More than Just Talk

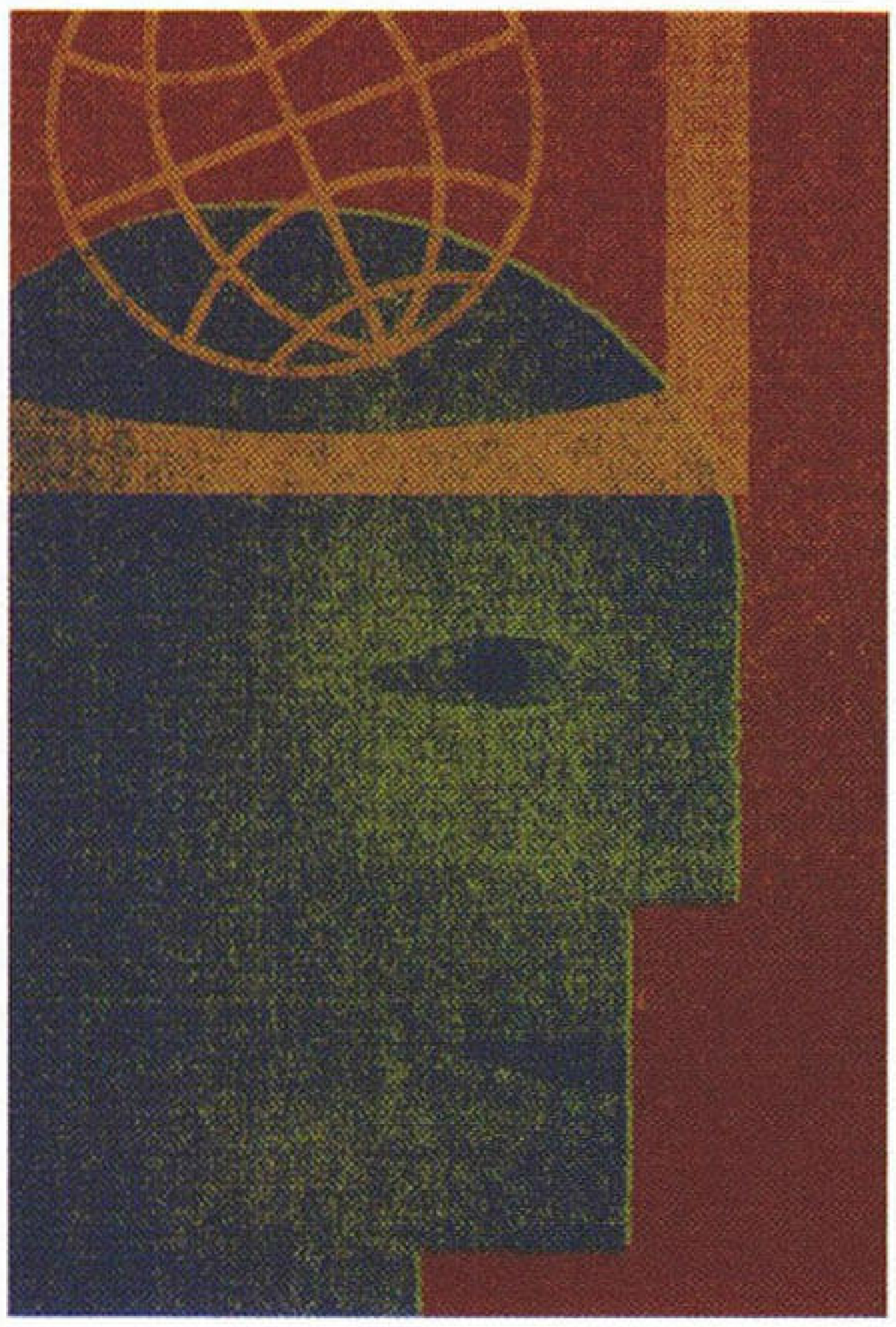
Connecting Science and Decisionmaking

by Katharine Jacobs, Gregg Garfin, and Melanie Lenart

The movement toward integrating science into decisionmaking processes has its origins in several arenas: environmental regulations initiated in the 1970s that encourage participation from the public and other agencies on proposed federal projects; integrated assessments associated with the U.S. Global Climate Change Research Program; the U.S. Congress's demand for greater accountability in terms of science budgets that support "useful" science; and a general recognition that the more we know, the more we are daunted by the complexity in natural and social systems.

For these reasons and others, many organizations are working to develop scientific information that is more useful to society.[1] Funding agencies, including the National Science Foundation (NSF), now require the identification of specific stakeholders who will benefit from the knowledge gained by research proposed for funding. Although many scientists welcome these efforts to connect science to policy and decisionmaking, identifying appropriate stakeholders and working with them in relevant ways produces its own set of challenges that are quite different from those traditionally faced by academics.

Ensuring that science is more relevant to society is particularly important to those working toward environmental sustainability and to people whose livelihoods are directly related to resource availability and environmental quality. Developing the relationships and information flows necessary for the full integration of scientific knowledge into the decisionmaking process is a daunting task, but it is an increasingly important part of producing science that supports sustainability-focused management.[2] Monitoring the effects of management actions and using new information to improve management outcomes in real time is the foundation of the concept of "adaptive management." Changing management practices as knowledge improves over time is data-intensive and expensive, requiring managers to use professional judgment and take more risks as they continually interpret new information. More than most scientific research ventures, efforts to define and attain sustainability require the input, interaction, and acceptance of diverse sectors of society. The social-science component of sustainability efforts is especially challenging for traditionally trained natural science experts, who are frequently frustrated by issues such as public perception and the role of politics in science.



The recognition that many issues facing society are too complex to be answered by researchers in one discipline also has promoted integration among various branches of the natural and social sciences.[3] Whether integrative efforts involve researchers from disparate disciplines or members of academia working with managers and decisionmakers, such endeavors must surmount various challenges based on differences in worldviews and communication styles.

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Perhaps related to the growing intensity of development pressure and the environmental concerns of the public in many regions in the United States, efforts to engage stakeholders in decisionmaking processes and to encourage an interdisciplinary perspective on policy issues have become more focused over time. In the late 1990's, major efforts such as the U.S. National Assessment of the Impacts of Climate Change mobilized thousands of citizens and scientists across the country to participate in regional and sectoral analyses of the observed and expected impacts of global warming in the context of multiple existing stressors.[4] This analysis deliberately focused on the complexity and interrelated nature of social and physical factors in creating vulnerability.

The Regional Integrated Science Assessments (RISAs), which are sponsored by the Office of Global Programs at the National Oceanic and Atmospheric Administration (NOAA), were developed in the context of this movement toward stakeholder-driven and interdisciplinary work. RISAs were created to respond to the need for integrated knowledge in a regional context, assess critical climate-sensitive issues and vulnerability to climate conditions, and provide scientific support for decisions at a scale that is commensurate with the design and support of effective responses. There are now eight RISAs located throughout the United States,[5] including one for the southwest region, the Climate Assessment for the Southwest (CLIMAS), which was established in 1998 at the University of Arizona.

The southwestern United States is characterized by aridity, topographic complexity, and an economy in transition between its resource-based origins and its rapidly growing population and urban, information-based future. A combination of rapid ecological changes, increasing population, and changing societal values results in many challenges in defining and attaining sustainability. Key decisions relate to water availability in the context of growth and significant threats to environmental quality, forest and fire management in the context of a growing urban interface, and the ability to maintain traditional, resource-based livelihoods in the rural areas.

