off-site backup computing facilities at CRREL. To begin IWRSS Center collaboration, this task could be inverted so that the current NOHRSC facility in Chanhassen, MN is maintained as an off-site backup facility for the IWRSS Center, and new computing installations at CRREL become the primary site. From a practical point of view, the NOHRSC is now at its smallest size in 15 years, and is comparatively easy to move.

There may be other options to consider for locating the Center. The key criteria for consideration are an attractive location for recruiting scientists and professional operational staff, proximity for interagency collaboration or willingness of agencies to locate staff there, reasonable ease of travel, adequate space, and reasonable cost.

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[10] USACE ERDC Coastal and Hydraulics Laboratory: http://chl.erdc.usace.army.mil/

Chapter 8 Regional Watershed Demonstrations

Regional watershed demonstrations will be the venue for much of the integration activity planned for IWRSS. Here is where many of the IWRSS elements will be implemented and tested, where learning will occur to establish new workflow and operating procedures, where national-regional interactions will be worked out, and where most of the stakeholder interactions will take place. The number of regional demonstration projects has not been determined; it is a function of resources, interest, and purpose. Some regional demonstrations may focus on just one or two elements, such as interoperability. At least one will be designated as a "super" demonstration, with the intention to demonstrate end-to-end IWRSS capabilities to their fullest extent – the leap ahead. Since a) IWRSS is focused on enhancing existing enterprise systems that are or will be available to all regions, b) interoperability and data synchronization is targeted for the national network, and c) a set of baseline water resources products will be produced for all regions through the national support center, the overall framework is conducive to exporting tested capabilities from the demonstration regions to other regions to build on a baseline capability.

8.1 Purpose, Actors, Roles and Relationships

The purpose of the regional projects is to implement new capabilities in an operational environment, test them to work out kinks in procedures, workflow, communications strategies, and so forth, and demonstrate that the new capabilities work and are beneficial before implementation in other areas. In the framework of Technical Readiness Levels discussed in Chapter 5, this is analogous to advancing capabilities up through the ranks of TRL 6-8. Recalling this, TRL 6 requires demonstration of a system or subsystem model or prototype in a relevant environment, which can be a simulated operational environment, TRL 7 requires demonstration of an actual system in an operational environment, and TRL 8 is achieved when the system is proven to work well under expected conditions through successful operations. Obviously the exact meaning of this varies depending on the "system"; successful demonstration of a high-resolution land-surface model in a regional operations center involves different criteria than successful demonstration of stakeholder participation. Even the process of working through criteria such as these to help formalize IWRSS activities and progress is part of the purpose of the regional demonstration projects.

One lesson learned through IWRSS planning is the importance of lexicons to successful communication; what "implementation" means to one group another may be call "demonstration", and the two aren't necessarily interchangeable. This is part of why IWRSS will adapt and adopt common standards such as TRLs to facilitate communication between all the actors. Nonetheless, the point of the regional projects is to implement capability, develop necessary procedures and workflow, test the capability in operational settings, and demonstrate success.

The potential actors in regional demonstrations are offices at all levels in all participating agencies, and ultimately participation will depend on the areas selected and the capabilities being demonstrated. NWS River Forecast Centers, USACE Districts and USGS Water Science Centers will be key players, along with the national support center for regional-national interactions and NWS Weather Forecast Offices for regional-local interactions. As noted in the previous chapter, some national support center staff will be physically located in selected regions to facilitate these interactions. The various elements described for each of the crosscutting themes will involve different combinations of actors, with different roles and purposes.

8.1.1 Human Dimensions Theme

The regional demonstrations will serve as the front lines for identifying regional and local stakeholders, developing effective approaches for engaging them, assessing stakeholder's needs, and establishing the overall participatory process. Early activities will be focused on assessment of who are regional and local stakeholders for water resources information in the area, and on beginning to establish and formalize their needs. Regional participants should expect to engage in surveys and workshops, conduct social research and interviews, and engage in coordinated dialog and synthesis to communicate and document results of these assessments.

Following the abstraction used earlier of all offices at all scales as nodes on a national network, regional demonstrations will work on to strengthen and use this network as a communication tool to both acquire and disseminate information related to IWRSS. When only one agency's network of local and regional offices is considered, there are often large areas without local coverage. When considering three agencies together, the network coverage is significantly improved and there are fewer areas without at office nearby that can serve as a 2-way conduit for water resources information (Figure 8.1). In this way, IWRSS can "reach out and touch someone" by communicating through all offices in a given area, and can listen to stakeholder needs through many ears. Fostering trans-boundary communication in this way through regional demonstrations will be a powerful tool for identifying local water resources stakeholders, gathering gather basic information about their needs, and distributing information back to them.

Through this theme regional demonstrations will be used to develop consistent outreach and messaging through web site content and other materials. The goal of presenting a unified front to stakeholders, of providing the experience of one-stop shopping regardless of how distributed the information content actually is, will require some effort and regional demonstrations are a good venue to develop this. By working with small groups of offices in a geographic region, common threads in content can be woven together more easily to achieve the goal.

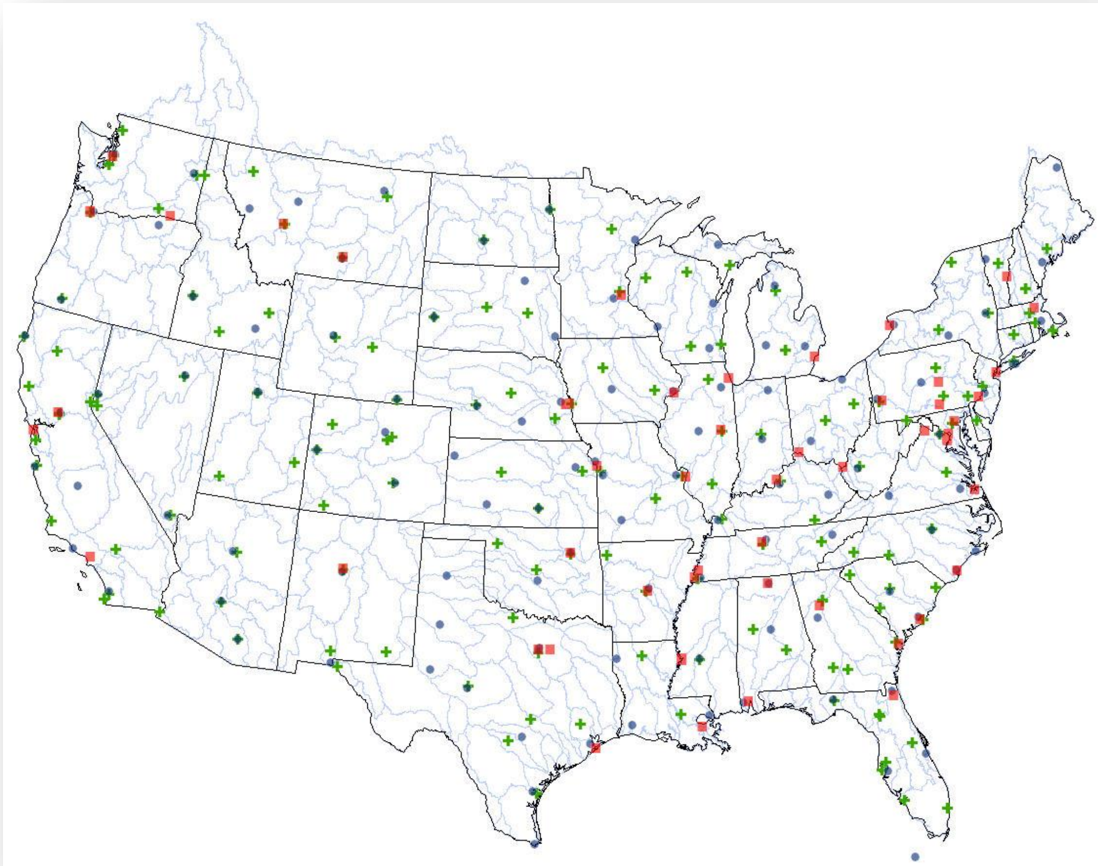

Figure 8.1. Local and regional offices of three agencies within the continental U.S. are shown: NOAA's National Weather Service River Forecast Centers and Weather Forecast Offices (blue dots), USGS Water Science Centers and Field Offices (green crosses), and USACE District Offices (red squares).

8.1.2 Technical: Information Services Theme

Regional demonstration projects will be the principal venue for most of the technical elements planned for IWRSS. By focusing on smaller geographic domains with a smaller group of agency actors, many of these elements can be demonstrated intensively. For example, one goal for the regional demonstrations is to develop and provide a comprehensive suite of high fidelity and high-resolution eGIS data layers (e.g. Figure 5.4), geospatially "wiring" the watershed into the CHPS and CWMS systems. This can be accomplished most easily when the geographic domain is a manageable size.

Since in this theme the focus *is* on system and sub-system elements, the TRL concepts recalled above apply closely. New subsystem communications frameworks, for example, will obviously be bench-tested during development on relevant systems, but the real proof is in day-to-day use in normal operations. Major system interoperability elements will be implemented through regional demonstrations, most notably interoperability between CHPS and CWMS.

Focus here will be on developing procedures and workflow between NWS River Forecast Centers and USACE Districts to take advantage of interoperable systems in river forecasting and management operations. Some aspects of interoperability and data synchronization involving national scales will still be rolled out through the regional demonstrations. For example, central data synchronization for archiving and related purposes will be first implemented in regional demonstration areas, and then extended to other areas. From the national point of view, this is like turning on one "feed" at a time, which is preferable to turning all on at once.

As noted above for Human Dimensions, the integrated information delivery element will be honed through the regional demonstration projects. For the technical theme the regional implications of this are configuration and testing of the mechanisms that move information products, such as web data services, in an operational setting.

8.1.3 Operational Science Theme

All elements planned for the operational science theme will have a significant role in the regional demonstration projects. The general focus here is on production of high-resolution water resources analyses (historical and current) and predictions. Recognizing regional diversity, the strategy for this theme is to support flexible and adaptable ways of accomplishing this but still yielding a spatially and temporally consistent product. In this theme, one size most definitely does not fit all. The regional demonstrations will be the principal mechanism for developing the necessary procedures and workflow for the desired approach.

At what might be called "Level 0", baseline high-resolution gridded products produced nationally will be available for use in regional forecasting and management operations, similar to the way National Snow Analyses products are available now through NOAA NWS and USACE systems, with the addition of two components: 1) relevant toolkits for comparative analysis with regional model states and generation of guidance information, and 2) deliberate collaboration and communication on a routine basis between national and regional centers to coordinate, evaluate and respond to mutual operational needs. At this level, regional centers may or may not choose to use enhanced flow/flood forecasting and water management tools (Section 6.3) made available through this theme. At this baseline level, a basic set of high-resolution water resources data sets are available for the region with a minimal amount of regional involvement.

At progressively higher levels of regional-national interaction, more mechanisms are available through this theme. Regional application of high- or very-high resolution land surface models is expected to be the most likely option, either to expand the suite of ensemble members for uncertainty analysis and regional forecasting, or to provide higher resolution or improved regional information than is provided nationally. Nationally, there is a choice of either assimilating these regional products into the national system, or not, depending on specific situations and objectives. "Level 1" might be where regional offices run comparable high-resolution models for their own purposes, with interest but not necessarily action at the national level, and "Level 2" might be where regional offices run advanced or higher-resolution models, and more engagement is necessary at the national level to acquire and assimilate this information. Developing the necessary coordination, communication and workflow between national and regional levels in this regard will be a major focus of the demonstration projects.

Most other elements of the operational science theme will also be rolled out through the regional demonstration projects. For example, historical water budget studies planned through Water for America will advance on a regional basis, and implementation of some innovative information sources, such as crop progress statistics and water use data, will be done regionally. While most new moderate-resolution surveillance products, such as MODIS-derived mapping of evapotranspiration, are as easily done nationally as regionally, similar but very- high resolution products from Landsat will be provided only through the regional demonstration framework as part of the "end-to-end" demonstration of the leap-ahead sought by IWRSS.

8.2 Candidate Areas

Thirteen candidate regional demonstration areas have been suggested during the IWRSS planning process (Table 8.1, Figure 8.2). Each has different qualities and characteristics that would provide useful opportunities for demonstration. Three of these are highlighted in detail in following sections. Criteria for selection of regional demonstration areas include a) cooperation of offices within the region, b) funding, c) visibility, d) need, e) priority, and f) political champions.

Pragmatically, these criteria are necessary to ensure the success of the project. Cooperation of offices within the region is essential, and relevant offices need to be able to engage. Opportunities for funding from outside sources are certainly an important factor, as even in a windfall situation the challenges facing water resources will always be able to use more resources. Visibility is important to create demand in other areas. If the regional demonstration projects occur in the shadows, success will be more difficult. Need is essentially ubiquitous, but it is nonetheless important to make sure a bona fide need exists within the region. Priority may come from within one or more agencies, or from external drivers. Finally, political champions are necessary to sustain and grow the IWRSS project.

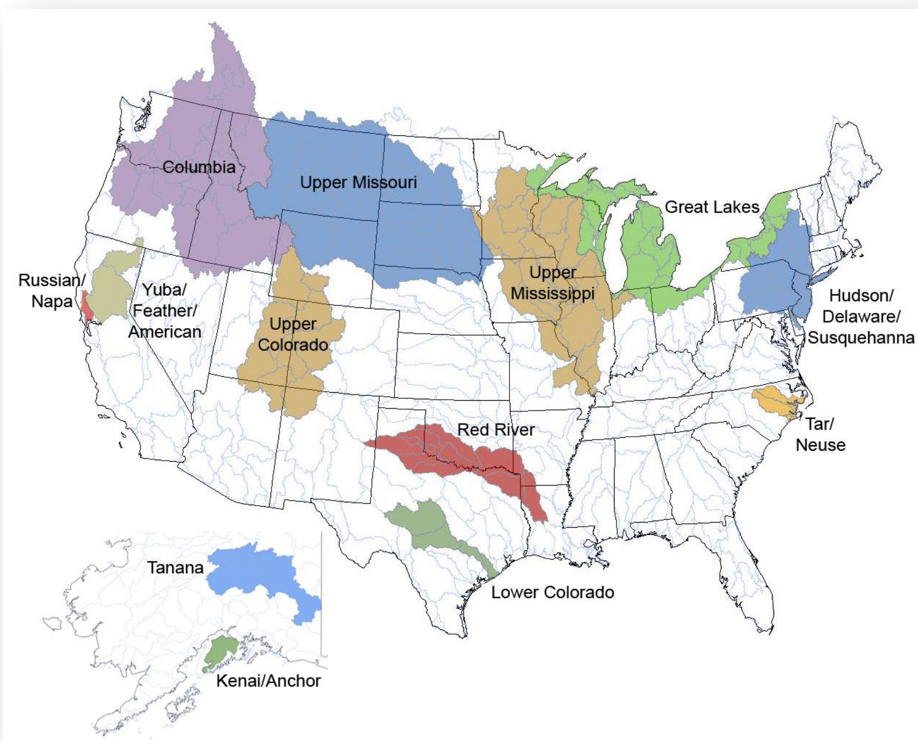

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Table 8.1. Thirteen candidate regional demonstration watersheds.

