EXECUTIVE SUMMARY

Convening Lead Author: Helen Ingram, Univ. of Arizona

Lead Authors: David Feldman, Univ. of California, Irvine; Nathan Mantua, Climate Impacts Group, Univ. of Washington; Katharine L. Jacobs, Arizona Water Institute

Contributing Authors: Anne M. Waple, STG, Inc.; Nancy Beller-Simms, NOAA

ES.1 WHAT IS DECISION SUPPORT AND WHY IS IT NECESSARY?

Earth's climate is naturally varying and also changing in response to human activity. Our ability to adapt and respond to climate variability and change depends, in large part, on our understanding of the climate and how to incorporate this understanding into our resource management decisions. Water resources, in particular, are directly dependent on the abundance of rain and snow, and how we store and use the amount of water available. With an increasing population, a changing climate, and the expansion of human activity into semi-arid regions of the United States, water management has unique and evolving challenges. This Product focuses on the connection between the scientific ability to predict climate on seasonal scales and the opportunity to incorporate such understanding into water resource management decisions. Reducing our societal vulnerability to changes in climate depends upon our ability to bridge the gap between climate science and the implementation of scientific understanding in our management of critical resources, arguably the most important of which is water. It is important to note, however, that while the focus of this Product is on the water resources management sector, the findings within this Synthesis and Assessment Product may be directly transferred to other sectors.

The ability to predict many aspects of climate and hydrologic variability on seasonal-to-interannual time scales is a significant success in Earth systems science. Connecting the improved understanding of this variability to water resources management is a complex and evolving challenge. While much progress has been made, conveying climate and hydrologic forecasts in a form useful to real world decision making introduces complications that call upon the skills of not only climate scientists, hydrologists, and water resources experts, but also social scientists with the capacity to understand and work within the dynamic boundaries of organizational and social change.

Up until recent years, the provision of climate and hydrologic forecast products has been a producer-driven rather than a user-driven process. The momentum in product development has been largely skill-based rather than a response to demand from water managers. It is now widely accepted that there is considerable potential for increasing the use and utility of climate information for decision support in water resources management even without improving the skill level of climate and hydrologic forecasts. The outcomes of "experiments" intended to deliver climate-related decision support through "knowledge-to-action networks" in water resource related problems are encouraging.

Linkages between climate and hydrologic scientists are getting stronger as they now more frequently collaborate to create forecast products. A number of complex factors influence the rate at which seasonal water supply forecasts and climate-driven hydrologic forecasts are improving in terms of skill level. Mismatches between needs and information resources continue to occur at multiple levels and scales. Currently, there is substantial tension between providing tools at the space and time scales useful for water resources decisions that are also scientifically accurate, reliable, and timely.

The concept of decision support has evolved over time. Early in the development of climate information tools, decision support meant the translation and delivery of climate science information into forms believed to be useful to decision makers. With experience, it became clear that climate scientists often did not know what kind of information would be useful to decision makers. Further, decision makers who had never really considered the possibility of using climate information were not yet in a position to articulate what they needed. It became obvious that user groups had to be involved at the point at which climate information began to be developed. Making climate science useful to decision makers involves a process in which climate scientists, hydrologists, and the potential users of their products engage in an interactive dialogue during which trust and confidence is built at the same time that climate information is exchanged.

The institutional framework in which decision-support experiments are developed has important effects. Currently there is a disconnect between agency-led operational forecasts and experimental hydrologic forecasts being carried out in universities. However, as shown by the experiments highlighted in this Product, it is possible to develop decision-support tools, processes and institutions that are relevant to different geographical scales and are sufficiently flexible to serve a diverse body of users. Such tools and processes can reveal commonalities of interests and shared vulnerabilities that are otherwise obscure. Well-designed tools, institutions, and processes can clarify necessary trade-offs of short- and long-term gains and losses to potentially competing values associated with water allocation and management.