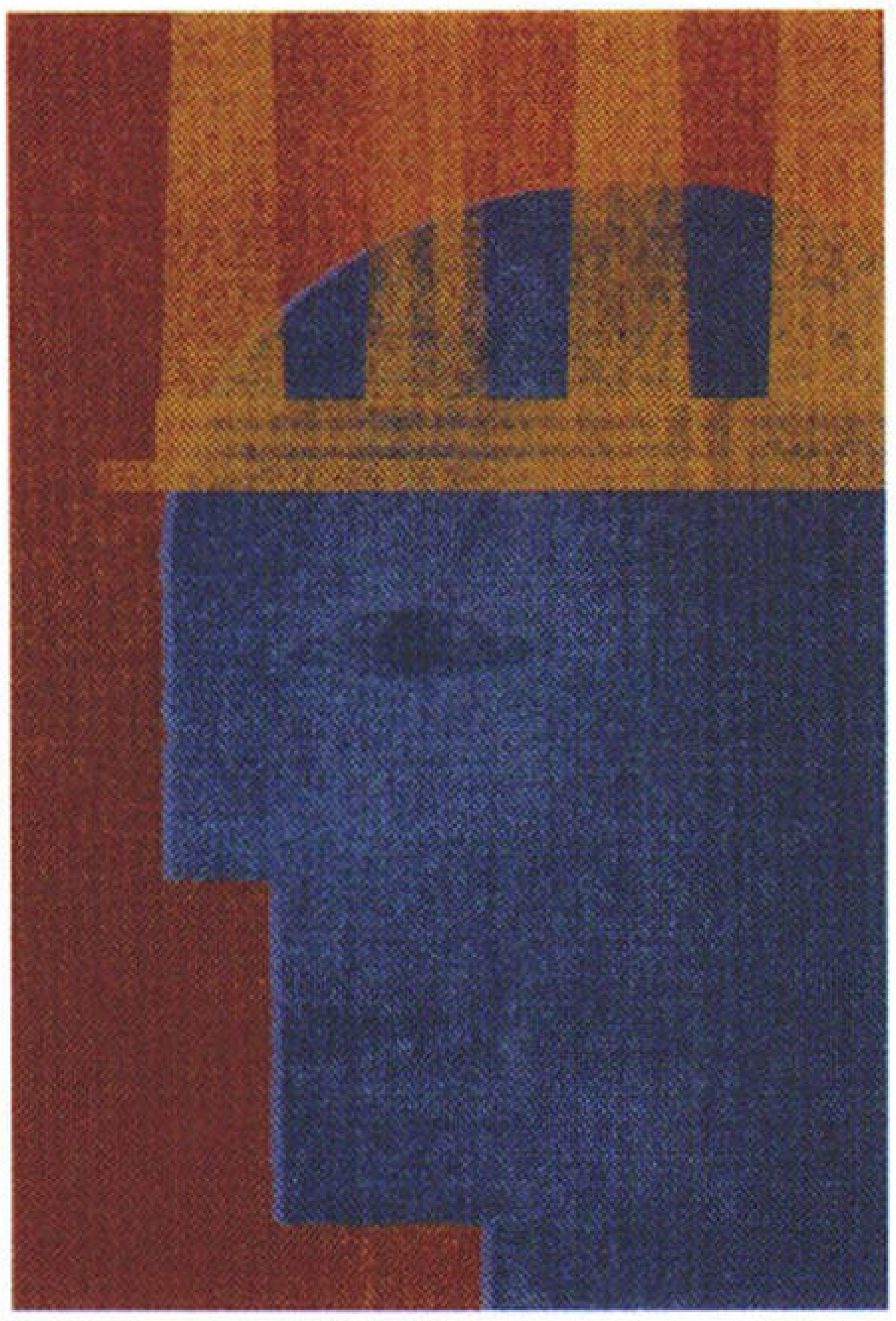
CLIMAS was launched to assess the impacts of climate variability and longer-term climate change on human and natural systems in the southwestern United States, a goal that requires an integrated approach by a team of researchers from a variety of disciplines. To fulfill its mission to help the region respond effectively and appropriately to climatic events and climate changes, CLIMAS interacts with stakeholders who are or may be affected by climate.

To describe the background conditions for providing science services and products, it is useful to divide the discussion into three themes: conditions for providing useful services and products; methods for interacting with stakeholders, with a focus on communication and collaboration; and equity issues and measures of success in integrating science and decisionmaking. To illustrate, it will be valuable to look at lessons gained from CLIMAS and others' efforts in working with diverse stakeholders to connect science, policy, and decisionmaking. Generally, such examples involve efforts that promote resource sustainability for future generations, such as managing wildfires, ensuring dependable water supplies, and maintaining urban air quality.

Conditions for Providing Useful Services and Products

The scientific and social complexity of the interaction of human systems and the natural environment results in the need for decision support systems that are relatively sophisticated. Any organization seeking to build these systems to promote sustainability needs to establish specific metrics to ensure that its services and products are useful. In this context, at least six key questions arise:

- Are scientists asking and answering the right questions?
- Are the data and associated analyses available to and understandable by the targeted decisionmakers?



- Are the findings seen as accurate and trustworthy?
- Are the results provided at a scale relevant to management decisions?
- Is the information timely in relation to potential decisions?
- Are the findings useful given the constraints in the decisionmaking process?

Understanding the Context

A first step in developing useful products and services involves understanding the context in which they will be used. With a worldview strongly influenced by the boundaries of their own research, scientists may not recognize that the new information they produce may be only a very small consideration in a manager's "decision space" (that is, the range of realistic options that can be used to resolve a particular problem). Thus, although scientists might perceive that climate information is crucial to the management of a water system, they might fail to realize that multiple institutional, political, and legal issues dominate the decisionmaking process. For example, a logical scientific response to the fact that the Colorado River is overappropriated would be to reduce the allocations to the seven basin states. The reality of this situation is that although minor changes to the "Law of the River" may be made by consensus, the states are not willing to reopen key allocation issues that have evolved over the last century of court battles and compacts, so water managers have few options available to address this problem. Thus, scientists should not expect their interactions and information to provide the impetus for immediate change in the way decisions are made. They can, however, provide insights and information that could lead to incremental changes over time, assuming the information is viewed as salient, credible, and legitimate by potential users.[6]

Gaining insight into how decisions are made, then, can be considered an important part of scientist-stakeholder interactions. Social scientists, including anthropologists, sociologists, historians, and policy experts, are essential members of the research team for such endeavors.

CLIMAS anthropologists have led a series of investigations in Arizona and New Mexico to identify the historical, social, cultural, and economic sources of vulnerability to climate conditions. In several recent studies, they conducted in-depth interviews in rural areas, with a focus on climate-sensitive livelihoods such as ranching and farming.[7] By evaluating the context in which climate-influenced decisions are made (that is, the interplay of socioeconomic and cultural factors) the researchers have been able to identify key vulnerabilities and opportunities for improved use of climate information in decisionmaking as well as potential impediments to its use. For example, southeastern Arizona farmers dodged substantial drought impacts in the late 1980s due to the use of such technological innovations as center-pivot irrigation. Such innovations, however, are likely to provide less buffering for future drought as a result of decreasing groundwater levels. These contextual studies are also essential for CLIMAS to identify early adopters of climate forecasts, formal and informal mechanisms for sharing information, and tolerances for uncertainty. Current investigations in northern Arizona and New Mexico are examining how social and cultural differences between Arizona's Mormon agriculturalists (whose historic adaptation to streamflow variability is through a system of tithing to redistribute agricultural harvests) and bordering New Mexico's acequia irrigators (whose system of irrigation ditches is managed through a traditional community-wide allocation system) inform response and adaptation to severe sustained drought.

CLIMAS has also investigated the decision context of water managers within the major metropolitan areas of Arizona—an investigation that concluded that the managers' decisions did not include a perspective on the impacts of long-term shortages in deliveries from the Colorado River (via the Central Arizona Project aqueduct system) on groundwater pumping.[8]

Understanding the Perspective of the Potential User

The potential to use particular data sets or decision support tools depends in large part on what kinds of individuals might be interested in using the information. Are the expected users researchers themselves? Are they employees of nonprofit organizations, the private sector, or government? Is the necessary equipment or technical skill readily available, or will it require the distribution of specialized software, equipment, or training?