Candidate Watershed	Regional Offices Involved		Unique or Principal Rationale
Russian and Napa Rivers	Districts	San Francisco	Agricultural; flows to coast and estuary; good opportunities for developing stakeholder participation and social science
	RFCs	California-Nevada RFC	
	WSCs	CA	
American, Feather and Yuba Rivers	Districts	Sacramento	Considerable work done here already, NOAA Hydromet Testbed; unique regulatory flexibility; broad interest
	RFCs	California-Nevada RFC	
	WSCs	CA	
Columbia River	Districts	Portland District Seattle District	Bilateral treaty being renogtiated so high attention; Northwest Division USACE undergoing extensive IT transformation so good opportunity for technical information services demo
	RFCs	Northwest RFC	
	WSCs	OR, WA	
Tanana River	Districts	Alaska	Complex physiography and hydrology, ubiquitous cold regions processes, ice jams and flooding a recurring problem near major population center.
	RFCs	Alaska-Pacific RFC	
	WSCs	AK	
Kenai, Anchor Rivers	Districts	Alaska	Glaciers important to water budget, river ice problems, seasonal flooding common, critical fisheries.
	RFCs	Alaska-Pacific RFC	
	WSCs	AK	
Upper Colorado River	Districts	Sacramento District Albuquerque District Omaha District	Broad interest; pilot study area for National Integrated Drought Information System (NIDIS)
	RFCs	Colorado Basin RFC	
	WSCs	UT, WY, CO, NM, AZ	
Upper Missouri River	Districts	Omaha	Upper Missouri River Basin Restoration Project, broad interagency collaboration already in place, USACE has already developed extensive eGIS framework
	RFCs	Missouri Basin RFC	
	WSCs	WY, MT, ND, SD, NE	
Upper Mississippi River	Districts	St. Paul Rock Island Chicago Detroit St. Louis	Agricultural; frequent flooding; river ice, frozen ground, snowmelt; levee issues; a start for bigger Mississippi Basin and integration needs to address Dead Zone.
	RFCs	North Central RFC	
	WSCs	MN, WI, IA, IL, IN, MO	
Lower Colorado River	Districts	Fort Worth Galveston	Flows to Gulf; agricultural; extensive reservoir management.
	RFCs	West Gulf RFC	
	WSCs	TX	
Red River	Districts	Tulsa, Vicksburg	Unique opportunities for developing interoperability, low flows, agricultural issues and impacts, reservoir management issues.
	RFCs	Arkansas Basin RFC	
	WSCs	TX, OK, AR, LA	
Great Lakes	Districts	Detroit Buffalo	Well-organized social network in place and well-documented needs; coastal-terrestrial linkages; water quality issues; fisheries issues; lake levels; effects of climate change
	RFCs	North Cenral RFC Ohio RFC Northeast RFC	
	WSCs	MN, WI, MI, IN, OH, PA, NY	
Susquehanna, Delaware, Hudson Rivers	Districts	Baltimore Philadelphia New York	Flows to estuary; river ice and ice-jam issues, snowmelt flooding issues; storm surge; low flows, active river basin commissions, well-organized, political connections.
	RFCs	Northeast RFC Mid-Atlantic RFC	
	WSCs	NY, PA, NJ, MD, DE	
Tar, Neuse Rivers	Districts	Wilmington	Flows to coast; storm surge issues; NOAA Hydromet Testbed East
	RFCs	Southeast RFC	
	WSCs	NC	

8.3 Susquehanna/Delaware/Hudson Watersheds

8.3.1 Description

The three watersheds (Susquehanna, Delaware, and Hudson River) originate in New York State. The Susquehanna River begins at Otsego Lake near Cooperstown meandering south through Pennsylvania before emptying into Chesapeake Bay. The Delaware River begins its journey in the Catskill Mountains flowing south forming the border of Pennsylvania and New Jersey before emptying into Delaware Bay. The Hudson River originates in the Adirondack Mountains in north New York flowing south before emptying into New York Bay.

8.3.2 Pros/Cons

Pros: The three adjacent river systems flow into a very densely populated coastal region with significant flooding and water quality issues. River flooding in this region has a variety of causative mechanisms including tropical system rainfall, spring snowmelt (usually combined with rainfall), frontal rainfall, convective rainfall, and occasionally ice jams. Coastal flooding from winter storms (Nor'easters) or tropical storms is also a fairly frequent occurrence. Several major to record floods in recent years have drawn attention to the need for improvements in flood warning and flood mitigation. Because of the regions physical geography, water is resident in the river/estuary/coastal system for long periods of time. This, in combination with high population and intensive land use, makes estuary/coastal water quality a major issue throughout the region. The potential impacts of climate change and the associated sea level rise are also of significant concern. Every few years, the area is impacted by drought. Though not typically severe, drought is of increasing concern and impact as water supplies are stretched thin by increasing demand. Therefore, long term low flow and ground water forecasting is becoming increasingly important for water supply management.

Cons: Doing a demonstration for this large an area will require the cooperation of multiple River Forecast Centers, COE offices, and USGS offices.

8.3.3 Elements to Focus On

The elements in these watersheds most appropriate or relevant to focus on:

- One stop shopping web service delivery
- USCACE/NWS forecast and reservoir real-time data exchange
- Ensemble storm surge modeling and inundation mapping
- 0-7 day ensemble stream flow predictions
- Low flow/reservoir inflow forecasting for water supply/water quality applications
- Ground water forecasting services
- Coupled river/coastal models with estuary water quality components
- River ice and ice jam modeling
- Climate change, including sea level rise, impact studies

8.3.4 Stakeholders

Potential watershed stakeholders with whom we can begin to interact with:

- Federal: NOAA, USACE, USGS

- States: MD, NJ, NY, PA, VA
- Cities: New York City, Philadelphia, Baltimore, Albany
- Susquehanna River Basin Commission
- Delaware River Basin Commission
- Meadowlands Commission
- New York State Department of Environmental Conservation
- New York City Department of Environmental Protection
- Maryland Department of the Environment
- New Jersey Department of Environmental Protection
- Chesapeake Bay Observing System (Chesapeake Inundation Prediction System)
- Chesapeake Research Consortium
- University of Maryland Center For Environmental Science (Chesapeake Bay)
- Virginia Institute for Marine Sciences (Chesapeake Bay)
- Rutgers Haskins Laboratory (Delaware Bay)
- Industries: water supply, power generation, commercial fishing & shellfish, beaches & boating, tourism & recreation, agriculture, commercial shipping

8.3.5 Actors

An IWRSS Demonstration Project in the Susquehanna/Delaware/Hudson would involve several organizational units and provide a rich but manageable opportunity to demonstrate concepts that must transcend organizational boundaries.

8.4 Great Lakes

8.4.1 Description

The Great Lakes constitute the largest surface freshwater system on Earth, and have been recognized as a national and international treasure (Figure 8.3). The Great Lakes contain around 95% of the US fresh surface water, and roughly 18% of all the fresh surface water of the World. The US Great Lakes shoreline is over 4,500 miles long bordering eight states, with the total Great Lakes shoreline over 10,000 miles long with the inclusion of the Ontario, Canada border. The land surface drainage area is 201,460 sq. mi., and a water surface area of 94,250 sq. mi. Outflow from the Great Lakes basin is less than 1 percent of the total volume per year, resulting in retention times in the lakes from as low as 2.6 years (Erie) to 191 years (Superior)[11].

8.4.2 Justification

A wide array of political and user/client-based drivers exist to support focus on the Great Lakes as a premiere watershed candidate for IWRSS demonstration.

8.4.3 Presidential Drivers

President Bush issued an Executive Order in 2004 that recognized the Great Lakes as a "national treasure" and created a federal Great Lakes Interagency Task Force to improve federal coordination in the Great Lakes. The Order directed the U.S. Environmental Protection Agency

[11] Source: EPA, http://www.epa.gov/greatlakes/physfacts.html

(U.S. EPA) to convene a "regional collaboration of national significance for the Great Lakes." It was from this directive that the Great Lakes Regional Collaboration (GLRC) was created.

The GLRC is a wide-ranging, cooperative effort to design and implement a strategy for the restoration, protection, and sustainable use of the Great Lakes. An Executive Committee made up of senior elected and appointed officials from different levels of government helps to guide the GLRC in its decision-making procedures. Key partners in the Great Lakes region include the Great Lakes Interagency Task Force, Council of Great Lakes Governors, Great Lakes and St. Lawrence Cities Initiative, Great Lakes Indian Fish and Wildlife Commission, and the U.S. EPA (Great Lakes National Program Office). In December 2004 these key partners signed a declaration and a Framework Document, outlining the business operations and collaboration procedures for the GLRC, was adopted.

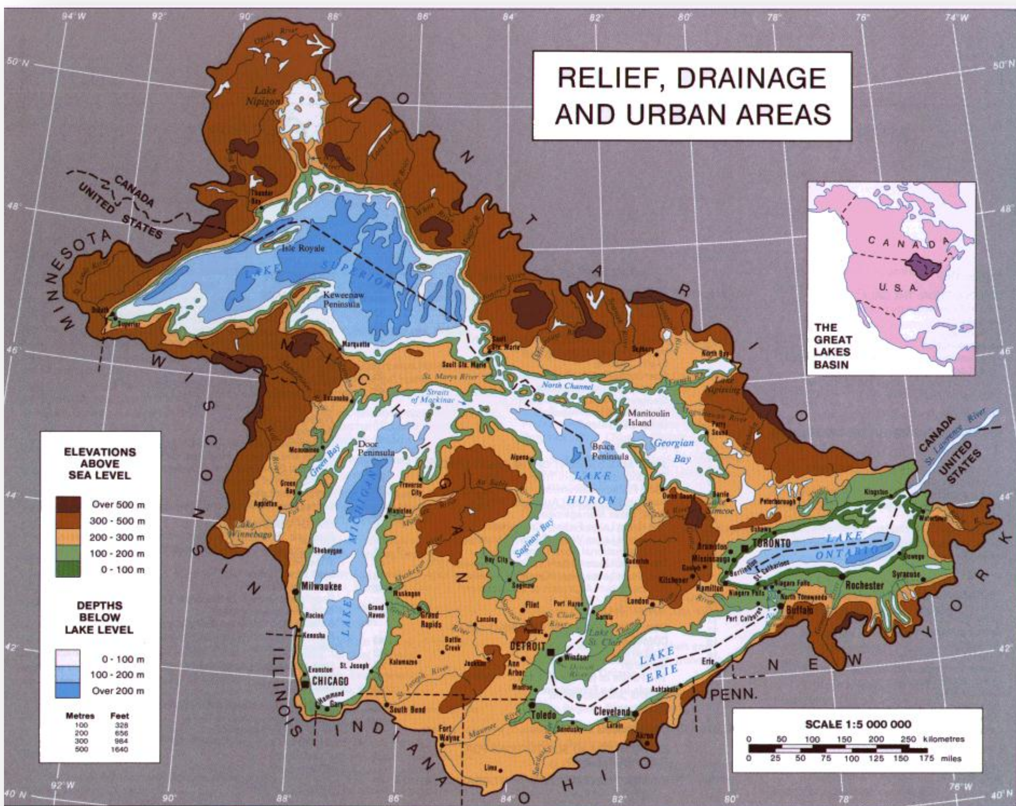

Figure 8.3. Great lakes and Upper St. Lawrence River watershed. Source: http://www.epa.gov/greatlakes/atlas/images/big01.gif

Since that time, a strategy has been developed through the work of the GLRC that strives to address eight priorities for Great Lakes restoration and protection, including aquatic invasive species, habitat/species, coastal health, areas of concern/sediments, non-point source, toxic pollutants, indicators and information, and sustainable development.

An IWRSS demonstration project in the Great Lakes would help inform decision-making on all of the GLRC priorities listed above as well as bring to bear additional services for integrated water resource product delivery.

8.4.4 Congressional Drivers

At the request of Congress, the U.S. Geological Survey (USGS) is assessing the availability and use of the Nation's water resources to gain a clearer understanding of the status of our water resources and the land-use, water-use, and natural climatic trends that affect them. The goal of the National Assessment of Water Availability and Use Program is to improve our ability to forecast water availability for future economic and environmental uses. As a pilot, the USGS has focused on the Great Lakes Basin study to improve fundamental knowledge of the water balance of the basin, including the flows, storage, and water use by humans. An improved quantitative understanding of the basin's water balance not only provides key information about water quantity but also is a fundamental basis for many analyses of water quality and ecosystem health.[12]

The information gathered in the USGS Great Lakes Basin study provides for a strong information/data foundation on which to build an IWRSS demonstration project in the Great Lakes. Other U.S. watersheds/regions do not yet have this type of information on which to build from, given that the Great Lakes pilot is the first focus area studied by the USGS.

8.4.5 State Drivers

In 1955, five Great Lakes States adopted the Great Lakes Basin Compact.[13] The compact was later ratified and adopted by all eight Great Lakes states. It created through the collective legislative action of its member states and later granted congressional consent through Public Law 90-419 -- established five general areas of responsibility for the Great Lakes Commission. These areas include:

1. To promote the orderly, integrated, and comprehensive development, use, and conservation of the water resources of the Great Lakes Basin (hereinafter called the Basin).
2. To plan for the welfare and development of the water resources of the Basin as a whole as well as for those portions of the Basin which may have problems of special concern.
3. To make it possible for the states of the Basin and their people to derive the maximum benefit from utilization of public works, in the form of navigational aids or otherwise, which may exist or which may be constructed from time to time.
4. To advise in securing and maintaining a proper balance among industrial, commercial, agricultural, water supply, residential, recreational, and other legitimate uses of the water resources of the Basin.

An IWRSS demonstration project in the Great Lakes would help the Great Lakes Commission and its member states to maintain the water resource related responsibilities outlined under the Great Lakes Basin Compact, by providing an integrated water resource information delivery service – in one stop shopping format.