Evidence suggests that many of the most successful applications of climate information to water resource problems occur when committed leaders are poised and ready to take advantage of unexpected opportunities. In evaluating the ways in which science-based climate information is finding its way to users, it is important to recognize that straightforward, goal-driven processes do not characterize the real world. We usually think of planning and innovation as a linear process, but experience shows us that, in practice, it is a nonlinear, chaotic process with emergent properties. This is particularly true when working with climate impacts and resource management. It is clear that we must address problems in new ways and understand how to encourage diffusion of innovations.

The building of knowledge networks is a valuable way to provide decision support and pursue strategies to put knowledge to use. Knowledge networks require widespread, sustained human efforts that persist through time. Collaboration and adaptive management efforts among resource managers and forecast producers with different missions show that mutual learning informed by climate information can occur between scientists with different disciplinary backgrounds and between scientists and managers. The benefits of such linkages and relationships are much greater than the costs incurred to create and maintain them, however, the opportunities to build these associations are often neglected or discouraged. Collaborations across organizational, professional, disciplinary, and other boundaries are often not given high priority; incentives and reward structures need to change to take advantage of these opportunities. In addition, the problem of data overload for people at critical junctions of information networks, and for people in decision-making capacity such as those of resource managers and climate scientists, is a serious impediment to innovation.

Decision-support experiments employing climate related information have had varying levels of success in integrating their findings with the needs of water and other resource managers.

ES.2 CLIMATE AND HYDROLOGIC FORECASTS: THE BASIS FOR MAKING INFORMED DECISIONS

There are a wide variety of climate and hydrologic data and forecast products currently available for use by decision makers in the water resources sector. However, the use of official seasonal-to-interannual (SI) climate and hydrologic forecasts generated by federal agencies remains limited in this sector. Forecast skill, while recognized as just one of the barriers to the use of SI climate forecast information, remains a primary concern among forecast producers and users. Simply put, there is no incentive to use SI climate forecasts when they are believed to provide little additional skill to existing hydrologic and water resource forecast approaches (described in Chapter 2). Not surprisingly, there is much interest in improving the skill of hydrologic and water resources forecasts. Such improvements can be realized by pursuing several research pathways, including:

- Improved monitoring and assimilation of real-time hydrologic observations in land surface hydrologic models that leads to improved estimates for initial hydrologic states in forecast models;
- Increased accuracy in SI climate forecasts; and

- Improved bias corrections in existing forecasts.

Another aspect of forecasts that serves to limit their use and utility is the challenge in interpreting forecast information. For example, from a forecast producer's perspective, confidence levels are explicitly and quantitatively conveyed by the range of possibilities described in probabilistic forecasts. From a forecast user's perspective, probabilistic forecasts are not always well understood or correctly interpreted. Although structured user testing is known to be an effective product development tool, it is rarely done. Evaluation should be an integral part of improving forecasting efforts, but that evaluation should be extended to factors that encompass use and utility of forecast information for stakeholders. In particular, very little research is done on effective SI forecast communication. Instead, users are commonly engaged only near the end of the product development process.

Other barriers to the use of SI climate forecasts in water resources management have been identified and those that relate to institutional issues and aspects of current forecast products are discussed in Chapters 3 and 4 of this Product.

Pathways for expanding the use and improving the utility of data and forecast products to support decision making in the water resources sector are currently being pursued at a variety of spatial and jurisdictional scales in the United States. These efforts include:

- An increased focus on developing forecast evaluation tools that provide users with opportunities to better understand forecast products in terms of their expected skill and applicability;
- Additional efforts to explicitly and quantitatively link SI climate forecast information with SI hydrologic and water supply forecasting efforts;
- An increased focus on developing new internet-based tools for accessing and customizing data and forecast products to support hydrologic forecasting and water resources decision making (*e.g.*, the Advanced Hydrologic Prediction Service [AHPS] described in Chapters 2 and 3); and
- Further improvements in the skill of hydrologic and water supply forecasts.

Many of these pathways are currently being pursued by the federal agencies charged with producing the official climate and hydrologic forecast and data products for the United States, but there is substantial room for increasing these activities.