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The majority of natural resource decisionmakers focus primarily on using climate information that is available for shorter time frames, in the weeks-to-seasons range, although this may change as longer-term climate predictions gain accuracy. This short-term focus presents a potential problem for researchers and decisionmakers who are concerned about global changes and adaptations to enhance sustainability. However, events of a more immediate nature—such as droughts of historic proportions[9] and related insect outbreaks, large wildfires, and water or energy shortages—can provide an opportunity to address questions that also relate to climate change.[10] CLIMAS researchers have found that once stakeholders are engaged in dialogue, it is easier to introduce new information that previously may not have seemed relevant to them.

In some cases, government mandates may influence the type of information likely to be sought by users. For instance, federal air quality mandates require city managers to address smog and other types of pollution. This guarantees some interest in the types of climatic conditions that affect smog and particulate trends in large cities. A major climate-related concern for these decisionmakers is the strong role of daily and seasonal meteorological conditions in determining air quality trends. A CLIMAS project, in collaboration with air quality managers from five southwestern cities, analyzed stakeholder-selected air quality records and separated the climate signal for clearer identification of air pollution trends.[11] This analysis can be used to identify climatic conditions that exacerbate pollution concentrations and their probabilities of occurrence, which can, in turn, help to improve air quality management. For example, air quality managers are able to assess how stricter dust abatement policies at construction sites have influenced trends in particulate matter—as well as how the underlying trends in ozone pollution relate to traffic congestion, gasoline formulation, and other mitigation measures over the last decade.

Integral to the research were two CLIMAS workshops, the most recent in December 2004. Sponsored by the Pima Association of Governments, the workshops brought together air quality managers from local and state environmental agencies and researchers from five major southwestern cities as well as tribal, federal, state, and county decisionmakers. The workshops enabled researchers to evaluate stakeholder perspectives and needs and work with them on implementation of the research. The success of these workshops led to a commitment by the stakeholder group to continue holding similar workshops annually. These "air-quality forum" workshops were among the first such events to enable communication among jurisdictions across state boundaries. Because the participants assumed ownership of the agenda and planning, the workshops became community events rather than something imposed by the researchers. One challenge was to schedule the workshops so that participants could get permission to attend. This problem was solved by providing travel costs and scheduling the workshops adjacent to another professional meeting.

In other cases, such as in public health scenarios, the desire for new information generates its own momentum. CLIMAS work on valley fever, a debilitating and sometimes deadly disease found in the Southwest, demonstrated strong connections between climate conditions and the spread of spores from the soil-dwelling fungus (*Coccidioides*) that causes the disease.[12] Using data provided by the Arizona Department of Health Services, researchers worked in collaboration with physicians and other scientists to create a model that health officials can use to predict outbreaks based on antecedent climate conditions.[13]

After careful quality control of the health data, the researchers used regression models to link precipitation conditions in the dry foresummer to valley fever outbreaks in windy periods up to 18 months later. The success of the project enabled the researchers to obtain extramural funding to test and refine the work and implement a decision support system with the Arizona Department of Health Services.[14]

Accuracy and Credibility of the Information

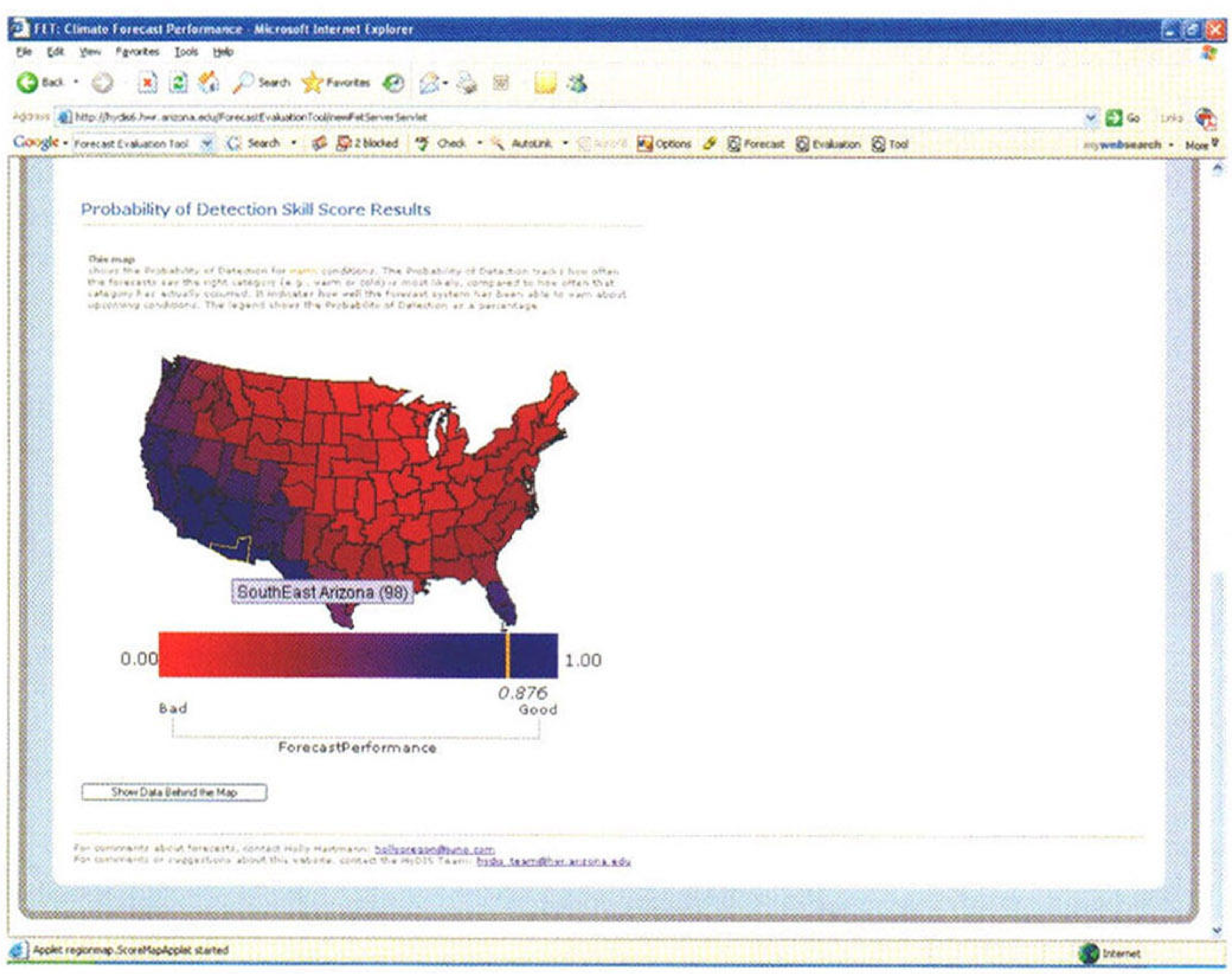
Stakeholder-relevant work requires an understanding of the stakeholders' perceptions about the accuracy and credibility of the information.[15] When designing communication and decision support systems, it is helpful to understand that decisionmakers require an assessment of accuracy for new data or tools, the potential benefits of the information to the decisions they make, and the risks associated with failure.

From CLIMAS's inception, its scientists found that resource managers resisted using NOAA's Climate Prediction Center (CPC) seasonal outlooks, because the assessment of forecast accuracy was not adequately conveyed and difficult to assimilate. Managers expressed a preference for transparency to improve credibility; that is, they preferred ease of interpretation, clear conveyance of forecast accuracy for subregions of the United States, and a means for users to evaluate the accuracy of forecasts by being able to make choices with regard to regions, seasons, and forecast lead times germane to their operations. These managers valued information on regions of low forecast accuracy as well as high forecast accuracy so they could assess the level of uncertainty for themselves.[16] To improve forecast credibility, CLIMAS researchers evaluated NOAA-CPC forecast accuracy (see Figure 1 below).