[12] Source: http://water.usgs.gov/wateravailability/greatlakes/
[13] Source: http://www.glc.org/about/glbc.html

8.4.6 Local (Watershed level) and Public Drivers

A variety of local and user based needs assessments have been conducted in the Great Lakes region, for a variety of purposes. They include assessments focused on coastal community development, data integration and distribution, navigation services, agriculture issues, biodiversity, etc. [14]

8.4.7 Focus Areas

As noted above, a variety of user based needs assessments and other vehicles for public/stakeholder input exist from which information on focus areas can be obtained. A precursory review of available information[15] indicates that an IWRSS demonstration project in the Great Lakes would need to address the following requirements:

- Climate Change Trends
- Coupled River/Coastal/Estuary Models
- Mid-to-Long Range Climate Forecasts
- Water Quality
- Water Quantity (including water levels for consumptive/non-consumptive uses)
- Fisheries / Wildlife
- Invasive Species
- Commerce and Transportation
- Tourism and Recreational Water Uses

8.4.8 Support Infrastructure

The Great Lakes are unique in that they have a regional ocean governance structure, which has water resource responsibilities for the entire geographic range of the watershed, a watershed specific research laboratory (i.e., NOAA Great Lakes Environmental Research Lab), and an international water resource interest component. The Great Lakes also have a wide range of managers/user/stakeholders/clients with interests in water resource science and services. These include:

- Federal: EPA, USACOE, ARS, FSA, FS, NRCS, NOAA, HHS(ATSDR), Coast Guard, F&WS, NPS, USGS
- States: MN, WI, MI, IL, IN, OH, PA, NY
- International: Environment Canada, Province of Ontario
- Tribal Nations (numerous)
- Commissions: Great Lakes Cities Initiative, Great Lakes Commission, International Joint Commission

8.4.9 Potential Products/Services

A variety of user based needs assessments have been conducted in the Great Lakes region, for a variety of purposes. While few of these assessments have focused solely on the services/science requirements for a fully integrated national water resource regime, many of them do record user needs in this regard. A document/literature review of all user/stakeholder

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[14] Source: http://www.great-lakes.net/

[15] Source: EPA, http://www.epa.gov/greatlakes/

requirements should be conducted before attempting to outline what products and service delivery mechanics are needed for the Great Lakes.

8.5 Tar/Neuse

8.5.1 Description

The **Tar River** begins in Piedmont farmlands between Oxford and Roxboro and flows southeasterly (Figure 8.4). It passes through Louisburg and crosses the Fall Line at Rocky Mount, where it enters the Coastal Plain. The Tar River passes Tarboro and becomes tidal near Greenville. The river is about 215 miles long, located in northeast North Carolina, flowing generally southeast to an estuary of Pamlico Sound. The Tar River becomes the tidal Pamlico River just south of Washington, NC. The Tar River was strongly affected by Hurricane Floyd in 1999 and caused much flooding in the area. The Tar River suffered the worst flooding from the hurricane, exceeding 500-year flood levels along its lower stretches.

HUC 4

The **Neuse River** is a major permanent stream (total length is approximately 275 miles) rising in the piedmont of North Carolina and emptying into the Pamlico Sound below New Bern. As a typical river in the Coastal Plain, the Neuse enters a basin of intermittent bottomland swamp on its journey towards its outlet. The Neuse is prone to extremes in its flow carriage, often escaping its banks during wet periods, and then reducing to a trickle that can be forded on foot during prolonged drought conditions. The Neuse has a history or water quality problems. It has been plagued in recent years with environmental and public health problems related to municipal and agricultural wastewater discharge, storm runoff, and other sources of pollution. Pollution was particularly bad in the aftermath of Hurricanes Fran and Floyd in the late 1990s.

Both River lie entirely inside the state of North Carolina and they discharge into Pamlico Sound.

8.5.2 Pros/Cons

Pros. The Hydrometeorological Testbed (HMT-Southeast) Management Council has decided that their next regional focus area, HMT-Southeast, will be in the Tar and Neuse River basins in North Carolina starting in FY10. The Hydrometeorology Testbed (HMT) is a concept aimed at accelerating the infusion of new technologies, models, and scientific results from the research community into daily forecasting operations of the National Weather Service (NWS) and its River Forecast Centers (RFCs).

Because of its location, it is faced with serious flooding when tropical storms make landfall, thus the Tar/Neuse could be used to test tropical rainfall, storm-surge modeling/effects, coastal issued in general. The Tar River Basin is highly visible and there are already several on-going studies. For example we can leverages efforts through NOAA's Sea Grant program (CI-Flow) and the NOAA in the Carolinas program. Inundation mapping has been started at this location.

Because of its size, only one state is involved, North Carolina, one River Forecast Center (SERFC), one USACE District office, and one USGS State Water Science Center.

Cons. There are already many projects focusing in the Tar/Neuse Basins. It might be more beneficial to find another basin with similar or better characterization. Any other basin affected by storm-surge could serve the purpose of testing tropical conditions/ products. Nothing is too particular in this basin. Snow and ice would not be variables of consideration in this basin.

Chapter 9 Synopsis: Concept of Operations

This chapter briefly summarizes the IWRSS concept of operations (CONOPS) as described in detail throughout the previous chapters. It describes both the quantitative and qualitative characteristics of IWRSS from the perspective of the user and stakeholder.

Water resources are broadly described as one of the greatest challenges facing our Nation in the 21st century. Water resources stakeholders contend with increasing risks associated with water shortages, reduction of water availability for environmental needs, contamination and pollution of water bodies, flood loss, drought loss, wetland loss, and coastal ecosystem deterioration. Managing these risks requires better information. The stakeholders for the IWRSS project are consumers of water resources information who can benefit from the new and improved information and integrated service delivery that IWRSS will provide. They require data and information to develop knowledge necessary to make decisions and take actions. IWRSS stakeholders include decision makers who manipulate water, water and environmental resource managers and planners, emergency managers and responders, public-sector information consumers with a variety of commercial and private interests, and "internal" stakeholders involved in the collection, analysis, prediction and delivery of water information and services.

9.1 Objectives and Goals

The overarching objective of the IWRSS project is to demonstrate a broad integrative *national water resources information system* to serve as a reliable and authoritative basis for adaptive water-related planning, preparedness and response activities from national to local levels. The project seeks to make intersections between relevant systems more seamless, synthesize information better across systems to improve services and service delivery and improve the overall quality of information, and provide new information and services to better support the needs of water resources stakeholders. Chapter 1 described three operational goals associated with these objectives: 1) integrate services and service delivery, 2) increase accuracy and lead time of river forecasts, and 3) provide new "Summit-to-Sea" high-resolution water resources information and forecasts.

To address these goals, three crosscutting implementation themes have been identified for the IWRSS project: 1) Human Dimensions: Stakeholder Interactions and Communications, 2) Technical: Information Services, and 3) Operational Science: Summit-to-Sea Modeling and Prediction Framework. Tasks for implementation in IWRSS are structured around these three crosscutting themes.

The IWRSS project is designed with these goals and themes to achieve four tangible outcomes:

1. **Integrated Water Resources Services.** IWRSS will result in improved internal and external communication and better, more productive engagement with stakeholders. Delivery of water resources data, services and products will be more integrated to provide stakeholders with an experience that appears to be one-stop shopping. Communication of risk and uncertainties will be improved, both in terms of quantitative measures and through the efforts of enhanced training and outreach.

2. **System Interoperability, Collaborative Tools and Workflow.** Major systems in use across multiple agencies will be made interoperable, meaning data and information will be able to flow between them more seamlessly and models, tools and other applications will be cross functional across systems. Models used nationally will be made available regionally, and new models will be made accessible. Toolkits will be provided to improve access and analysis of information and improve collaborative workflow.
3. **Common Operating Picture.** Several elements of the IWRSS project will work in combination to provide a common operating picture across multiple agencies, enabling river forecasters in one agency using their system to see the same information as river managers in another agency using a different system, and external stakeholders to see much of the same information through common web services. The Common Operating Picture will be dominantly geospatial, meaning enterprise GIS and geo-Intelligence will be ubiquitous within agency systems.
4. **Integrated, Sustainable Consistent Water Resources Modeling and Forecasts.** The centerpiece of IWRSS for IWRSS stakeholders will be a new national suite of integrated high-resolution water resources analyses and forecasts. Analyses will include historical water budget studies going back as long as records permit, current conditions for immediate situational awareness, and forecasts of future water budget conditions. This suite will include basic short-term ensemble water budget forecasts at 1 km^2 resolution for U.S., advanced modeling in selected regional demonstration areas with mechanisms to transition best practices to other regions, and advanced regional river and flood forecasting and water management models, including linkages between terrestrial and coastal/estuarine environments, surface water and groundwater, and water quality.

9.2 Strategies, Tactics, Policies and Constraints

Recognizing that no single agency possesses all of the capabilities and expertise needed to meet these objectives, the IWRSS project was created as a Consortium of federal agencies with operational missions in water science, observation, management and prediction. The Consortium was initiated by NOAA and currently includes USACE and USGS, but the collaboration is open and it is expected that other partners will participate.

The IWRSS project is fundamentally outcome-driven, and is designed with emphasis on stakeholder participation, and with emphasis on flexibility and adaptability to meet shifting and emerging needs as stakeholders work to address complex water resources challenges. At the core of the IWRSS project design is a *spiral development model* that continuously iterates between project planning and execution, outcomes, and needs, to gradually build capability without ever losing touch with what stakeholder's need to support their decision-making. Along with this strategy is a tactical approach of *agile development*, borrowed from contemporary software engineering, which uses innovative social organization in project development to transcend organizational boundaries and hierarchies to get work done quickly and efficiently.

The IWRSS project will require and seek considerable resources to meet its objectives, but in a difficult budgetary climate this is often not a reliable strategy. Thus the project design exploits the same flexibility and adaptability is seeks to create by adopting a philosophy of "*opportunity driven, opportunity executed*". In other words, by focusing on partnerships, communication, coordination, and forward planning, IWRSS will strive to be well positioned to take advantage of opportunities, large or small, as they become available. This is the bargain; in the absence of large funding resources, the IWRSS project must be granted flexibility to move quickly and adroitly.

The IWRSS project is constrained, by deliberate strategic choice, to operate and function within existing local, regional and national frameworks. While it can be tempting to dream of an idealized structure or system for water resources, if only one could start over, this is neither practical nor feasible. Instead, the IWRSS project design has taken the approach of embracing the existing structure and systems, objectively assessing their strengths, weaknesses and needs, and focusing on key aspects to solidify, strengthen and transform them. It's a renovation, not new construction.

Similarly, a major premise for IWRSS is that much of what is needed already exists in a reasonably mature form – perhaps not perfect, but reasonably mature. The major emphasis in IWRSS is on connecting and integrating science with sound technical approaches to move quickly towards a baseline capability that approaches the objectives and goals. In this sense IWRSS is more about implementation than research, although it will be a very useful vehicle to draw research results into operational use.

9.3 Organizations, Activities, Roles and Interactions Among Participants and Stakeholders

Within the initial Consortium agencies of NOAA, USACE and USGS, several key organization elements have been identified where focused integration efforts will be beneficial (Figure 9.1). Others elements will be identified as IWRSS proceeds. Within NOAA these

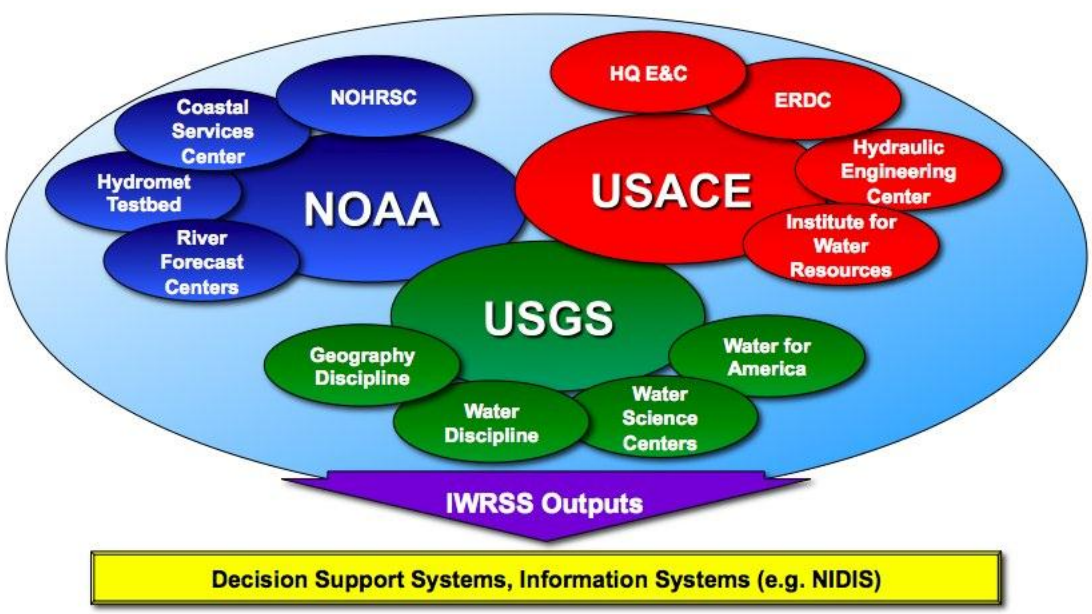

Figure 9.1. Focal points for enhanced integration and collaboration in IWRSS.

include NWS River Forecast Centers and the NOHRSC, the NOS Coastal Services Center, and NOAA's Hydromet Testbed. Within USACE these include Engineering and Construction (HQ), the Engineer Research and Development Center, the Hydrologic Engineering Center, and the

Institute for Water Resources. Within USGS, these include both the Water and Geography Disciplines, including State Water Science Centers and field offices, and the Water for America project.

9.3.1 Operational Roles and Interactions

Most of the operational analyses (current situation) and prediction activities will involve interactions between RFCs, USACE Districts, and the NOHRSC (i.e. national IWRSS operational support center). Historical analyses will primarily involve collaboration between USGS Water for America (both project management and the State Water Science Centers, who will conduct the studies) and NOHRSC, to coordinate historical water budget studies with high-resolution reanalyses needed to support regional forecast model calibration. Interactions with Coastal Services Center will occur in two major categories: 1) leveraging their knowledge and experience in stakeholder participatory processes in particular, and in service provision for resource management in general, and 2) coordination on a variety of issues where terrestrial water resources and coastal resources intersect, including coordinating needs and solutions.

River Forecast Centers and USACE Districts will continue to provide river forecasting, management and related services, working and interacting as they do now and as they plan to do in the future. The chief difference will be that a number of intersections involving systems and data will be streamlined through development of CHPS/CWMS interoperability and data synchronization, making data exchange and coordinated forecasting tasks easier and in general making much more data and information readily available in both directions. By leveraging interoperability and data synchronization, the addition of eGIS and geo-Intelligence information will result in a Common Operating Picture within both systems, allowing offices in both agencies to view key information nearly simultaneously. Together, these new capabilities will transform many aspects of current RFC-District interaction, especially during emergency events, allowing dialogue and communication between offices with the same view up front.