Recent improvements in the use and utility of data and forecast products related to water resources decision making have come with an increased emphasis on these issues in research funding agencies through programs like the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessments (RISA), Sectoral Applications Research Program (SARP), Transition of Research Applications to Climate Services (TRACS) and Climate Prediction Program for the Americas (CPPA) and the World Climate Research Programme's Global Energy and Water Cycle Experiment (GEWEX) programs. Sustaining and accelerating future improvements in the use and utility of official data and forecast products in the water resources sector rests in part on investments in programs focused on improving the skill in forecasts, increasing the access to data and forecast products, identifying processes that influence the creation of knowledge-to-action networks for making climate information useful for decision making, and fostering sustained interactions between forecast producers and consumers.

ES.3 DECISION-SUPPORT EXPERIMENTS IN THE WATER RESOURCE SECTOR

Decision-support experiments that test the utility of SI information for use by water resource decision makers have resulted in a growing set of successful applications. However, there is significant opportunity for expansion of applications of climate-related data and decision-support tools, and for developing more regional and local tools that support management decisions within watersheds. Among the factors as to how and/or whether tools are used depends on:

- The range and complexity of water resources decisions. This is compounded by the numerous organizations responsible for making these decisions and the shared responsibility for implementing them.

- Policies and organizational rules that impact the rate at which innovation occurs. Some larger institutions have historically been reluctant to change practices, in part because of value differences, risk aversion, fragmentation, and sharing of authority. This conservatism impacts how decisions are made as well as whether to use newer, scientifically generated information, including SI forecasts and observational data." However, its not necessarily true that policies and rule inhibit all innovation, or that policies and rules are always inflexible. In fact many policies are specifically developed to advance innovation and the quality of information can promote use even under unfavorable circumstances.
- Different spatial and temporal frames for decisions. Spatial scales for decision making range from local, state, and national levels to international. Temporal scales range from hours to multiple decades impacting policy, operational planning, operational management, and near real-time operational decisions. Resource managers often make multi-dimensional decisions spanning various spatial and temporal frames.
- Communication of risks differs among scientific, political, and mass media elites, each systematically selecting aspects of these issues that are most salient to their conception of risk, and thus, socially constructing and communicating its aspects most salient to a particular perspective.

Decision-support systems are not often well integrated into planning and management activities, making it difficult to realize the full benefits of these tools. Because use of many climate products requires special training or access to data that are not readily available, decision-support products may not equitably reach all audiences. Moreover, over-specialization and narrow disciplinary perspectives make it difficult for information providers, decision makers, and the public to communicate with one another. Three lessons stem from this:

- Decision makers need to understand the types of predictions that can be made, and the tradeoffs between longer-term predictions of information at the local or regional scale on one hand, and potential decreases in accuracy on the other.
- Decision makers and scientists need to work together in formulating research questions relevant to the spatial and temporal scale of problems the former manage.
- Scientists should aim to generate findings that are accessible and viewed as useful, accurate, and trustworthy by stakeholders.

ES.4 MAKING DECISION-SUPPORT INFORMATION USEFUL, USEABLE, AND RESPONSIVE TO DECISION-MAKER NEEDS

Decision-support experiments that apply SI climate variability information to basin and regional water resource problems serve as testbeds that address diverse issues faced by decision makers and scientists. They illustrate how to articulate user needs, overcome communication barriers, and operationalize forecast tools. They also demonstrate how user participation can be incorporated in tool development.

Five major lessons emerge from these experiments and supporting analytical studies:

- The effective integration of SI climate information in decisions requires long-term collaborative research and application of decision support through identifying problems of mutual interest. This collaboration will require a critical mass of scientists and decision makers to succeed, and there is currently an insufficient number of "integrators" of climate information for specific applications.
- Investments in long-term research-based relationships between scientists and decision makers must be encouraged. In general, progress on developing effective decision-support systems is dependent on additional public and private interest and efforts to facilitate better networking among decision makers and scientists at all levels as well as public engagement in the fabric of decision making.
- Effective decision-support tools must wed national production of data and technologies to ensure efficient, cross-sector useful-

ness with customized products for local users. This requires that tool developers engage a wide range of participants, including those who generate tools and those who translate them, to ensure that specially-tailored products are widely accessible and are immediately adopted by users insuring relevancy and utility.