During the course of repeat engagements with stakeholders from a variety of decisionmaking contexts, it became clear that an interactive online forecast evaluation tool would best serve stakeholders' diverse needs for information on forecast accuracy.[17] The components of the tool were dictated by the stakeholders. For example, most non-expert stakeholders failed to distinguish between weather and climate; thus, a tutorial was added. Fire managers frequently use historical analogs as a basis for speculation about future conditions; thus, the online tool includes an analog instrument for fire managers so that they may contrast analog scenarios with dynamic forecasts.[18]

For some decisionmakers, the frequency of correct forecasts provides the best evaluation of forecast accuracy and associated management risk. For others, predictions that do not pan out translate to a waste of critical resources; thus, forecast credibility is best assessed by evaluating false alarms. Based on insights from user perspectives, CLIMAS researchers incorporated a vari-

Figure 1. Forecast Evaluation Tool: A web-based tool to assess climate forecast skill



NOTE: The Forecast Evaluation Tool website, which evolved from Climate Assessment for the Southwest stakeholder research, allows decisionmakers to evaluate the accuracy of previous seasonal climate forecasts. In the example above, the colors indicate the relative success of the National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center forecasts issued in August, September, and October for above-average temperatures during winter (December through February). Southeast Arizona is highlighted in this "Probability of Detection" test, which indicates the proportion of time in which forecasts for specified months issued since 1994 were accurate.

SOURCE: *Forecast Evaluation Tool*, http://hydis6.hwr.arizona.edu/ForecastEvaluationTool/. Forecasts considered by the tool come from the NOAA National Weather Service's Climate Prediction Center (http://www.cpc.ncep.noaa.gov/).

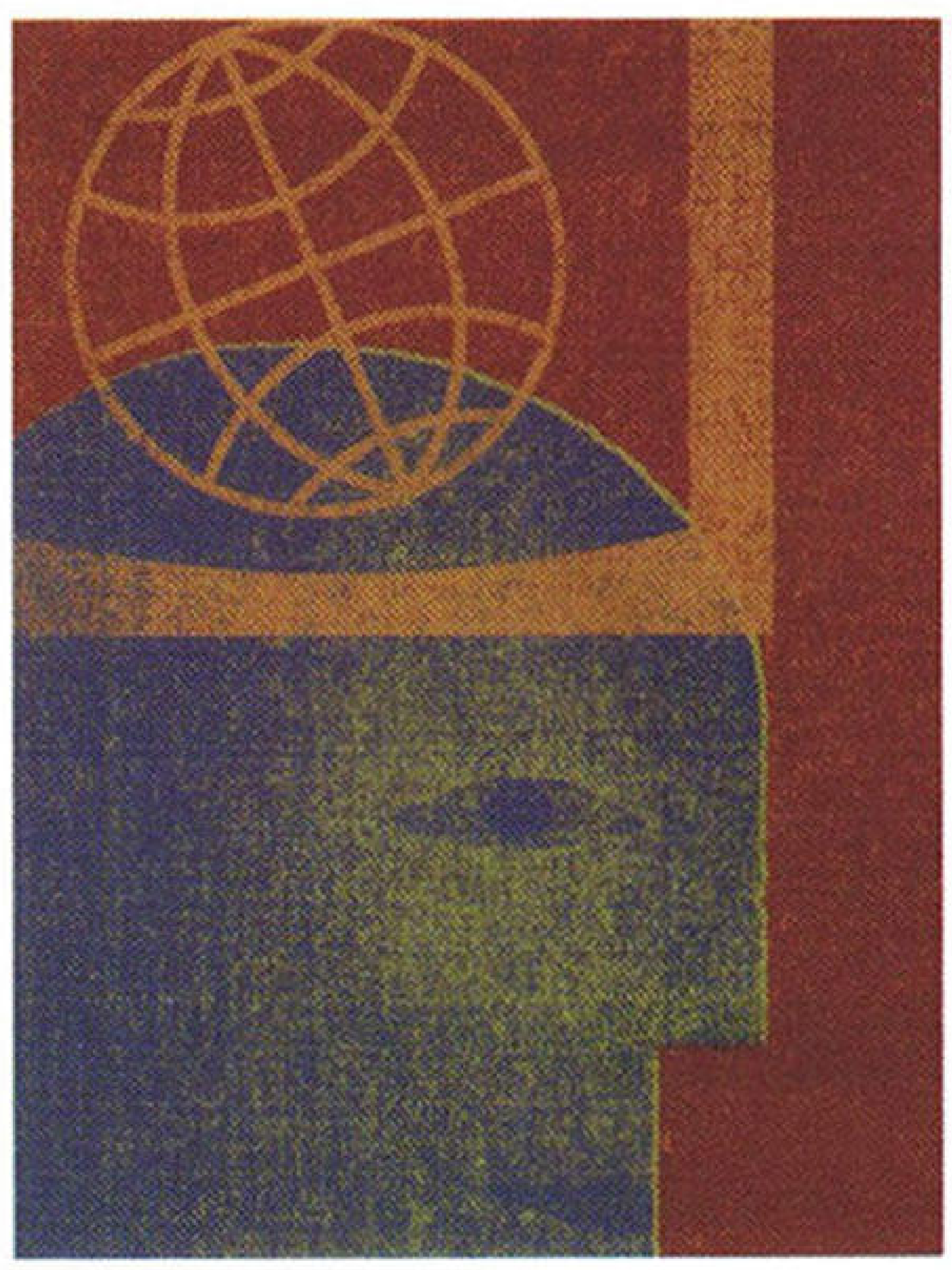
ety of evaluation measures in the online tool, including highly sophisticated measures for water resources managers, who routinely use probabilistic information in operations.

In some cases, even a perfect prediction of future conditions may not make a significant difference to decisionmakers, because there is little room for movement in the decision space. In other words, improved information does not always provide managers with new options, because they are institutionally constrained in ways that preclude using it.[19] For instance, as discussed above, water managers in the lower basin of the Colorado River see little opportunity for improved management based on reconstructed estimates of streamflow because of the constraints of the Law of the River, which essentially limit the response options available. However, regional managers for the Salt River Project, which serves the Phoenix area, recently commissioned tree-ring researchers to extend streamflow records to consider how often drought has occurred simultaneously in the Colorado and Salt-Verde watersheds. The University of Arizona's Laboratory of Tree Ring Research correlates tree-ring data at specific sites with known streamflow records and then, based on older ring samples, develops proxy streamflow records many years before actual streamflow data were measured. The same water managers have supported CLIMAS efforts to use remotely sensed estimates of snow water equivalent to improve predictions of Salt River streamflow.[20] This technique involves satellite-based observations of land surface characteristics, snow cover, forest cover, and surface temperature that are integrated with surface observations of snow amount and snow depth to derive spatially continuous estimates of snow water equivalent.

Getting the Scale Right

Water managers and other stakeholders frequently point out that the scale of most available climate information is too large to be useful. For instance, the general circulation models that predict how different parts of the globe will be affected by global warming do not include detailed topography, nor do standard seasonal climate forecasts. Yet these features have a tremendous impact on local climate. Developing products that match the boundaries of areas of interest to potential user groups will improve the utility of a given product.[21]

From CLIMAS' inception, stakeholders have requested higher resolution information (for example, at the scale of "my ranch") on historical climatic conditions.[22] Initial efforts to meet users' needs included interpolating weather station data to a resolution of 1 square kilometer using models that factored in topographic features such as mountains and valleys.[23] Along with a consortium of university and NOAA partners and their interpolation models, CLIMAS researchers are developing applications for stakeholders to view maps of monthly temperature and



precipitation between weather stations as well as data graphs for any location or area. In an important related effort, CLIMAS researchers are working with NOAA to apply these "downscaling" techniques to current regional seasonal climate forecasts, making them available station-by-station for the nation.