Interactions between River Forecast Centers and NOHRSC will change in several ways. The NOHRSC will be transformed into a national IWRSS operational support center, and will operate high-resolution gridded land-surface models nationally to provide baseline water budget analyses and predictions. Implemented through regional demonstrations, RFCs will have access to these data products and have options for using them within regional river forecast models. RFCs will also have opportunity to run the same and similar models regionally, either in similar configurations to national runs to expand the ensemble suite for XEFS, or in higher resolution modes to sharpen the nationally produced information. The NOHRSC, RFCs and other regional and local offices, will coordinate on a regular and frequent basis. For example, the NOHRSC and Northeast RFC instituted a weekly snow coordination teleconference in 2008, and this year have expanded it to include Weather Forecast Offices in the region. This has proven to be a mutually useful exercise and is being expanded to Colorado Basin RFC this year. This type of routine weekly coordination will occur year-around for the complete water resources activity, and daily communication between regional and national forecasters will be common.

In addition to operational analysis and forecasting, interactions with NOHRSC will be expanded through its transformation to a national support center to provide a variety of science, technical and operational support. NOHRSC will provide national archiving for CHPS and associated backup and verification functions, data services to provide gridded model and forcing data sets to regional and local offices (throughout the Consortium), technical support and development on certain aspects of IWRSS such as data synchronization and interoperability, and science support associated with IWRSS.

The USGS will continue its normal mission and functions in the IWRSS framework, but will see increased interactions with NOAA in at least three areas. First, the NOHRSC's central THREDDS data service will provide a common feed of high-resolution model and weather forcing data that Water Science Centers or USGS support centers can easily tap into and extract what they need to support their modeling activities, reducing their data acquisition and preprocessing overhead. Second, State Water Science Centers and the Water for America project will interact with NOHRSC (and likely RFCs and Corps Districts) as they work to conduct regional historical water budget studies, and as NOHRSC works to conduct historical reanalyses of the high-resolution modeling system. The USGS will be conducting intensive historical water budget studies in selected regions, going back as far as the record permits. The NOHRSC must conduct historical model reanalyses to support regional river forecasting, which requires this information for calibrating empirical models and assessment of biases to provide guidance for model updating. Coordination between these modeling reanalyses and the intensive USGS studies makes sense to ensure that the two historical stories are consistent with each other. Moreover, the modeling may be helpful to the USGS studies.

NOHRSC will interact with the USGS Geography Discipline to obtain national geospatial and surveillance data sets for distribution through the IWRSS eGIS framework, working to make USGS data, Landsat and other imagery routinely available within the CHPS and CWMS environments for the high-resolution modeling at both national and regional scales. In particular, the NOHRSC will work with Geography to enhance coordination during emergency events for high-resolution imagery and flood extent mapping that proved to be useful during the Midwest Floods of 2008. Third, NOHRSC and NWS OHD will interact with the USGS Water Discipline to take delivery of and implement operational groundwater modeling capabilities through GSFLOW or MODFLOW in order to add these variables to the baseline suite of IWRSS gridded water budget products and begin making a key linkage for low flow predictions. In this arena NOAA and USGS will also work to identify other USGS models and tools that would be useful to NOAA/USACE river forecasting and management if made available to CHPS through adapters and plug-ins. Here the goal is to take maximum advantage of models already developed.

As noted above, several modes of routine operational interactions are expected between several combinations of actors. For overall operational coordination, a quarterly IWRSS operations management meeting is planned to review status and progress towards operational goals, identify issues and gaps, and coordinate needs and responses. Technical working groups are planned for both operational and R&D aspects of IWRSS, and are discussed further below.

9.3.2 Research and Development Roles and Interactions

A major focus of IWRSS is implementation of existing information, models, tools and utilities to enable a new comprehensive operational water resources prediction enterprise. In this sense IWRSS must initially be focused more on technical and IT engineering aspects of implementation than on new research, but tactical R&D is needed to fill critical gaps along the implementation path, and as the water resources prediction capability gets going, new R&D will be needed on many fronts. IWRSS is designed to fast-track operational implementation of ready capabilities and to provide a well-organized research-to-operations framework for injecting new capabilities over time. Standard readiness metrics commonly used elsewhere for science and technology acquisitions (e.g. TRLs, described in Chapter 5) will be incorporated into IWRSS to make it easy for all to see where different science and technology capabilities are at in terms of operational readiness, and what steps are needed to advance desired capabilities to operational levels. This is needed to facilitate interagency coordination and interaction on R&D activities.

Research and development supporting IWRSS goals will be coordinated through twice-annual workshops involving R&D directors and managers from several laboratories and facilities within NOAA, USACE, and USGS. The purpose of these workshops will be to review current and planned R&D activities within each agency/facility and coordinate investments within the budget-scheduling framework. IWRSS R&D activities are expected to involve at least:

- USACE
  - Institute for Water Resources (Alexandria, VA)
    - Hydrologic Engineering Center (Davis, CA)
  - Engineer Research and Development Center
    - Coastal and Hydraulics Laboratory (Vicksburg, MS)
    - Cold Regions Research and Engineering Laboratory (Hanover, NH)
- USGS
  - Water Discipline, National Research Program (Reston, VA; Denver, CO; Menlo Park, CA)
  - State Water Science Centers / Water for America
- NOAA
  - Office of Hydrologic Development Hydrology Laboratory (Silver Spring, MD)
  - Office of Atmospheric Research Earth Systems Research Laboratory (Boulder, CO)

9.3.3 Roles and Interactions in the Regional Demonstration Projects

The intensive focus of the regional demonstration projects will require additional interactions between actors directly involved in the projects. The actors in any given regional demonstration would include interagency offices at all scales within, or responsible for the region, the national support center, and various R&D facilities with identified roles in the demonstration. So, national centers (e.g. national support center and CSC), Regional or Division HQ, River Forecast Centers, Weather Forecast Offices, USACE Districts, Water Science Centers, and USGS field offices might all be involved in regular coordination activities for the regional demonstrations. These activities, such as teleconferences and face-to-face meetings, will be organized as Regional Demonstration Teams (see below) and scheduled as appropriate for the specific purposes of the project. Others will be engaged in these coordination activities as needed to support the goals of the projects.

9.4 Responsibilities and Authorities

The governance structure planned for IWRSS consists of an Executive Oversight Council, a Project Management Team, Technical Working Groups, and teams for each regional demonstration area selected (Figure 9.2). The Executive Oversight Committee will provide high-level agency oversight and programmatic authority for the IWRSS Project. Its members will consist of senior executive service leadership representing water resources programmatic interests from each agency, which will meet twice to discuss IWRSS agenda twice annually. The Council will engage the Federal Advisory Committee for Water Information (ACWI) as a source of guidance and direction for the IWRSS project. ACWI represents the interests of water-

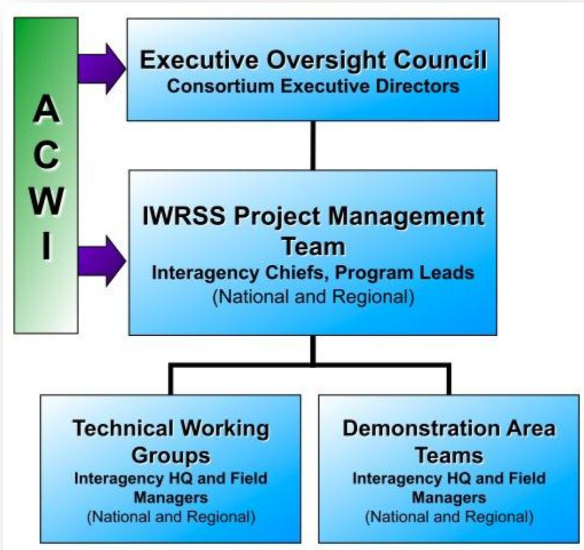

Figure 6.4. Twenty-one USGS Water Resource Regions (upper left). Within each region, watersheds are nested

information users and professionals in advising the Federal Government on Federal water-information programs and their effectiveness in meeting the Nation's water-information needs. ACWI's purpose is to improve water information for decision-making about natural resources management and environmental protection. USGS is designated by OMB as the lead agency for ACWI. Other Federal organizations that fund, collect, or use water resources information work together with the USGS to implement program recommendations.

The Project Management Team will be responsible for overall strategic planning, integration and operations of the Project. Consisting of national and regional chiefs and program leads from each agency, this team will be the primary planning and decision-making body for IWRSS operations, services, science and technology. It will regularly engage the Executive Oversight Council for programmatic direction, and will also engage with ACWI. It will meet frequently as necessary during initial IWRSS planning, and quarterly thereafter. This team will be established in early 2009.

Technical Working Groups consisting of national and regional managers will be formed to focus on specific topical areas identified for the human, technical and science themes of IWRSS. It is clearly recognized that many teams and workgroups already exist to address issues related to IWRSS. Here the focus is on a) cross-agency needs and issues, and b) finding relevant intersections with existing teams for coordination. If it makes sense in some cases, some existing teams could be re-purposed or given expanded scope to address IWRSS. Some necessary working groups already identified include 1) social science strategy development, 2) needs assessment and coordination, 3) interoperability and data synchronization, 4) eGIS and geo-Intelligence, 5) centralized data archive, backup and COOP, 6) S&T readiness standardization, 7) national-regional modeling, 8) model forcings, 9) historical reanalyses, and 10) terrestrial-marine linkages. In addition to these, a synthesis working group consisting of all working group leads is planned to ensure intersections are well coordinated. These groups are discussed further in Section 9.6 below.

This governance structure is designed to help coordinate water resources planning, activities, operations, products and services across Consortium agencies. It does not replace or supersede normal organizational structures and authorities.

9.5 Operational Implementation

The major operational implementation elements (technical and science) planned for IWRSS include 1) developing interoperability between key systems, 2) data synchronization, archive and backup, 3) eGIS and geo-Intelligence, 4) enhanced observations and surveillance, 5) historical water budget analyses and modeling reanalyses, 6) national and regional implementation of high-resolution water budget models for analysis and prediction, 7) data services for model and pre-processed forcings data sets, and 8) new products and services delivered through a unified front to customers. These are interrelated and much of the identification and prioritization of these elements concerns establishing effective workflow. Thus the science implementation is most effective if the technical elements to enhance interoperability and data flow are established. Such dependencies are not absolutely critical; the major science elements could be implemented independently, but with greatly reduced potential for collaboration and effective workflow. Relationships between these major elements are shown as a straw flow chart (Figure 9.3). In the absence of IWRSS, this diagram would have to be drawn essentially as independent vertical flows for river and flood forecasting, national distributed modeling, regional distributed modeling, and local and regional modeling efforts such as groundwater, each with separate data feeds and product distributions, and lacking the Common Operating Picture in the middle. Instead of interacting with a common framework for water resources products and services, the various stakeholder end users would see a variety of different sources, web sites, and distribution mechanisms.

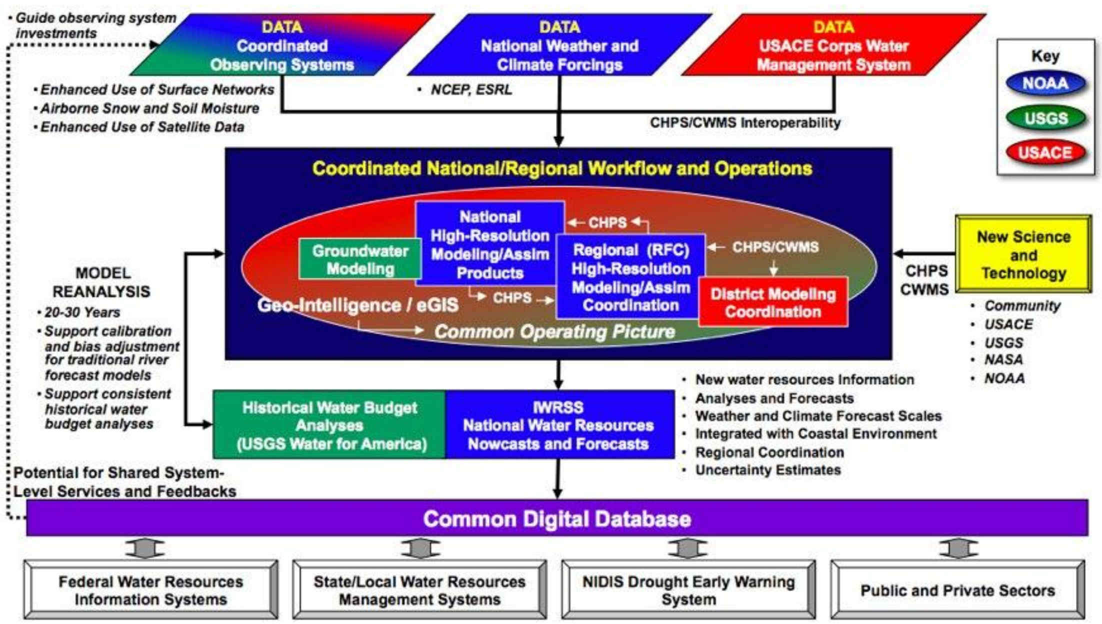

Figure 9.3. Straw flow chart illustrating principal relationships and workflow between the major technical and science elements planned for IWRSS implementation.

9.6 Initiation, Development, Maintenance, and Retirement of IWRSS

As noted above, the implementation strategy for IWRSS employs a spiral development model to advance toward IWRSS goals incrementally through an iterative process involving stakeholder participation and regular reassessment of outcomes. In conjunction with expected resource availability and budget planning, this strategy leads to initial focus on starting implementation of major elements that have already been identified as important needs or key foundational elements, then ramping up over time as opportunities allow.

The first three priority elements for initial implementation efforts are 1) interoperability and data synchronization (foundational), 2) eGIS and geo-Intelligence (established need), and 3) national gridded high resolution water budget analyses and predictions (established need). Using existing opportunities, efforts have already begun or can start quickly on all three of these fronts. The NOHRSC has begun working with USACE (CWMS) and Deltares (CHPS) to develop technical approaches for (1); for (2) USACE CRREL has significant eGIS capabilities and expertise in place for CWMS and related systems, and can be leveraged quickly through collaboration to begin extending this to CHPS and other systems. For (3), the NOHRSC has demonstrated the capability for national high-resolution land surface modeling and data assimilation through the National Snow Analyses, has recently implemented the NWS RDHM model nationally, and is working with NASA to implement LIS operationally. A Water for America pilot study has been completed by USGS for the Great Lakes region, and a project has been funded through NWS AHPS to begin working on development of bias assessment and update guidance procedures through historical model reanalyses. Over the next 1-3 years, work on these and additional fronts is expected to begin ramping up IWRSS capabilities.