- The process of tool development must be inclusive, interdisciplinary, and provide ample dialogue among researchers and users. To achieve this inclusive process, professional reward systems that recognize people who develop, use, and translate such systems for use by others are needed within management and related agencies, universities, and organizations. Critical to this effort, further progress in boundary spanning—the effort to translate tools to a variety of audiences—requires considerable organizational skills.
- Information generated by decision-support tools must be implementable in the short term for users to foresee progress and support further tool development. Thus, efforts must be made to effectively integrate public concerns and elicit public information through dedicated outreach programs.

ES.5 LOOKING TOWARD THE FUTURE; RESEARCH PRIORITIES

A few central themes emerge from this Product, and are summarized in this Section. Key research priorities are also highlighted.

ES.5.1 Key Themes

1) The "Loading Dock Model" of Information Transfer is Unworkable.

Skill is a necessary ingredient in perceived forecast value, yet more forecast skill by itself does not imply more forecast value. Lack of forecast skill and/or accuracy may be one of the impediments to forecast use, but there are many other barriers as well. Such improvements must be accompanied by better communication and stronger linkages between forecasters and potential users. In this Product, we have stressed that forecasts flow through knowledge networks and across disciplinary and occupational boundaries. Thus, forecasts need to be useful and relevant in the full range from observations to applications, or "end-to-end useful".

2) Decision Support is a Process Rather Than a Product.

As knowledge systems have come to be better understood, providing decision support has come to be understood not as information products but as a communications process that links scientists with users.

3) Equity May Not Be Served.

Information is power in global society and, unless it is widely shared, the gaps between the rich and the poor, and the advantaged and disadvantaged may widen. Efforts to meet, communicate effectively with, and incorporate the perspectives of the poor and disadvantaged require the ability: to transmit and disseminate information in a clear, non-technical and vernacular language; to embrace the actual concerns of farmers, peasants, villagers, *etc.* (*e.g.*, drought, floods, their effects on crops, livelihoods), and to undertake public outreach that elicits the type of information they need – not just the kind of information scientists are likely to generate.

4) Science Citizenship Plays an Important Role in Developing Appropriate Solutions.

A new paradigm in science is emerging, one that emphasizes science-society collaboration and production of knowledge tailored more closely to society's decision-making needs. Concerns about climate impacts on water resource management are among the most pressing problems that require close collaboration between scientists and decision makers.

5) Trends and Reforms in Water Resources Provide New Perspectives.

Some researchers suggest that, since the 1980s, a "new paradigm" or frame for federal water planning has occurred, although no clear change in law has brought this change about. This new paradigm appears to reflect the ascendancy of an environmental protection ethic among the general public. The new paradigm emphasizes greater stakeholder participation in decision making; explicit commitment to environmentally-sound, socially-just outcomes; greater reliance upon drainage basins as planning units; program management via spatial and managerial flexibility, collaboration, participation, and sound, peer-reviewed science; and, embracing of ecological, economic, and equity considerations.

6) Useful Evaluation of Applications of Climate Variation Forecasts Requires Innovative Approaches.
There can be little argument that SI forecast applications must be evaluated just as most other programs that involve substantial public expenditures are assessed. This Product illustrates many of the difficulties of using standard evaluation techniques.

ES.5.2 Research Priorities

As a result of the findings in this Product, we suggest that a number of research priorities should constitute the focus of attention for the foreseeable future. These priorities (not in order) are:

- Improving climate and hydrologic forecasts;
- Improving the communication of uncertainties;
- Enhancing monitoring to better link climate and hydrologic forecasts;
- Expanding our understanding of the decision context within which decision support tools are used,
- Enhancing assessments of decision-maker perceptions of climate risk and vulnerability;
- Understanding the role of public pressures and networks in generating demands for climate information,
- Bettering integration of SI climate science into decision making;
- Improving the generalizability/transferability of case studies on decision-support experiments, and
- Sustaining long-term scientist-decision-maker interactions and collaborations and development of science citizenship and production of knowledge tailored more closely to society's decision-making needs within a variety of natural resource management areas.