Precipitation-sensitive tree-ring chronologies extend back hundreds to thousands of years at some western U.S. sites. Using these chronologies, CLIMAS developed 1,000-year estimates of past precipitation at the scale of the commonly used climate division level.[24] These estimates are of increasing interest to resource managers whose operations are affected by multi-year drought. CLIMAS posts online time series of cool-season precipitation (November–April) for Arizona and New Mexico climate divisions.[25]

The major challenges working with stakeholders to increase or improve the use of paleoclimate data have been generating interest in these data sets—the misfortune of having a multi-year drought brings about the more fortunate circumstance of actually getting people interested in looking at the past—and working with stakeholders to help them understand the caveats about using these data. For example, tree rings often best record below-average precipitation. Also, the estimates are season specific, although people often take them to be annual estimates. Because stakeholders do not have exposure to this commonly used form of generating data, they are skeptical and have asked for training regarding (for example) their accuracy and robustness as well as how the estimates are generated.

Timing Is Everything

Making science useful involves making information available at appropriate times within the annual or seasonal decisionmaking process. This requires that researchers understand and be responsive to the time frames during the year in which specific types of decisions are made. Decision calendars provide researchers with a useful tool for characterizing these time frames as well as the entry points for information into the process.[26] Failure to provide information at a time when it can be inserted into the annual series of decisions made in managing water levels in reservoirs, for example, may result in the information losing virtually all of its value to the decisionmaker.

During the winter of 2000, in anticipation of a potentially severe fire season, CLIMAS researchers, in collaboration with other University of Arizona investigators, convened a workshop of fire managers and climate experts.[27] A second dry La Niña winter portended high fire potential for large regions of the United States, including the Southwest, Southeast, and northern Rockies. During the workshop, researchers learned more about fire managers' decision calendars for various areas of the United States. In fact, the 2000 fire season turned out to be one of the busiest and most costly on record.[28] In this case, the climate information was timely, but the fire management community was not yet prepared to incorporate this information into national management plans.

Building on this knowledge, CLIMAS, in partnership with the National Interagency Coordination Center and the Program for Climate, Ecosystem and Fire Applications, launched an annual series of pre-season fire potential assessments beginning in 2003.[29] The assessments, which bring together fire and weather specialists from all across the country, have been highly successful in terms of reaching and informing managers and integrating climate information into decisionmaking; such success is due to a combination of improved timing, enhanced cooperation, and institutional change (see Figure 2 on this page).

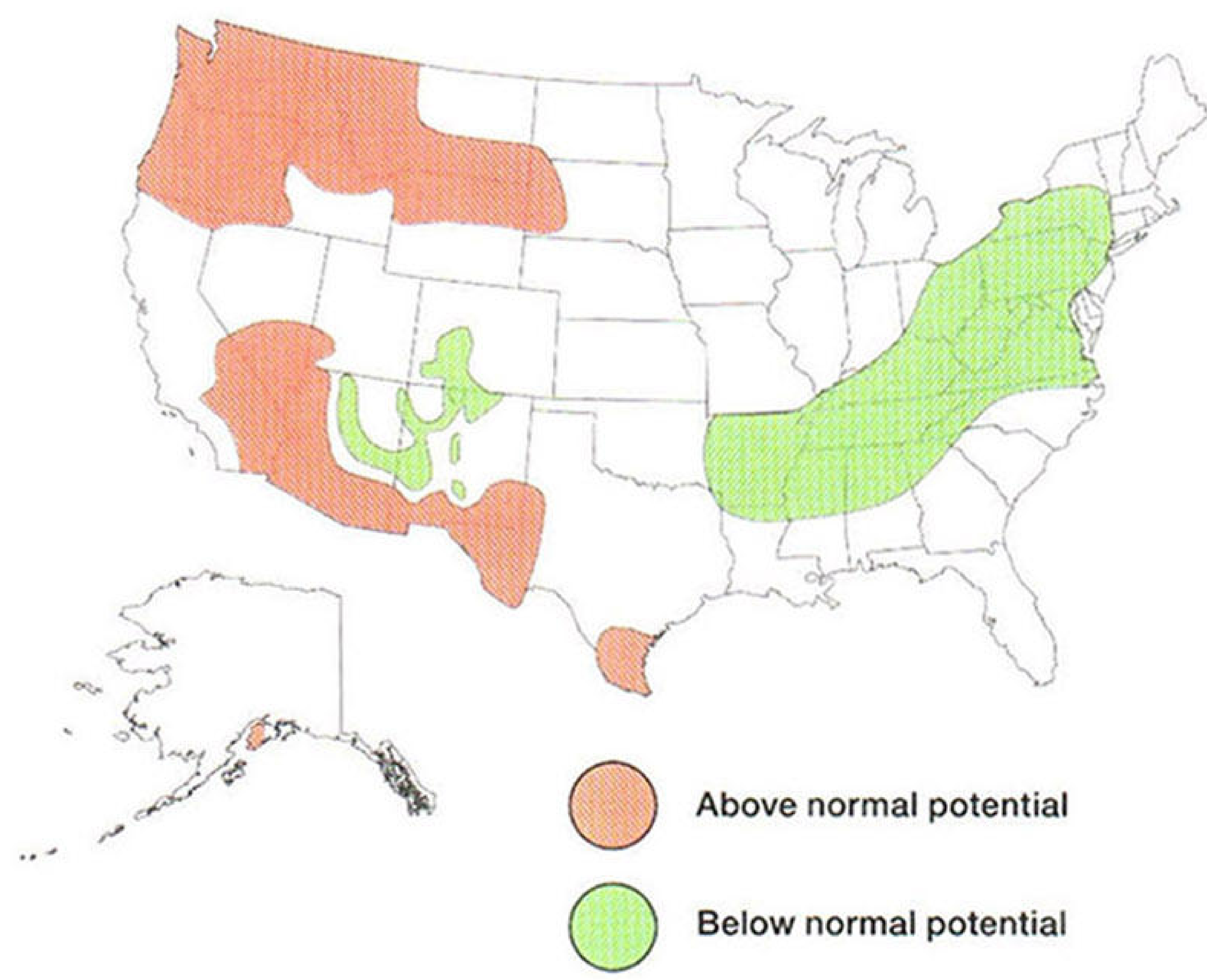
Similarly, the negative consequences of recent drought in the Southwest focused the interest of the public and decisionmakers on climate. As drought developed, CLIMAS initiated a rapid response project (called El Niño-Drought (END) InSight) to provide stakeholders with value-added climate information, including forecasts and reports of recent conditions and a magazine-length article about a timely climate topic (such as how El Niño might affect drought status).[30] (See Figure 3 on page 15.) By anticipating stakeholder needs and providing timely drought information to Southwest stakeholders, CLIMAS was positioned to make major contributions to Arizona's first drought plan.[31] Contributions built on existing CLIMAS efforts to characterize vulnerability to climate variations; in addition, CLIMAS initiated new studies on drought history, impacts, and planning specifically for the drought plan.[32] A major contribution was the design of the monitoring system and trigger mechanisms for drought response, again focused on provision of timely information to decisionmakers. These projects benefited state drought planners, who might not otherwise have been able to develop a sophisticated science-based system of indicators and triggers—and enhanced CLIMAS credibility.

Interacting with Stakeholders

Effective communication is the cornerstone of integrating science, policy, and decisionmaking. Yet it takes time and effort to maintain effective relationships with potential decisionmakers, and it takes patience and determination to communicate clearly. However, the workload can be distributed through collaboration with other research groups, as demonstrated below.

There are multiple facets to communication. Concerted efforts may be required to overcome barriers caused by differences in training and perception.[33] There is a natural tendency for groups to create special forms of communication, such as acronyms, that, intentionally or not, help define the "insiders." A common problem for researchers is lapsing into their own jargon and using acronyms that are unfamiliar to those outside their discipline. Most practitioners also have their own jargon. Use of jargon may be one of the most significant limitations to applied interdisciplinary work and integrating science with decisionmaking.