These early starts towards IWRSS goals are useful, and even the initial planning effort has resulted in early implementation of low-hanging fruit, adding beneficial capability to the enterprise. For example, the planning process has resulted in new capability for the NWS to enter information into the USACE Ice Jam Database, an important element for northern hydrology. Other similarly useful elements have been identified for quick implementation. Most of the major elements, however, will require detailed planning efforts to prepare for implementation; this will be established over the coming months through the formation of technical working groups, as noted in the discussion of the governance structure for IWRSS. Initial tasks for planning and implementation are described below.

9.6.1 Implementation Tasks

Given the many activities already underway that begin to form a foundation for this focal area, and the immediate science goal to operationally "breadboard" the IWRSS design concept, near-term implementation tasks focus on gathering key elements and establishing a coordinated framework. There are five fundamental steps necessary to demonstrate a baseline summit-to-sea modeling and prediction framework in the shortest time allowed by limited resources:

1. Start bringing the right people together.

This task involves the key groups who will be responsible for the implementation and operation of the baseline system, including a) the national operational IWRSS support center that will have primary responsibility for operating nationally consistent high-resolution water budget models, b) regional operational offices involved in demonstration projects that will serve as testbeds for developing regional-national interactions and workflow and for implementing additional integrated high- or very-high resolution modeling capability, c) facilities operating coastal and estuary models within the IWRSS demonstration regions, d) R&D focal points from various locations with subject matter expertise in the relevant models to be operated for this task, and e) social scientists and service experts that will be design the participatory process for IWRSS.

Needed first is a series of workshops dedicated to major components of the baseline system. Each workshop should focus on the role of the specific component in the overall goals of the baseline modeling and prediction system and on key intersections with other components. Each workshop should pragmatically assess in-hand capability with the idea of bread boarding a prototype system quickly, identify critical implementation gaps requiring additional resources to fill, and develop a blueprint for the implementation of the component. From these workshops a series of similarly focused working groups or sub-groups should be established to carry on routine planning and coordination. To be clear, each working group should include representatives from across the Consortium. The major components requiring workshops and standing working groups include:

- **Water Resources Modeling for IWRSS Workshop.** A highly integrative workshop covering all aspects of summit-to-sea water resources modeling described in the preceding sections is needed very soon. The workshop should be focused on knowledgeable IWRSS implementers and practitioners – the people who will be principally involved in implementing, operating, maintaining and using the models described in the preceding sections. This integrative forum is needed for this particular group to become very clear about existing and emerging capabilities within the Consortium, identify the elements and components that need to be included in the baseline, and begin to determine how these pieces will fit together. The agenda for this workshop should assume a high level of familiarity with modeling concepts and needs, and require little review of overarching IWRSS goals. The agenda should be pragmatically focused on identifying in detail the constitution of the baseline IWRSS summit-to-sea modeling and prediction framework. It should include presentations and discussions on themes of national, regional and local high-resolution land-surface modeling using NSA, RDHM, LIS and FASST, groundwater modeling using MODFLOW or GSFLOW, river modeling using CWMS and CHPS, coastal and estuary modeling using ADCIRC, special-purpose modeling, including very-high-resolution polygonal frameworks, and model forcings for short-term, mid- and long-range forecasts. The outcome of the workshop should be an outline identifying the pieces, the players, and the major role, responsibilities and milestones for implementing the baseline framework.
- **Social Science Strategy Workshop/Workgroup.** Also needed very soon is a workshop is to formulate major characteristics of the social science strategy for IWRSS. As described in Chapter 4, this workshop will be focused on developing the framework for IWRSS to identify and engage stakeholders, conduct needs assessments, establish outcomes and metrics for both the high-level IWRSS goals and for regional demonstrations projects, and conduct a social networking study to monitor communication effectiveness in IWRSS. Prior to this workshop, a brief, simple survey canvassing all local, regional and national offices (e.g. map shown in Figure 8.1) is prescribed to identify an initial set of stakeholder characteristics, which will be used in the workshop to begin forming a more comprehensive strategy. Following the workshop, a working group will be established to work on this issue.
- **Needs Assessment Coordination Working Group.** Many assessments of water resources stakeholders' needs have been conducted, a major one assessing needs State-by-State is underway (lead by USACE), and others will be collected in the future through IWRSS and by others. The USACE State of the States assessment

includes a series of regional workshops followed by a national workshop to facilitate synthesis. A standing working group will be established in IWRSS to synthesize user needs from these various assessments, identify those that are commonly expressed over large areas (e.g. national needs) versus those that are specific to certain regions or locales, and begin honing the methodology needed to ensure routine updating of stakeholder needs at all scales. The outcome of this group will be a synthesis report that summarizes needs geographically, with companion geospatial data sets that will enable future needs analyses using GIS. Included in this report will be a strategy for conducting future user-based needs assessments to fill gaps and maintain currency.

- **Interoperability and Data Synchronization Working Group.** The technical feasibility of enabling interoperability and data synchronization has been confirmed and fundamental mechanisms for both have been identified. A working group is needed to refine the technical approaches and identify specific system intersections, data to be exchanged, and so forth. This working group will have much to sort out at first, so will need to meet often in the first several months. Eventually, once the necessary elements are identified, this group may be retired or may meet periodically to update requirements. The initial outcome of this group will be a technical report outlining the requirements and the technical methodology for enabling interoperability and data synchronization. Then, depending on specific options selected for the methodology, a second report will be prepared outlining the operations framework for configuring and exercising interoperability and data synchronization.
- **eGIS and geo-Intelligence Working Group.** This working group will require close ties with the interoperability and data synchronization group, as these capabilities are important enablers for eGIS. This group will have three principal functions. The first is to work out the technical details of how eGIS will be implemented within the space of IWRSS interoperability and major systems, existing USACE capability and methodology, and COTS solutions. The outcome of this function will be a technical implementation plan. The second function is to identify requirements for enterprise data sets, metadata, and data standards, recommend sourcing strategies, and provide guidelines for provision of these data in the enterprise system. The outcome of this function will be a data requirements document. The third function is to establish recommendations, guidelines and requirements for geospatial integration, analysis and visualization capabilities, relating these to existing system capabilities including the CHPS Spatial Viewer, CorpsMap and CorpsView. The outcome of this function will be a gap analysis and implementation plan that either builds upon or suggests an alternative to these capabilities.
- **Centralized Data Archive and Related Services Working Group.** This group will develop and articulate specific system and data requirements for centralized archiving and related services such as rapid operational backup and continuity of operations. It will establish what data and information need to be archived and related parameters such as archive frequency, etc. In conjunction with this, it will develop requirements for retrieval capabilities for archived data, addressing issues such as how much archived data must be retrievable how quickly for operations recovery or other purposes, accessibility of archived data to external applications and any associated

restrictions, and related topics. The outcome of this team will be a comprehensive strategic plan for centralized data archive and backup for IWRSS.

- **S&T Readiness Working Group.** This group will perform two key functions. First, it will review readiness assessment frameworks commonly used in the acquisitions community, such as Technical Readiness Levels. It will assess these for IWRSS purposes and either recommend adopting an existing framework, or recommend adaptations of an existing framework. The outcome of this function will be a summary, findings and recommendations report. Once a framework is adopted, the second function will be to review existing capabilities across the Consortium organizations, assign relevant readiness levels, and catalog these in an on-line system. This task will include a systematic survey of capability "owners", e.g. the developer or principal user of a given model, tool, or code, to help identify realistic readiness levels as well as any perceived limitations or needed improvements. The outcome of this function will be a searchable on-line catalog of existing capabilities, such as models or model components, tools, utilities, or technical elements, which provides easy identification and assessment. Given this catalog, an operation requiring a widget to perform a specific function will be able to search and locate relevant options and assess their readiness. Using this capability will become standard operating procedure prior to investing in new development.
- **National-Regional Modeling Workgroup**. This group is needed to establish and refine modeling operating plans and milestones for the national IWRSS support center and regional modeling activities within the regional demonstration framework, and to develop and coordinate operational workflow between the national and regional scales. This group will be responsible for defining and coordinating the interactions needed to effectively use national and regional capabilities and resources. This group will intersect with many components of the baseline system, and will engage other groups within and outside of IWRSS that are involved with related activities. This group will likely require one or more workshops to facilitate communication, and regular teleconferences to maintain progress towards goals. The outcome of this group will be regular recommendations to guide modeling operations, development of toolkits to facilitate model intercomparison and analyses, and establish practices to improve workflow and operations between national and regional scales.
- **Model Forcings Workgroup**. This group is needed to establish, refine and coordinate the forcings framework for IWRSS modeling as well as for centralized preprocessing services. Many practical questions must be answered about model forcings – which ones to use in which priority order, standard operating procedures for missing or problematic forcings, which downscaling techniques or what preprocessing steps to use, etc. – which require focused consideration by multiple stakeholders. Assessing and prioritizing needs and coordinating different interests will be the principal responsibilities of this group. This workgroup may initially meet frequently by teleconference to develop a basic operating plan for model forcings, then periodically to review and update this plan. An early workshop may be warranted to facilitate this task, and the workgroup should plan to communicate its results at relevant internal meetings.

- **Model Reanalysis Workgroup**. This group is needed to establish integrated requirements for model reanalyses that incorporate related goals for historic bias adjustment, evaluation and validation of forecasts, provision of historical information as a fundamental part of IWRSS, reforecasting and design studies, and plans for Water for America. At least one workshop should be conducted to facilitate the discovery of these requirements. The outcome of this workgroup will be a requirements document that comprehensively describes each of these needs, identifies common and unique requirements for each goal, and prescribes a flexible (e.g. based on different resource scenarios) strategy to conduct the reanalyses and serve the potentially large volumes of information.
- **Terrestrial-Marine Linkages Workshop/Workgroup**. Several related activities are currently aimed at improving operational modeling and prediction of marine circulations in coastal and estuary waters, and developing improved physical linkages between these and terrestrial flows where they interact. A workshop is needed to review these developments, particularly those related to expanding the use of the ADCIRC model by NOAA/NOS and USACE/ERDC/CHL, in relation to the terrestrial connections. The workshop should focus on connecting different groups, reviewing activities and plans, and identifying key gaps to merge marine circulations and water elevations under wind and tidal influences with river inflow information. A component of the workshop should focus on the intersections: marine-freshwater interactions, saltwater intrusion into rivers and ecosystem linkages. Following the workshop, a working group is needed to develop an integrated strategic plan to link marine and terrestrial capabilities to address the edge in between. This group should represent both operational and R&D groups. The outcome of this workgroup will be an actionable plan to move forward and improve integration of activities.
- **Synthesis Workgroup**. This group is needed to ensure that issues are well integrated between working groups and that smaller, less obvious issues are not overlooked. This group will consist of the team leads or designees from each working group. It will perform a routine function of cross-walking the activities of each group, and assessing work group results and recommendations in an outward-looking context of the consortium or broader community. This purpose is to regularly look for overlap with other activities or organizations, possible intersections for integration, or related solutions that may be available elsewhere. The outcome of this group will be a working list of needs, solutions and recommendations from the collective of working groups, cross-walked with external groups and activities. One principal focus of this group will be on synthesis of modeling needs and available solutions, and it will make recommendations for implementing solutions via relevant system adapters or plug-ins. In this regard, one goal of this group is to coordinate and encourage the migration of necessary modeling tools and utilities into the CHPS and CWMS environments. This group will work largely through teleconferences, and will report back to respective working groups as needed. A workshop may be appropriate to summarize findings and recommendations in a wider forum. The group will be initiated early, then meet periodically to review and update. The national IWRSS support center will maintain the list and make it accessible to the Consortium. The list should serves as a working record and summary of needs, solutions, recommendations and cross-references across the working groups.

2. Assemble key science components and make necessary connections.

The major modeling component needs for the IWRSS Summit-to-Sea Modeling and Prediction framework have been identified through earlier workshops and will be refined through the focused workshops and workgroups outlined above in Task One.

Many of the modeling components needed for a breadboard implementation are available independently but need to be assembled and firmed up in an operational setting. On the terrestrial side, the national operational modeling framework of the NOHRSC provides a basis to begin the centralized modeling activities of the national IWRSS support center, beginning with the National Snow Analyses capability and the national implementation of the NWS RDHM. Additional models are being introduced at NOHRSC through collaboration with USACE CRREL involving the FASST model, and through an ongoing NASA-funded projected focused on implementation of LIS at the NOHRSC. NWS OHD also has an ongoing NASA project involving LIS R&D. USGS is preparing a version of MODFLOW for operational use and expects it to be ready within a year, and GSFLOW (surface water coupled to groundwater) can potentially be run operationally now. The ADCIRC model is being implemented more extensively on the coastal and estuary side.

Operating capacity, subject matter expertise covering the range of modeling applications, and software engineering support are required to move forward with the summit-to-sea modeling and prediction framework. The strategy for moving forward is to assemble the breadboard capability first in the national IWRSS support center, then work through the subsequent tasks to extend this to regionally specific capabilities. To this end, this task involves ramping up operating capacity and staffing at the national IWRSS support center, and as that occurs, working on assembly and integration. Building operating capacity involves extending the current capacity used for national snow modeling to accommodate the increased computational and storage demands of multi-model ensemble forecasts as well as the associated human analytical demands. Building subject matter expertise involves gathering individuals with knowledge, skills and abilities necessary to make sound scientific decisions regarding the use of models across the spectrum of water resources. If sufficiently close at hand, much of this expertise can potentially be borrowed as needed. Software engineering capacity is the principal need for technical integration tasks involving connecting data flows between modeling components, developing application adapters and plug-ins to link components. Specific elements of this task include:

- Begin the forward planning to transform the NOHRSC into a national IWRSS support center and opportunistically begin ramping up operating capacity and staffing. The NOHRSC is nothing more than a seed for what the support center will need to become to meet IWRSS objectives, so it important to consider the big-picture and the steps that need to be taken now to get there. The planning will need to involve several practical considerations, starting with space and location. Here the practical matter is two-fold: there is insufficient space at NOHRSC to grow by more than a couple of people, and looking ahead the most important consideration is what is the best location and situation for a national IWRSS operational support center. This decision is needed early so that early growth can be directed towards wherever the center is going to be to avoid relocation costs later on. A multi-agency planning team should be formed to evaluate the objectives of a national support center, identify existing opportunities and develop alternatives, then make recommendations for how to proceed.

- Begin assembling and connecting the modeling components noted above and in conjunction with the workgroups begin shaping up a breadboard system. Here the top three priorities are to get started on 1) system interoperability, 2) data synchronization and services, including eGIS, and 3) national high-resolution water budget modeling.
- Develop cases for all of the candidate demonstration watersheds, as has been done for the Susquehanna/Delaware/Hudson, Tar/Neuse, and Great Lakes so far. Internal stakeholders with interests in these areas should be responsible for this task.