Figure 2. National Seasonal Assessment Workshop product



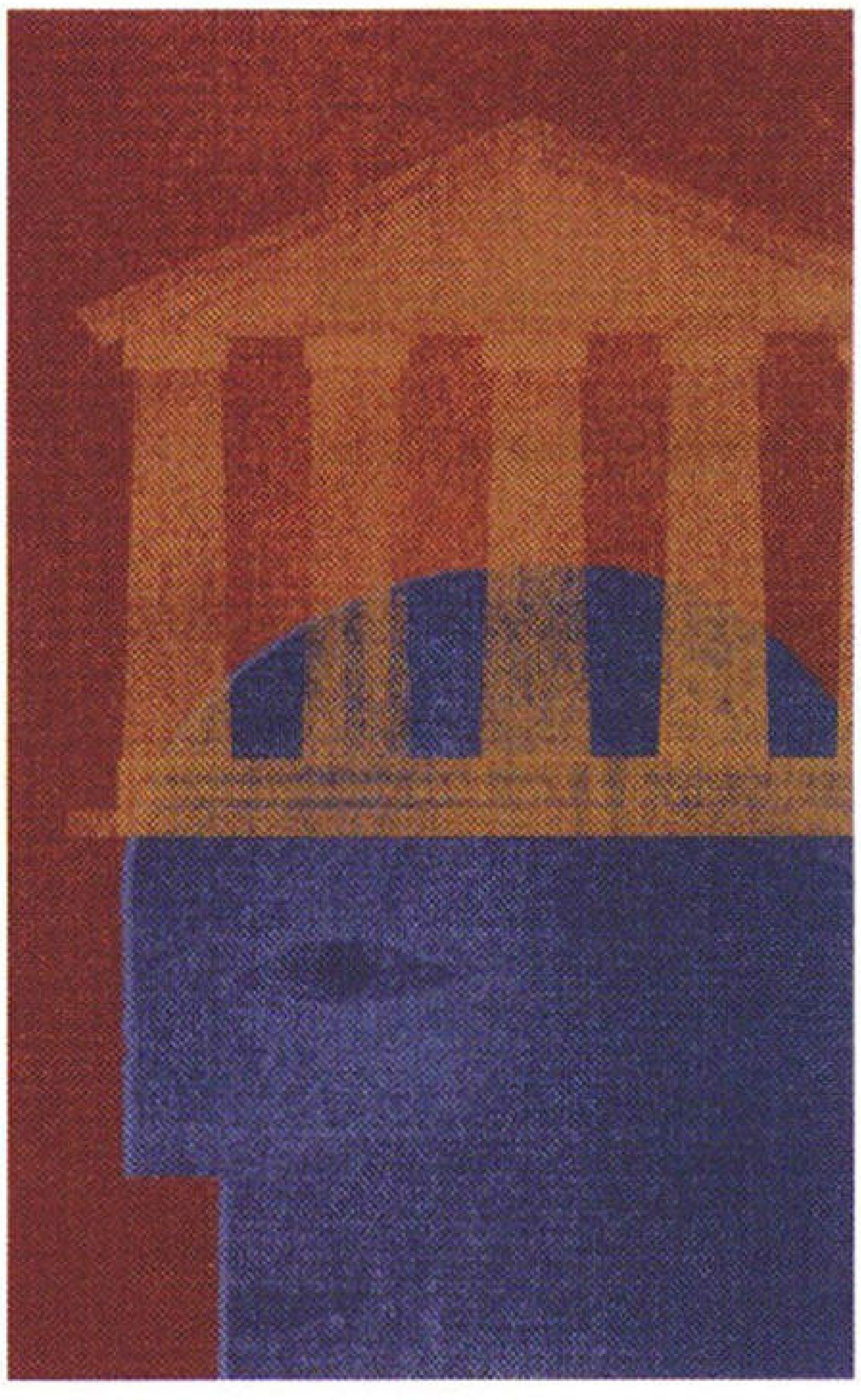
NOTE: This map shows the 2005 outlook for national significant fire potential as of late March. At an annual three-day workshop to assess regional fire season resource needs, regional fire managers and fuels specialists create a version of this map, relying in part on insight from climatologists and seasonal climate forecasts. These pre-season fire potential outlooks supplement monthly outlooks produced by the National Interagency Coordination Center (NICC). NICC, the Climate Assessment for the Southwest, and the Desert Research Institute's Program for Climate, Ecosystem and Fire Applications collaborate each year to organize the workshop and distribute the products.

SOURCE: M. Lenart, T. Brown, R. Ochoa, H. Hockenberry, and G. Garfin, *National Seasonal Assessment Workshop, Western States and Alaska, Final Report, March 28–April 1, 2005, Boulder, CO* (Tucson: Institute for the Study of Planet Earth, University of Arizona, 2005), http://www.ispe.arizona.edu/climas/conferences/NSAW/west05/NSAWwestproceedings.pdf.

Initial encounters with stakeholders need to be carefully structured. Research teams can benefit by acknowledging that some communicators are better than others at reaching particular audiences. Emphasizing from the beginning an expectation of two-way information exchange allows for a constructive approach to interactions. CLIMAS has found it beneficial to adopt a sustained, iterative approach, such as testing products and services using feedback over time and evaluating reactions to product improvements.[34] Experience involving agency personnel in the water management context, such as the joint development of groundwater models between the U.S. Geological Survey and the Arizona Department of Water Resources, also indicates that iterative evaluation through long-term working relationships is an effective approach to building useful products.

Identifying Likely Stakeholders

Some time spent on defining candidates likely to use a particular product is appropriate, because it will affect the types of collaboration that may be necessary, the sophistication of the products, and the ways in which they will be distributed.



Working through and within existing professional organizations as well as organizations that exist specifically to transmit and translate scientific information for practical applications (such as Cooperative Extension) is often an effective way to start identifying likely candidates.[35] Good follow-through with professional societies facilitates the identification of the people most open to new ideas; such people may be early adopters. Working with early adopters within organizations or user groups may provide inside contacts to facilitate information flows and meetings or demonstrate to their colleagues how climate products can be used. This has been important in working with water managers who initially seemed reluctant to focus on climate information.[36]

In seeking to identify stakeholders, CLIMAS researchers also employ snowball sampling (asking existing contacts for names of others who might be interested in the topic or research at hand).[37]

Soliciting Stakeholder Feedback

Providing opportunities for feedback strengthens relationships and helps to gauge success. Feedback that is directly incorporated into product development and shared with the affected parties provides evidence that the researchers are listening to stakeholder perspectives, and it also encourages future collaboration.

Gathering feedback through formal surveys and interviews can provide a research opportunity as well as a chance to learn more about stakeholder views. The END InSight project, launched in 2002, was designed to foster timely knowledge exchange during a potentially confusing situation: the combination of El Niño, which often brings wet winters to the Southwest, and intensifying drought. Each month, project participants received a packet of region-specific climate products showing recent climate conditions and forecasts. In addition to raising awareness about climate products and caveats regarding their use, project goals included soliciting evaluations of the utility of specific climate products for decisionmaking and gathering feedback that could lead to climate product improvement.[38] Thirty-six stakeholders from a variety of sectors throughout Arizona and New Mexico participated in the one-year initiative and provided feedback through monthly written and telephone surveys and a summary workshop. The combination of feedback methods was important, as different insights were gained from each method.

The project was well received, with 95 percent of exit survey respondents expressing an interest in continuing to receive monthly climate information through the Web. During the course of the project, participants stated that they used the information to make decisions with regard to endangered species management, eradication of non-native species, rangeland stocking rates, and irrigation allocation, in addition to monitoring regional conditions and sharing information with their clients and colleagues.

The project increased the understanding of stakeholder needs, alerted researchers to the successes and failures of climate product designs, and initiated many fruitful and ongoing contacts with stakeholders. The effort was time-consuming and resource intensive for the researchers, and some participants experienced survey fatigue due to the frequency of written surveys. The researchers working on this project found that monthly contacts were excessive from the stakeholders' perspective—a factor to consider for future feedback instrument designs.

Working with Mass Media

Working with the media can help to disseminate information and encourage stakeholder interest in climate issues. Cultivating relationships with individual local press and broadcast station reporters who appear to have interest and technical competence in the subject matter will improve the likelihood of successful knowledge transfer.

In 2002, CLIMAS formed an alliance with SAHRA, NSF's Center for Sustainability of semi-Arid Hydrology and Riparian Areas, to host occasional press briefings in Tucson, Phoenix, and Albuquerque. The ventures have included briefings on drought, El Niño, wildfire potential, and climate change. Typically, four to five speakers talk for 5–7 minutes each on related topics, with ample time scheduled for questions at the end; reporters are more likely to write an article if they are engaged in such a question-and-answer session. It is useful for presenters to prepare handouts and quotable insights ahead of time, as reporters will focus on those who express themselves in interesting and quotable ways.

Trade journals and publications by professional societies are another form of media to consider for outreach to decisionmakers. At a May 2005 workshop, CLIMAS asked water managers what types of journals they read to keep up with research in their field. Not surprisingly, they were almost unanimous in responding that they read professional society publications, such as the American Water Works Association newsletter, rather than peer-reviewed articles published in scientific journals. Unfortunately, the traditional system of rewards for university researchers recognizes only peer-reviewed publications, so currently there is little career incentive for scientists to publish in trade journals. Peer-reviewed papers are the "currency" of academia; publishing in a trade journal has no value in the context of tenure review.

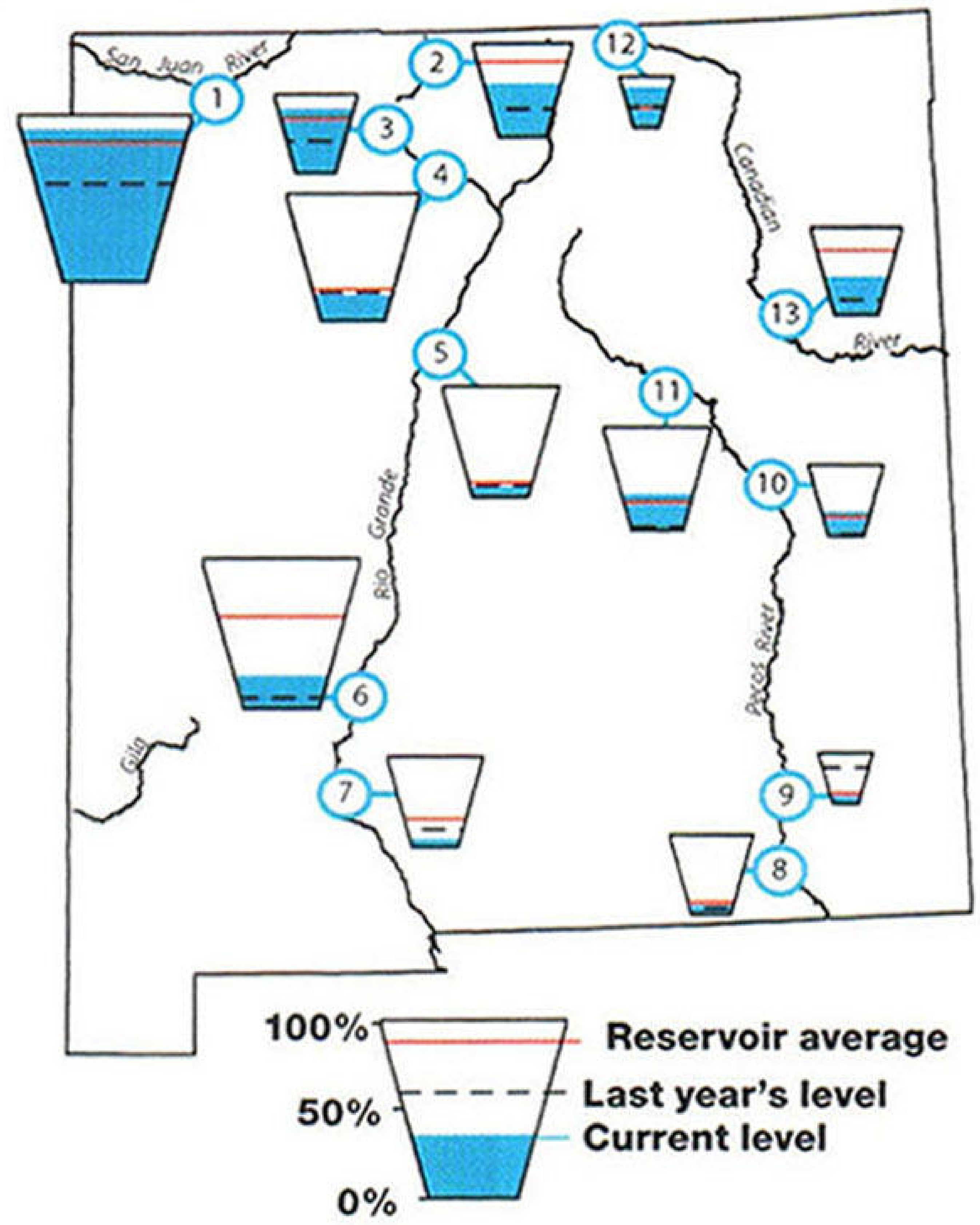
Although CLIMAS has made this a priority for its staff, the decision does pose a career risk that not every researcher would be willing to take.

Holding Workshops and Short Courses

Offering workshops and short courses can be an effective way to interact with stakeholders. Both offer valuable opportunities for knowledge exchange through training and interactive components. The appropriate ratio of stakeholders to scientists is a key consideration. If researchers overwhelm stakeholders in numbers, stakeholders may feel intimidated unless the format specifically features their participation.

For instance, CLIMAS, SAHRA, and the New Mexico-based Sandia National Laboratories held a one-day drought short

Figure 3. Southwest Climate Outlook product on reservoir levels



Reservoir name	Capacity level (percent)	Current storage (thousands of acre-feet)	Max storage (thousands of acre-feet)
Navajo	92	1,557.2	1,696.0
Heron	58	231.3	400.0
El Vado	82	152.2	186.3
Abiquiu	21	115.3	554.5
Cochiti	10	48.7	502.3
Elephant Butte	23	478.1	2,065.0
Caballo	10	34.2	331.5
Brantley	12	17.5	147.5
Lake Avalon	22	1.3	6.0
Sumner	36	37.2	102.0
Santa Rosa	21	94.3	447.0
Costilla	80	12.8	16.0
Conchas	44	111.4	254.0

NOTE: The map shows levels (blue fill) of New Mexico's major reservoirs as of 30 June 2005 and how it compares to total capacity (cup outline), average levels (red line), and last year's level (dotted line). The size of cups is representational of reservoir size but not to scale. This product, also available for Arizona, was developed after resource managers and agriculturalists expressed a need for a visual representation of the reservoir data provided by the U.S. Department of Agriculture's Natural Resources Conservation Service.

SOURCE: Climate Assessment for the Southwest (CLIMAS), *Southwest Climate Outlook*, July 2005, accessible via http://www.ispe.arizona.edu/climas/forecasts/swoutlook.html. Map based on data from the Natural Resources Conservation Service, some of which is available at http://www.wcc.nrcs.usda.gov/wsf/reservoir/resv_rpt.html.

course in March 2005 for water managers in conjunction with the New Mexico Rural Water Association's (NMRWA) annual meeting. The event was one of a number of NMRWA short courses for which managers received credit as part of their ongoing training. Participants received an overview of the dominant climate processes in the Southwest and learned specific skills, such as how to interpret seasonal climate forecasts, assess forecast skill, and create municipal drought plans. Six scientists gave presentations to about 35 water managers.

Given the observed importance of integrators in connecting science and decisionmaking, how can their numbers be expanded?