3. Begin early production to provide experience and examples.

National production of some water budget products should be possible as early as summer of 2009, using outputs from the NWS RDHM model, and LIS modeling is expected to follow soon. Early production is important to begin developing experience for both the producers and consumers, and to have examples to begin working with in operations. The NOHRSC plans to set up a THREDDS data service to begin experimenting with distribution of gridded forcings data sets as well as modeled products.

4. Begin developing the workflow between actors.

At this point attention needs to turn to focused activities through the regional demonstration projects. The first task will be to review the cases made for each candidate watershed, then make a selection of one or more watershed to proceed with. The project management team will make the selection, and the number of sites selected will be based on balancing resources with what needs to be demonstrated. Criteria for selection were discussed earlier, but the high-level consideration is to make sure that the gamut of the demonstration is not too narrowly focused to enable exportation of successful capabilities and to reduce project risk. For example, a successful end-to-end demonstration of capability in New England loses some relevance in the west; there are different issues at work. So a small number of demonstrations that cover a range of regional issues is the goal here.

Once regional demonstration areas are selected, the project will focus on implementing IWRSS elements and developing integrated procedures and workflow. Regional Demonstration Teams will be formed as described above to provide the coordination framework for the demonstration projects. From this point on, each demonstration will begin to take on unique characteristics. One demonstration may focus most on exploiting new interoperability capabilities, while another may focus on new modeling capabilities. These focal areas are suggested in the cases for each candidate watershed, but remain to be determined.

5. Engage more stakeholders in the process to begin refining product and service.

As soon as regional demonstration areas are selected, intensive efforts to engage stakeholders in the area and develop a participatory process will begin. Early stages of operational production and workflow are focused on basic components and will be sufficient to develop and communicate understanding of capabilities, plans and directions. As stakeholder needs are refined and turned into project outcomes and metrics, implementation and development efforts can also be refined to help meet these outcomes. At this stage, the project officially begins its first turn on the spiral development model, and the process of iteration between implementation, operations, outcomes, stakeholder feedback and new development begins.

9.6.2 Expanding the Consortium and Partnerships

The IWRSS Consortium was initiated with three agencies, but is expected to expand to include other agencies with equally important roles in water science, observation, management and prediction. By now it should be clear that the task is complex even with three agencies, so the initiation strategy was "start small". At the federal planning level, there is a clear need for involvement with other agencies, and at the regional demonstration level, several additional partnerships are expected as projects evolve.

As the fundamental IWRSS Roadmap (this plan) is accepted within the Consortium, other agencies will be invited to participate, and the governance bodies at all levels will work to integrate new needs and ideas into the framework. Several new directions and partnerships are conceivable; two are considered below as examples.

The USDA Forest Service (USFS) is both a potential partner and a stakeholder in IWRSS. The USFS offers long-term data sets important to IWRSS, including hydroclimatic data for 10-100 year durations, spatially explicit information on forest distribution and health, land use and land cover data that includes information on treatments and disturbance, and extensive expertise on plant-water use and interactions with emphasis on forested environments. The USFS Forest Inventory and Analysis (FIA) database provides detailed forest metrics on a nation-wide gridded data set, with a sample point every 6000 acres. The USFS operates several stable research and infrastructure sites that may benefit IWRSS R&D needs. It maintains a wide array of GIS databases, including the Natural Resource Information System (NRIS) WATER module, which is dedicated to serving the aquatic information management needs of the USFS, its partners and stakeholders. WATER is a geospatially enabled ORACLE database and toolkit for integrated management of aquatic resource information, including information on stream and lake systems plus water improvement and rights. As a stakeholder responsible for managing vast tracts of public lands in the U.S., including water resources, the USFS needs integrated modeling capabilities that will allow land managers to better manage water generated from Forest Service lands. Foresters need modeling capabilities to assist in NEPA preparation, interact with water partners and customers, forecast effects of treatments such as various logging practices, forecast effects of disturbances such as fire, pine beetle, blowdown, etc., and forecast effects of climate variability and change. Public land managers need simple tools that allow them to predict the effects of potential actions or non-actions at the hill slope, basin and regional scale. These tools could be in the form of interaction with experts that could supply the needed information in a timely fashion, or by delivering tools that were simple and versatile enough to be used at the district level by hydrologists and land managers. Integrated modeling efforts and capabilities would benefit National Forest Systems, Forest Service R&D, and State and Private Forestry.

The EPA's Watershed Assessment, Tracking and Environmental Results (WATERS) is a geospatially enabled coordination framework linking EPA Water Program databases to better support its mission goals and needs. The databases as well as the lessons learned in developing WATERS are important to IWRSS objectives. WATERS consists of four major components:

1. **National Hydrography Dataset.** The National Hydrography Dataset is a comprehensive set of digital geospatial data that contains information about surface water features. The NHD includes an addressing system for linking EPA Water Program data to the underlying NHD surface water drainage network in order to facilitate its geographic integration, analysis and display.

2. **Reach Address Database (RAD).** The Reach Address Database stores the reach address for each Water Program feature that has been linked to the NHD. These reach addresses record the geographic extent of Water Program features in both tabular and spatial formats. The reach addresses link to a static copy of the NHD obtained from the USGS, which also resides in the RAD.
3. **Water Program databases.** The EPA Office of Water has numerous programs that collect and store water related information in separate databases. By linking the features stored in these Water Program databases to the NHD, the collective information held within the databases can be shared across programs to better facilitate water quality management.
4. **WATERS Tools**. Tools and applications that generate and use the reach addresses in the RAD to query, analyze and display information across Water Programs. The process of assigning NHD reach addresses to Water Program features is often referred to as reach indexing and the tools that support this assignment as reach indexing tools (RIT).

These are just two examples of where other federal partners can benefit IWRSS and vice versa. The incorporation of new partners and ideas are an important part of ensuring healthy development and maintenance of IWRSS, as well as improving integration of federal activities and solutions in water resources.

9.6.3 Project Retirement

The integration and enhanced collaborations among federal water agencies and stakeholders envisioned for the IWRSS project will hopefully not be retired per se. As explained in the introductory chapters, the project is designed to be, and to promote flexibility and adaptability. The governance structure, spiral development strategy, use of working groups and agile development methods, and the focus on outcomes suggest that IWRSS will more likely evolve over time, since the fundamental need for federal integration and collaboration is not expected to diminish.

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Chapter 10 Business Concept

10.1 Objectives and Goals

The IWRSS project seeks to operationally demonstrate a broad integrative *national water resources information system* to serve as a reliable and authoritative basis for adaptive water-related planning, preparedness and response activities from national to local levels. The project involves an open Consortium of federal agencies with missions in water science, observation, management and prediction, to provide the broad scope necessary to meet 21st century water resources challenges. The project's outcomes are expected to include:

5. **Integrated Water Resources Services.** IWRSS will result in improved internal and external communication and better, more productive engagement with stakeholders. Delivery of water resources data, services and products will be more integrated to provide stakeholders with an experience that appears to be one-stop shopping. Communication of risk and uncertainties will be improved, both in terms of quantitative measures and through the efforts of enhanced training and outreach.
6. **System Interoperability, Collaborative Tools and Workflow.** Major systems in use across multiple agencies will be made interoperable, meaning data and information will be able to flow between them more seamlessly and models, tools and other applications will be cross functional across systems. Models used nationally will be made available regionally, and new models will be made accessible. Toolkits will be provided to improve access and analysis of information and improve collaborative workflow.
7. **Common Operating Picture.** Several elements of the IWRSS project will work in combination to provide a common operating picture across multiple agencies, enabling river forecasters in one agency using their system to see the same information as river managers in another agency using a different system, and external stakeholders to see much of the same information through common web services. The Common Operating Picture will be dominantly geospatial, meaning enterprise GIS and geo-Intelligence will be ubiquitous within agency systems.
8. **Integrated, Sustainable Consistent Water Resources Modeling and Forecasts.** The centerpiece of IWRSS for IWRSS stakeholders will be a new national suite of integrated high-resolution water resources analyses and forecasts. Analyses will include historical water budget studies going back as long as records permit, current conditions for immediate situational awareness, and forecasts of future water budget conditions. This suite will include basic short-term ensemble water budget forecasts at 1 km^2 resolution for U.S., advanced modeling in selected regional demonstration areas with mechanisms to transition best practices to other regions, and advanced regional river and flood forecasting and water management models, including linkages between terrestrial and coastal/estuarine environments, surface water and groundwater, and water quality.

To achieve these outcomes, the IWRSS project is focused on three operational goals: 1) integrate services and service delivery, 2) increase accuracy and lead time of river forecasts, and

3) provide new "Summit-to-Sea" high-resolution water resources information and forecasts. The project design focuses on both vertical and horizontal integration and addresses these goals through three crosscutting themes that include human, technical and science dimensions. IWRSS is outcome-driven and based squarely on stakeholder participation.

10.1.1 Authority

The project has been designed to ensure that IWRSS is sustainable and well aligned with water resources business areas of the Consortium agencies. The legal authority for these agencies to engage in the scope of activities planned for IWRSS is well documented. The IWRSS project design has drawn from an extensive array of agency planning instruments to identify and align with broadly held goals and objectives. The authority for IWRSS has been validated recently by several actions, including a 2008 five-agency memorandum authorizing expanded inter-agency collaboration in work to adapt water program management of reflect changing climate conditions (Appendix 2); a 2008 memorandum from NOAA's Administrator declaring water resources as one of NOAA's top priorities, and a subsequent decision by NOAA's Executive Council to transform NOAA's Hydrology Program into an Integrated Water Forecasting Program; 2008 USACE Campaign Goals identifying water resources as one of four priorities, specifying objectives to deliver integrated, sustainable water resources solutions and implement collaborative approaches; and recent emphasis in USGS strategic planning on a comprehensive focus on water resources issues.

10.1.2 Strategic Elements

The project design uses adaptive strategies for operational development and implementation. A spiral development model provides the high-level strategic framework for the project, and agile development methods form the low-level tactical approach. The comprehensive vision and design for integration and collaboration positions IWRSS to take advantage of opportunities, both large and small.

The project's governance structure has a simple vertical component of executive oversight, project management, and technical working groups. Within each of these levels the horizontal component is broad and includes representatives across agencies and line offices. The overall approach of forming a federal consortium to address water resource challenges, the governance model, the technical design for interoperability and a Common Operating Picture, and the design for participatory processes are all part of a larger strategy to foster a culture of trust and communication.

On the technical side, the project design promotes innovations in geospatially enabled science, communications, and information technology to produce a world-class integrated water resources information system that transcends organizational and geographic boundaries. The project is regionally focused but national in scope, and in one perspective ignores boundaries and considers the hundreds of multi-agency offices around the country as an integrated communications network for water resources information. This conceptual innovation, together with interoperable systems, improved workflow and geospatially enhanced operational models, tools and forecasting capabilities, comprise an integrative strategy to create a state-of-the-art operations environment to enable a highly skilled and motivated workforce to rise to what many expect will be this century's greatest challenge.

Together, these measures position IWRSS for distinctive and lasting success, with high benefit to a broad gamut of stakeholders.

10.2 Stakeholders and Customers

The stakeholders for the IWRSS project are consumers of water resources information who can benefit from the new and improved information and integrated service delivery that IWRSS will provide. They require data and information to develop knowledge necessary to make decisions and take actions. IWRSS stakeholders include decision makers who manipulate water, water and environmental resource managers and planners, emergency managers and responders, public-sector information consumers with a wide variety of commercial and private interests, and "internal" stakeholders involved in the enterprise collection, analysis, prediction and delivery of water information and services.

Operational Science: Summit-to-Sea Modeling and Prediction Framework Summary of Near-Term Tasks

12. Develop and implement a national high-resolution gridded water resources forecast system and associated products and services.
    a. Determine forcings to be used
    b. Implement RDHM and LIS models nationally
13. Prepare to conduct long-term historical reanalyses using models to be used for analysis and prediction
    a. Determine what information needs to be retained from historical model runs
    b. Plan the data storage and delivery service that will be required to support this very large data set.
    c. Determine what

10.3 Expected Value

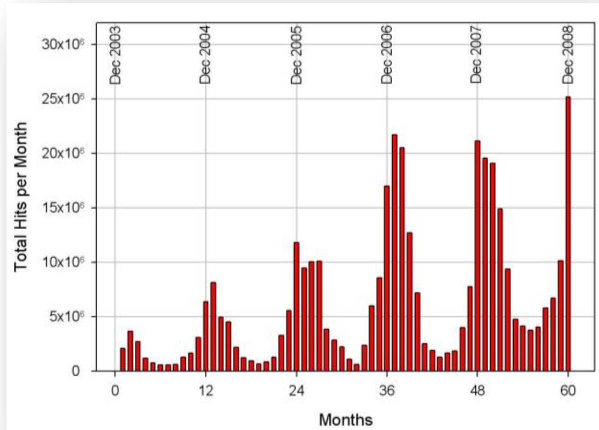
Information to be provided by IWRSS is expected to have very high value and benefit to a wide range of stakeholders and information consumers. Water is vital to life and affects almost every sector of the economy. Both too much water and not enough have economic consequences totaling tens of billions of dollars each year.[16] Individual flood events often cost billions in damages, and the story is similar for droughts and related wildfires. When considering the entire gamut of stakeholders and water information consumers, across all economic sectors (agriculture, industry, navigation, etc.), it is reasonable to speculate that economic impacts and linkages to water resources are in the hundreds of billions of dollars each year. The real question is "What is the value of new information for decision-making?" such as IWRSS will provide. The very breadth of potential applications and users makes it very difficult to fully estimate potential value of information. One study examining this for NOAA's National Snow Analyses concluded that the incremental value of new information about water resources stored in seasonal snow packs alone was worth $2-3B per year.[17] It seems reasonable to presume that comprehensive and well-integrated water resources information and forecasts, produced consistently and nationally, with explicit linkages to water, environmental and ecosystem resources management as well as

[16] Source: Economic Statistics for NOAA, Sixth Edition, 2008.
www.ppi.noaa.gov/PPI_Capabilities/Documents/2008_06_04_EconStatsFinal.pdf

[17] Adams, R., Houston, L., Weiher, R., *The Value of Snow and Snow Information Services*, Report prepared for NOAA's National Operational Hydrological Remote Sensing Center, August, 2004.

commerce, energy and navigation sectors and emergency services, should be worth at least several billion dollars annually.

Another metric for value is the demand for information – how much new information is acquired and used. In some respects NOAA's National Snow Analyses are a pilot for IWRSS, as they have been an early effort to demonstrate some of the goals in IWRSS and provide an integrated, national suite of snow information products. As a pilot, almost none of the stakeholder participation or outreach elements prescribed for IWRSS have been done. For the past six years, the suite of products (see Figure 6.3) has simply been reliably produced and delivered through web services, with little advertisement. Over this period, web traffic for the snow analyses grew from about 3 million hits per month at peak in 2003 to over 25 million hits per month in December 2008 (Figure 10.1).



From this it is possible to speculate about what demand for IWRSS information may be like. First, there is little demand for snow information in the summer, so traffic drops to low levels. IWRSS will provide water information that is of interest year around, so one scenario is that the demand for winter season information is already fully met, and the valleys in Figure 10.1 will be "filled in" to approximately the same levels as winter. This would represent about a doubling of current demand. A second scenario is that in addition to filling in during the summer, the IWRSS focus on stakeholder engagement and outreach would expand overall awareness so that the summer season would fill in and monthly magnitudes would increase. A third scenario, and perhaps the most likely one, is that a tipping point exists in this picture. In the age of information and wireless broadband everywhere, a comprehensive suite of well-integrated water resources information and forecasts could tip the scales and lead to a quantum leap in value and demand. This is exactly what IWRSS has in mind.

10.4 Value Propositions

The following value propositions relate to each of the specific outcomes identified above, and are reiterated from Chapter 1.

10.4.1 Integrated Water Resources Services

Customer satisfaction with federal water resources information and services will increase as a result of concerted efforts to engage stakeholders, better understand their challenges and needs, and incorporate this understanding throughout IWRSS operations.

Customer satisfaction will also increase as a result of integrated data, service and product delivery. IWRSS will strive towards the appearance of a single national portal for water resources information using consortium collaboration, effective web services and high-accessibility delivery mechanisms, and industry standards and protocols, especially for geospatial data. For information consumers, including commercial customers who add value to water resources information, satisfaction will increase because information acquisition effort/costs will decrease. Obtaining and using comprehensive water resources information will be simpler.

IWRSS will help meet corporate goals to improve risk information and communication and build community resilience through provision of comprehensive water resources information and a focus on outreach and stakeholder participation.

10.4.2 System Interoperability, Collaborative Tools and Workflow

Internal operating efficiency will increase, and risk will decrease, as a result of improved interoperability and reduction in effort, tools and applications necessary to exchange data and information. IWRSS-enabled interoperability will enhance continuity of operations by facilitating and providing mechanisms for backup, beneficial redundancies and failover.

IWRSS interoperability efforts and a focus on developing collaborative operational workflow will result in faster implementation of new tools across the enterprise, with an associated reduction in implementation costs.

Internal stakeholder satisfaction will increase as a result of improved operational communication, coordination and collaboration.

10.4.3 Common Operating Picture

Capacity to protect life and property during flood events and other hazards will be improved by increasing forecaster's access to relevant information through eGIS, sharing critical geo-intelligence across geographic and organizational boundaries, and providing state-of-the-art geospatial processing and analysis toolkits for operational systems.

Employee satisfaction and the ability to attract new members to the workforce will increase with the implementation of a Common Operating Picture and state-of-the-art geospatial processing and analysis tools. IWRSS will increase corporate competitiveness for the Nation's young geospatial and water resources talent.

Satisfaction of Congress and Corporate leadership will increase because a Common Operating Picture enables rapid, authoritative situational awareness of the state of the Nation's water resources with easy ability to drill-down to local scales and details.

10.4.4 Integrated, Sustainable Consistent Water Resources Modeling/Forecasts

Customer satisfaction will increase with the delivery of a new suite of high-resolution digital water resources information that is nationally consistent and provides both the big-picture and local details.

Customer satisfaction will increase with the assurance that a well-designed and supported framework is in place to produce integrative water resources information reliably and authoritatively, and that risks of this information not being available when needed are reduced.

New science and technology will be implemented faster, with reduced cost, as a result of implementing a centralized national hub with interoperable capabilities that are well-connected with regional capabilities, providing both national and regional testing capabilities, and avoiding monolithic architectures that limit flexibility.

10.5 Capability Delivery, Governance and Management

The IWRSS project takes a program approach to delivering capability and outcomes. Its aim is to improve the delivery of capability by aggregating related projects and associated lines of development and manage their delivery coherently and jointly. In this way interdependencies, risks and opportunities can be managed more effectively to focus on achieving outcomes with good value. This approach embraces the strengths of all actors at all scales in each agency, and seeks to draw the best solutions from the mix. This greatly increases flexibility, which is essential for IWRSS because water resources stakeholders are themselves working to become more flexible and adaptable, and IWRSS must be positioned to adapt with them.

The program approach of IWRSS engages stakeholders early and often to improve understanding of needs, planning, and operations. In this way IWRSS can better anticipate emerging needs, target high-value and high-impact opportunities, manage resources to sustain high-value functions and guide investments in new capabilities. By participating more closely with stakeholders, it's likely that it will be easier to recognize important opportunities.

The program approach is manifest throughout the IWRSS design; integration, interoperability, trans-boundary data synchronization and workflow are all aspects of this approach. Research and development is another important aspect of this approach. By considering the wide array of water-related research and development activities across multiple agencies as a virtual, integrated program, R&D assets can be managed more effectively with limited resources. In particular, by adopting a common framework for characterizing the readiness of science and technical capabilities, IWRSS can more readily identify capability sources and focus resources on advancing needed capability to operational levels.

The governance structure planned for IWRSS is vertically and horizontally integrated to broadly represent the various organizational elements important to the project (Figure 9.2). An executive oversight council consists of senior executive leadership from each agency: Gary Carter, NOAA Hydrology Program Manager; Bert Davis, Director of USACE/ERDC/CRREL, and Matt Larson, Director, USGS Water Discipline. A project management team consists of national and regional chiefs and program leads from each agency. This will be the primary planning and decision-making body for IWRSS operations, services, science and technology. The federal Advisory Committee for Water Information, which represents many water resources stakeholders and was established by OMB for this purpose, will advise this team and the Executive Oversight Council. A series of Technical Working Groups consisting of national and regional managers from across the agencies will focus on specific topical areas identified for the human, technical and science themes of IWRSS. Within the program approach of IWRSS, this governance structure does not replace or supersede existing management bodies, teams or working groups; it is an instrument for coordination.

10.6 Budget

A budget is being prepared to address the scope of new activities for IWRSS. Budget planning is focused on developing integrative capabilities and addressing objectives for new information through national and regional means. Major elements considered for this budget are implementation of 1) interoperability and data synchronization capabilities, 2) eGIS and geo-intelligence capabilities, 3) national high-resolution water budget modeling and prediction, 4) the national IWRSS operational support center, and 5) regional demonstration projects. The objective is to provide a comprehensive programmatic approach to delivering a national integrated water resources information system. The budget strategy assumes existing capabilities are sustained and that all new capabilities, staffing, and associated resources are to be provided through the design budget. The budget design is deliberately flexible and adaptable to take advantage of opportunities; implementation of specific elements can occur as capacity permits.. Thus multiple options are being considered with a range in budgets on the order of $100M to $500M.

Appendix 1: IWRSS Planning Workshop Participants

Three planning workshops with the following participants were conducted to develop the IWRSS design. Their contributions are greatly appreciated.

NOAA

Office of Climate, Water and Weather Services, NWS Headquarters

Glenn Austin (Hydrologic Service Division (HSD) Chief; now retired)
Tom Graziano (HSD Chief)
Don Cline (Director, National Operational Hydrologic Remote Sensing Center)
Andy Rost (National Operational Hydrologic Remote Sensing Center)
Mary Mullusky (River Forecast Center Services Liaison)
Diana Perfect (Hydrology/NIDIS Liaison and Outreach Lead)

Office of Hydrologic Development (OHD), NWS Headquarters

Gary Carter (Director, OHD)
Pedro Restrepo (Chief Scientist)

Hydrologic Services Division, NWS Eastern Region Headquarters

Reggina Cabrera (HSD Chief)
George McKillop (HSD Deputy Chief)

Hydrologic Services Division, NWS Southern Region Headquarters

Ben Weiger (HSD Chief)
Diane Cooper (Hydrologic Services Program Manager)

Hydrologic Services Division, NWS Central Region Headquarters

Noreen Schwein (Regional Hydrologic Services Program Manager)

Hydrologic Services Division, NWS Western Region Headquarters

Dave Brandon (Hydrology and Climate Services Division Chief)

Northeast River Forecast Center

Dave Vallee (Hydrologist in Charge)

Mid-Atlantic River Forecast Center

Peter Ahnert (Hydrologist in Charge)

North Central River Forecast Center

John Halquist (Development and Operations Hydrologist; now at NOHRSC)

Colorado Basin River Forecast Center

Kevin Werner (Service Coordination Hydrologist)

California-Nevada River Forecast Center

Rob Hartman (Hydrologist in Charge)

Northwest River Forecast Center

Don Laurine (Development and Operations Hydrologist)
Joe Intermill (Senior Hydrologist)

Earth System Research Laboratory (ESRL), Office of Atmospheric Research

Tim Schneider (Program Manager, Hydromet Testbed)

Climate Prediction Center

Fiona Horsfall (Director, Climate Test Bed)

Coastal Services Center, National Ocean Service

Betsy Nicholson (NOAA Northeast Regional Coastal Program Specialist)

USACE

Headquarters

Jerry Webb (Principal Hydrologic & Hydraulic Engineer)
John Hunter (Senior Hydraulic Engineer)
Kate White (Lead, USACE Actions for Change Theme 1: Comprehensive Systems Approach)

USACE Remote Sensing/GIS Center of Expertise

Tim Pangburn (Director, USACE RS/GIS CX)

New England District

Scott Hanlon

Engineer Research and Development Center (ERDC)

ERDC Cold Regions Research and Engineering Laboratory (CRREL)

Bert Davis (Director, CRREL)
Jon Zufelt (Technical Director, CRREL)

ERDC Coastal and Hydraulics Laboratory (CDL)

Jack Davis (Technical Director, CDL)

Institute of Water Resources (IWR)

Rolf Olsen

IWR Hydraulic Engineering Center (HEC)

Bill Charley
Mike Perryman (Senior Hydraulic Engineer)

Mississippi Valley Division

Eddie Brooks (Chief, Watershed Division)

Northwestern Division

Peter Brooks (Chief, Hydrologic Engineering Branch, Columbia Basin Water Management Division)

USGS

Headquarters

Bill Werkheiser (Acting Chief Hydrologist)
Eric Evensen (Coordinator, Water for America Initiative)

USGS Office of Surface Water

Mike Norris (Coordinator, USGS National Streamflow Information Program)

New Hampshire Water Science Center

Keith Robertson (Director)
Marilee Horn

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Appendix 2

AUG 2 2 2008

MEMORANDUM

SUBJECT: Federal Agency Cooperation on Adaptation of Water-Related Programs to the Impacts of Climate Change

FROM: Benjamin H. Grumbles
Assistant Administrator for Water
U.S. Environmental Protection Agency

VADM Conrad Lautenbacher, Jr.
Under Secretary and Administrator
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

John Paul Woodley, Jr.
Assistant Secretary of the Army for Civil Works
U.S. Department of Defense

Mark Rey
Under Secretary for Natural Resources and the Environment
U.S. Department of Agriculture

Kameran Onley
Acting Assistant Secretary for Water and Science
U.S. Department of Interior

TO: Agency Senior Staff (see addressees below)

This memorandum authorizes senior staff from our agencies to cooperate in work to adapt water program management to reflect changing climatic conditions. We recognize that the changing climate may have important implications for water resources and water programs and that our agencies are each working to identify and address the water-related consequences of climate change. We believe that this work will benefit from expanded cooperation among our agencies, including sharing of information and data, consideration of research priorities, and cooperative implementation of projects.

1

BACKGROUND

At an initial meeting in March of this year, we reviewed the likely impacts of climate change on water resources and the water programs that we administer. Based on that meeting, we concluded that a changing climate may have significant consequences for water resources and water programs. Some key impacts of climate change on water resources include:

- rising sea levels;
- changes in rain and snow levels;
- changes in the intensity of storms; and
- warmer air and water temperatures.

Although our agencies are cooperating on climate change research projects, less coordination is occurring as we work to adapt our program management and delivery to reflect the changing climate. In response to this concern, we directed senior staff to meet to review options for strengthening cooperation among our agencies on efforts to adapt program management to climate change.

Senior staff met over the past several months to share information about work to adapt water-related programs to climate change. The wide range of projects and activities now underway in this area were discussed in these meetings and agencies are sharing this information in various formats.

These meetings also included review and discussion of existing interagency coordination mechanisms that might be available to help facilitate coordination among our agencies on this topic. Although the various existing coordination mechanisms have important strengths, they are addressing a range of other issues and needs. In addition, amending the scope and direction of an existing group would involve an extended process at a time when prompt action is needed to begin cooperation on water and climate change matters.

CHARGE TO STAFF

We charge senior staff in each of our agencies to cooperate in work to adapt water program management to reflect changes in climate. This work should include, at a minimum:

- sharing of water-related climate change information and data;
- exchange of information about climate change programs and activities related to water;
- consideration of research priorities related to climate change and water; and
- cooperative implementation of water-related climate change adaptation programs and projects.

2

More specifically, this cooperative work could include:

- Establishment of a forum for cooperative efforts with appropriate staff support;
- Regular meetings and periodic reporting on the water and climate change adaptation work of each agency;
- Coordination with the National Integrated Drought Information System on issues related to climate variability and change;
- Identification of "best management practices" that facilitate adaptation to climate change and dissemination of supporting information and data;
- Development of common standards and definitions for data systems;
- Coordination of programmatic metrics;
- Identification of opportunities for cooperation with other Federal agencies and committees and with State, Tribal, and local program managers;
- Identification of opportunities for cooperation in the education of water program managers on issues related to climate change and water;
- Identification of emerging issues related to climate change of common concern to Federal water program managers;
- Identification of potential cooperative projects among the agencies;
- Identification of policy and program issues related to water and climate change needing to be elevated to the attention of senior managers;
- Exploration of the need for, and desirability of, a more formal coordination framework for climate change and water issues;
- Identification of measures of progress and supporting data that can be used to assess the success of adaptation strategies;
- Coordination with the Climate Change Science Program Interagency Working Group on Water in identifying research needs and priorities to strengthen adaptation of water programs to climate change; and
- Facilitation of the prompt sharing of climate change research findings among Federal water program managers.

We believe that all of our agencies will benefit from an expanded effort to coordinate our work related to climate change and water resources and we look forward to the results of this cooperative effort.

Addressees:

Michael Shapiro; Environmental Protection Agency, Office of Water
Jeff Peterson; Environmental Protection Agency, Office of Water
Ko Barrett; National Oceanic and Atmospheric Administration, Climate Program Office
Carolyn Olson; Department of Agriculture, Natural Resources Conservation Service
Anne Zimmermann; Department of Agriculture, Forest Service
Karl Wirkus; Department of Interior, Bureau of Reclamation
Peter Murdoch; Department of Interior, US Geologic Survey
Chip Smith; Office of the Assistant Secretary of the Army (Civil Works), Department of Defense
Rolf Olsen; Army Corps of Engineers; Institute for Water Resources

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Glossary

API (Application Programming Interface)

An API is a set of functions, procedures, methods, classes or protocols that an operating system, library or service provides to support requests made by computer programs.

CLM (Common Land Model)

CLM was conceived at the 1998 National Center for Atmospheric Research (NCAR) Climate System Model (CSM) meeting, and it was subsequently developed by a grass-roots collaboration of scientists. CLM includes superior components from each of three contributing models: the NCAR Land Surface Model (Bonan 1998), the Biosphere-Atmosphere Transfer Scheme (Dickinson et al. 1993), and the LSM of the Institute of Atmospheric Physics of the Chinese Academy of Sciences (Dai and Zeng 1997). The model applies finite-difference spatial discretization methods and a fully implicit time integration scheme to numerically integrate the governing equations. CLM can be run as a stand-alone, 1-D column model. It is also the land model for NCAR's coupled Community Climate System Model (CCSM). CLM continues to evolve, but only proven and well-tested physical parameterizations and numerical schemes are installed in the official version of the code. LIS currently uses CLM version 2.0. For more information, see: http://www.cgd.ucar.edu/tss/clm/.

CHPS (Community Hydrologic Prediction System)

NOAA's existing computational infrastructure software for water forecasting - the NWS River Forecast System (NWSRFS) - is no longer flexible enough to support the burgeoning needs of the hydrometeorological community of the 21st century. A new, modern CHPS software infrastructure, built on standard software packages and protocols, and open data modeling standards, will provide the basis from which new and existing hydraulic and hydrologic models and data can be shared within a broader hydrologic community. Developed using a "service oriented architecture," an emerging standard for large-scale system design, CHPS enables scientists and programmers to work together and rapidly transition new innovative analyses and forecast techniques (e.g., water quality models) from the drawing board to operational deployment.

CHPS assists the growing community of hydrologic users sharing data and computer models. This requires improved cooperation and coordination within NOAA, as well as with other federal, state, municipal, academic and private institutions. Better coordination among water agencies will improve the accuracy and utility of the entire community's water-based forecasts. CHPS provides a new business model in which members of the hydrometeorological community operate more collaboratively through the sharing and infusion of advances in science and new data, without each member having to build or take ownership of the entire system.

CWMS (Corps Water Management System)

The Corps Water Management System (CWMS) is the automated information system used by the U.S. Army Corps of Engineers to support its water control management mission. This mission encompasses the regulation of river flow through more than 700 reservoirs, locks, and other water control structures located throughout the Nation. CWMS is an integrated system of hardware and software that begins with the receipt of hydromet, watershed, and project status data. This data is then processed, stored, and made available through a user-friendly interface to the water manager to evaluate and model the watershed. Both model and processed data can be displayed and disseminated.

Types of incoming real-time data include: river stage, reservoir elevation, gage precipitation, WSR-88D spatial precipitation, quantitative precipitation forecasts (QPF) and other hydro-meteorological parameters. These data are used to derive the hydrologic response throughout a watershed area, including short-term future reservoir inflows and local uncontrolled downstream flows. The reservoir operation model flows are then processed to provide proposed releases to meet reservoir and downstream operation goals. Then, based on the total expected flows in the river system, river profiles are computed, inundated areas mapped, and flood impacts analyzed.

CWMS allows evaluation of any number of operation alternatives before a final forecast scenario and release decision are adopted. For example, various alternative future precipitation amounts may be considered, hydrologic response may be altered, reservoir release rules may be investigated, and alternative bridge obstruction, levee integrity, or other river conditions may be evaluated. When an operational decision is made the results, along with supporting hydromet, watershed, and project status and release data may be disseminated to others via web technology.

The system emphasizes visualization of information in time and space. The primary CWMS user interface is map based to provide clear spatial reference for watershed and modeling information. CorpsView, a Corps developed spatial visualization tool based on commercially available GIS software, provides a direct user interface to GIS products and associated spatial attribute information.

CorpsView

CorpsView is a water control data management tool developed to improve access to water control databases, access time series and relational data, show Geographic Information System coverages, link remote sensing imagery, and provide model input and results.

CorpsView is a customized ArcView application (ESRI, Redlands, Ca.) that provides a menu system and a geographic map in which data can be displayed and plotted from the following databases: HEC-DSS, ORACLE and INFO.

FASST (Fast All-Season Soil Strength Model)

FASST is a physically based 1-D dynamic state of the ground model forced by surface meteorological conditions. It calculates snow accretion/depletion, surface icing, soil freezing/thawing, soil moisture and temperature profiles and soil strength. It includes a 3-layer vegetation model.

The ability to predict the state of the ground is essential to manned and unmanned vehicle mobility and personnel movement, as well as determining sensor performance for both military and civilian activities. As part of the Army's Battlespace Terrain Reasoning and Awareness research program, the 1-D dynamic state of the ground model FASST (Fast All-season Soil STrength) was developed. It calculates the ground's moisture content, ice content, temperature, and freeze/thaw profiles, as well as soil strength and surface ice and snow accumulation/depletion. The fundamental operations of FASST are the calculation of an energy and water budget that quantifies both the flow of heat and moisture within the soil and also the exchange of heat and moisture at all interfaces (ground/air or ground/snow; snow/air) using both meteorological and terrain data. FASST is designed to accommodate a range of users, from those who have intricate knowledge of their site to those who know only the site location. It allows for 22 different terrain materials, including asphalt, concrete, bedrock, permanent snow, and the USCS soil types. At a minimum, the only weather information required is air temperature.

GIS-RS

GSFLOW

GSFLOW is a coupled Ground water and Surface-water FLOW model based on the integration of the U.S. Geological Survey Precipitation-Runoff Modeling System (PRMS, Leavesley and others, 1983) and the U.S. Geological Survey Modular Ground-Water Flow Model (MODFLOW-2005, Harbaugh, 2005). In addition to the basic PRMS and MODFLOW simulation methods, several additional simulation methods were developed, and existing PRMS modules and MODFLOW packages were modified, to facilitate integration of the models. Methods were developed to route flow among the PRMS Hydrologic Response Units (HRUs), between HRUs and the MODFLOW finite-difference cells, and between HRUs and streams and lakes. PRMS and MODFLOW have similar modular programming methods, which allow for their integration while retaining independence that permits substitution of and extension with additional PRMS modules and MODFLOW packages. PRMS is implemented in the U.S. Geological Survey Modular Modeling System (Leavesley and others, 1996), which provides input and output and integration functions used by PRMS and GSFLOW modules.

GSFLOW was developed to simulate coupled ground-water/surface-water flow in one or more watersheds by simultaneously simulating flow across the land surface, within subsurface saturated and unsaturated materials, and within streams and lakes. Climate data consisting of measured or estimated precipitation, air temperature, and solar radiation, as well as ground water stresses (such as withdrawals) and boundary conditions are the driving factors for a GSFLOW simulation. GSFLOW can be used to evaluate the effects of such factors as land-use change, climate variability, and ground-water withdrawals on surface and subsurface flow. The model incorporates well documented methods for simulating runoff and infiltration from precipitation; balancing energy and mass budgets of the plant canopy, snowpack, and soil zone; and simulating the interaction of surface water with ground water, in watersheds that range from a few square kilometers to several thousand square kilometers, and for time periods that range from months to several decades. An important aspect of GSFLOW is its ability to conserve water mass and to provide comprehensive water budgets.

GSFLOW allows for three simulation modes--integrated, PRMS-only, and MODFLOW-only. The capability of having PRMS-only and MODFLOW-only simulations in GSFLOW allows incremental model setup that provides flexibility in model calibration.

GSFLOW operates on a daily time step. In addition to the MODFLOW variable-length stress period used to specify changes in stress or boundary conditions, GSFLOW uses internal daily stress periods for adding recharge to the water table and calculating flows to streams and lakes. Only the first stress period specified in the MODFLOW input files can be designated as steady state for integrated simulations. No computations pertaining to PRMS are executed for an initial steady-state stress period.

HEC-RAS (HEC River Analysis System)

HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Defense, Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.

The Hydrologic Engineering Center (HEC) in Davis, California developed the River Analysis System (RAS) to aid hydraulic engineers in channel flow analysis and floodplain determination. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities.

Innovation

A new way of doing something. It may refer to incremental, radical, and revolutionary changes in thinking, products, processes, or organizations.

LIS (Land Information System)

The Land Information System is a high-performance land-surface modeling and data assimilation system, based on NASA Goddard Space Flight Center's Land Data Assimilation Systems. Land-surface models predict terrestrial water, energy and biogeophysical processes critical for applications in weather and climate prediction, agricultural forecasting, water resources management, and hazard mitigation and mobility assessment.

The main software components of LIS are a driver and land-surface models. The LIS driver is a model control and input/output system that executes multiple offline land-surface models over regional or global grids/tiles at spatial resolutions down to 1km. The LIS source code currently includes 4 different land surface models: 1) The NCAR Community Land Model (CLM), 2) the community Noah land surface model (Noah), 3) the MOSAIC model, and 4) the Variable Infiltration Capacity model (VIC).

The data used by LIS include parameter data (properties of the land surface that change on time steps of a day or longer, e.g., soil, land cover, topography), and forcing data (inputs to the land surface models, including precipitation, radiation, and surface winds, temperature, pressure and humidity).

MODFLOW

MODFLOW is a three-dimensional finite-difference groundwater model that was first published in 1984. It has a modular structure that allows it to be easily modified to adapt the code for a particular application. Many new capabilities have been added to the original model. OFR 00-92 documents a general update to MODFLOW, which is called MODFLOW-2000 in order to distinguish it from earlier versions.

MODFLOW-2000 simulates steady and nonsteady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through riverbeds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (restricted to having the principal directions aligned with the grid axes), and the storage coefficient may be heterogeneous. Specified head and specified flux boundaries can be simulated as can a head dependent flux across the model's outer boundary that allows water to be supplied to a boundary block in the modeled area at a rate proportional to the current head difference between a "source" of water outside the modeled area and the boundary block. MODFLOW is currently the most used numerical model in the U.S. Geological Survey for groundwater flow problems.

In addition to simulating ground-water flow, the scope of MODFLOW-2000 has been expanded to incorporate related capabilities such as solute transport and parameter estimation.

MOSAIC Model

MOSAIC (Koster and Suarez 1996) is a well established and theoretically sound LSM, as demonstrated by its performance in PILPS and GSWP experiments. MOSAIC's physics and surface flux calculations are similar to the SiB LSM (Sellers et al., 1986). It is a stand-alone, 1-D column model that can be run both uncoupled and coupled to the atmospheric column. MOSAIC was the first to treat subgrid scale variability by dividing each model grid cell into a MOSAIC of tiles (after Avissar and Pielke 1989) based on the distribution of vegetation types within the cell. This capability is now available in the LIS interface for all the models it drives.

NOAH Model

The community NOAH LSM was developed beginning in 1993 through a collaboration of investigators from public and private institutions, spearheaded by the National Centers for Environmental Prediction (Chen et al. 1996; Koren et al. 1999). NOAH is a stand-alone, 1-D column model that can be executed in either coupled or uncoupled mode. The model applies finite-difference spatial discretization methods and a Crank-Nicholson time-integration scheme to numerically integrate the governing equations of the physical processes of the soil-vegetation-snowpack medium. NOAH has been used operationally in NCEP models since 1996, and it continues to benefit from a steady progression of improvements (Betts et al. 1997; Ek et al. 2003).

Risk

A concept that denotes the precise probabilities of specific eventualities, which may have both beneficial and adverse consequences. Conventionally focuses on potential negative impact to some characteristic of value that may arise from a future event.

Tessellation

A collection of plane figures that fills the plane with no overlaps and no gaps.

THREDDS (Thematic Real-time Environmental Distributed Data Services)

Unidata's THREDDS is *middleware* to bridge the gap between data providers and data users. The goal is to simplify the discovery and use of scientific data by allowing data users to find datasets that are pertinent to their specific needs, access the data, and use them without necessarily downloading the entire file to their local system. Data providers publish lists of what data are available and to describe their data to enable discovery and use. *Catalogs* are the heart of the THREDDS concept. They are XML documents that describe on-line datasets. Catalogs can contain arbitrary metadata.

The THREDDS Data Server (TDS) actually serves the contents of the datasets, in addition to providing catalogs and metadata for them. The TDS uses the Common Data Model to read datasets in various formats, and serves them through OPeNDAP, OGC Web Coverage Service, NetCDF subset, and bulk HTTP file transfer services. The first three allow the user to obtain subsets of the data, which is crucial for large datasets. The TDS has the ability to aggregate many files into virtual datasets, which insulates users from the details of file storage and naming, and greatly simplifies user access to large collections of files.

Unidata's Common Data Model (CDM) is an ambitious project to unify scientific data access. It merges the OPeNDAP, netCDF, and HDF5 data models to create a common API for many types of data. As currently implemented by the NetCDF Java library, it can read (besides OPeNDAP, netCDF, and HDF5) GRIB 1 and 2, BUFR, NEXRAD, and GINI, among others. A pluggable framework allows other developers to add readers for their own specialized formats. The CDM also provides standard APIs for georeferencing coordinate systems, and specialized queries for scientific data types like Grid, Point, and Radial datasets.

VIC (Variable Infiltration Capacity Model)

VIC (Liang et al. 1994; Liang et al. 1996) was originally developed in early 90's and is maintained and upgraded at the University of Washington. The model focuses on runoff processes that are represented by the variable infiltration curve, a parameterization of sub-grid variability in soil moisture holding capacity, and nonlinear base flow. VIC is a stand-alone, 1-D column model that is run uncoupled. Various simulation modes are available including, water balance, energy balance, frozen soil, and other special cases. This macro-scale hydrology model is used extensively in research over the watersheds in the U.S. as well as globally (e.g. Liang et al. 1998; Hamlet et al. 1999; Nijssen et al. 2001). For more information, see: http://www.hydro.washington.edu/Lettenmaier/Models/VIC/VIChome.html

XEFS

The XEFS will be implemented within the CHPS framework and is intended to bring new capabilities and tools to the NWS RFCs to meet the need for short, medium, and long range forecasts with uncertainty information. This will require addressing pre-processing, analysis, visualization, and verification of the results produced. Many of the necessary components already exist in some form, but there is some additional development required. XEFS will integrate these existing and new components into a 3-tier distributed system with Presentation, Service, and Data layers and provide the basis for ensemble forecasts.

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