In contrast, the ratio of scientists to water managers was more even at a May 2005 workshop that promoted discussion on the use of tree-ring records to assist management decisions. CLIMAS organized the workshop with the Western Water Assessment, a sister RISA project in Colorado. The day's presentations started with morning talks from water managers followed by talks from scientists and facilitated break-out sessions, a format designed to put the focus on water management, make participants more comfortable, and effectively solicit feedback. Lack of a consistent message from the "experts" has been observed to be a major concern for stakeholders; thus, the scientists met the previous afternoon to coordinate their presentations.

Although hands-on training tools take time and effort to develop, CLIMAS resource economists found that hands-on spreadsheet-based computer simulations or "games" promote effective knowledge transfer by helping to evaluate the effect of using or not using climate information relative to risk management outcomes. To demonstrate risk management alternatives in the face of year-to-year climate variability, the resource economists developed a model that incorporated economic theory and climate variability information for the ranching community. The gaming workshop brought home the point that managers are always making decisions affected by climate—with or without climate information—and that science-based decisions can be effective if stakeholders make explicit their risk tolerance and scientists clearly convey the caveats to using science-based information.

The main drawback to workshops is that they are time-consuming. If the subject matter of the workshop is controversial, then facilitation might be required, and facilitation is costly. Even if the subject matter is noncontroversial, facilitation may be required to focus attention on tangible outcomes, such as the development of stakeholder-scientist partnerships, joint grant proposals, and joint education and outreach projects.

Integrating Information for Stakeholders

Communication between scientists and decisionmakers can often be enhanced with the help of professionals who specialize in translating information for wider use, sometimes known as integrators.[39] Many current integrators have evolved from activities supported by NOAA's Office of Global Programs or from other programs encouraging interdisciplinary and collaborative projects and applied research.

Given that most stakeholders are not reading the primary literature for management information, researchers who work with stakeholders can offer a much-needed but often-overlooked service by integrating current research and understanding into a format accessible by a variety of stakeholders or applicable to a specific group of decisionmakers.[40] CLIMAS researchers are often called upon to help bridge the communication gap between scientists and managers in a variety of forums. Groups requesting presentations include resource conservation groups, federal and tribal forest managers, public officials, water managers, wildlife societies, and religious congregations. Other nationwide examples include Cooperative Extension programs associated with land grant universities and Project WET (Water Education for Teachers), which is a national program to develop water-related curriculum and training for teachers.

Given the observed importance of integrators in connecting science and decisionmaking, how can their numbers be expanded? Some suggestions appear in the box on page 17.

Further Considerations: Equity and Measuring Success

The concept of equity emphasizes solutions based on fairness and flexibility. Equitable distribution of and access to scientific information is fundamental to integrating science into environmental decisionmaking, particularly when a "nonlevel playing field" has the potential to enhance one group's ability to gain from scientific knowledge at the expense of another group. Like establishing equitable access to information, measuring success is also a thorny issue in attempts to integrate science and decisionmaking. Measurable outcomes are seldom as clear as "the use of these forecasts saved 30 lives and $30 million," because environmental issues are inherently multifaceted. Nevertheless, decisionmakers, policymakers, and scientists require clear metrics of success to evaluate how to improve integrative efforts and to determine whether it is worthwhile to continue allocating scarce resources to integrative projects.

Consideration of Equity

Equity is a major concern in linking science with policy, because decision support systems require sustained resources. Depending entirely on the private sector to provide tailored information means potentially limiting access to a relatively small and privileged group.[41] This is especially true in the climate arena, where there are numerous health and welfare considerations. Working with south-

SCIENCE INTEGRATORS

The gap between science and decision-making is caused by multiple factors. Among the most important are the institutional complexity of the decision context and the difficulty in communicating sophisticated science findings to those who may not have a strong science background. In recognition of these facts, there are many applications where trained integrators are required to truly bridge the gap. Integrators need to understand both ends of the spectrum, which means they need to have an interdisciplinary but focused background to provide decision support that is timely and meaningful. There is great demand for people in this type of position, but few programs are designed to produce graduates who are well prepared to do this in an applied context.

Qualities of effective science integrators and translators include

- outside-the-box mentality;
- willingness to work across disciplines and think creatively;
- credibility in the science community, with the ability to understand and translate complex information correctly;
- expertise in a particular sector (such as energy or agriculture);
- understanding of the institutions and cultures of the particular country/region involved; and
- ability to facilitate, rather than replace, relationship building between the principals (scientists and user groups).

Suggestions to enhance training opportunities for science integrators:

- Incentives for including integrators in research projects can be provided by funding agencies—either in project review criteria or through separate direct funding for participation of integrators.
- Educational institutions can be encouraged or funded to set up programs to train integrators in various environmental applications, perhaps at the Master's level.
- There are at least two existing programs that are excellent examples of encouraging integration of science into agency activities at high levels. The American Academy for the Advancement of Science sponsors Science and Technology Policy Fellowships for post-docs (see http://fellowships.aaas.org/) to work for a year within agencies. Similarly, the Sea Grant program administers fellowships that may result in placement of recent science graduates in policy areas (see http://www.seagrant.noaa.gov/funding/fundingfellowships.html).
- Cross-training within and between agencies and public universities can be accomplished through Intergovernmental Personnel Agreements and less formal mechanisms.
- New programs can be developed to place government and academic scientists in policy and decisionmaking arenas and to bring stakeholders and decisionmakers into research arenas for specific time periods (ranging anywhere from a month to a year) to elicit interest in and understanding of each other's agendas.

SOURCE: K. L. Jacobs, *Connecting Science, Policy and Decision-Making: A Handbook for Federal Science Agencies* (NOAA Office of Global Programs, 2002).

eastern Arizona agricultural stakeholders from varied ethnic and economic backgrounds, CLIMAS researchers found that Hispanic farmers and migrant workers had the poorest access to technology and climate information.[42] The researchers found that intermediaries, such as Cooperative Extension and Natural Resource Conservation District specialists, provide important links in formal and informal knowledge transfer networks. These intermediaries facilitate equitable access to climate and environmental information from university researchers through community meetings, formal training programs, site visits, and print publications targeted at a general audience. CLIMAS researchers have also found that working with Native Americans requires particular sensitivity to the historical context of relationships with government and other entities.[43] Native nations are often loath to distribute their environmental data due to litigation on water rights (involving many tribes and native nations) and legal wranglings with energy companies (for example, the Navajo and Hopi Nations have had an ongoing dispute over use of groundwater to process and deliver coal slurry from Black Mesa). In addition, these stakeholders might require specific intellectual-property or data-distribution constraints. For example, they might prohibit distribution of raw environmental data, as such data may be integral to ongoing litigation or might compromise sovereignty issues.

Measures of Success

Being aware of a wide range of stakeholders' needs and respecting various sensitivities will likely bolster the success of any effort to integrate science and decisionmaking, but how will researchers know when they have attained success?[44] Establishing clear goals and milestones can help, but defining metrics of success before programs begin presents a greater challenge. Success from the perspective of a social scientist might include development of sustained relationships between scientists and stakeholders, an open and participatory process, and better scientific understanding of the decisionmaking process.[45] Success from the perspective of a physical scientist might include improved understanding of physical processes that results from working with decisionmakers who have years of hands-on experience managing resources. Success from the perspective of a science integrator might include increased demand for information or briefings. From the perspective of a stakeholder, success might be measured in terms of reduced losses from flooding or fire hazard. All these measures of success are legitimate, although some are more difficult to document than others. CLIMAS has found it difficult to document a reduction of societal vulnerability to climate impacts. Some additional ideas for measuring success can be found in the box on page 18.

Conclusions and Critical Observations

Working with stakeholders in meaningful ways is time-intensive and requires a variety of skills. Relatively minor changes in process and expectations can improve the utility of research and can result in more constituent support for federal programs that fund research. CLIMAS has found that building relationships is the key component in bridging the gap between climate science and decisionmakers. Sustained contact with stakeholders also allows researchers to make the most of opportunities created by legislative initiatives or crises. In fact, sustained contact may be more important in the long run than specific product characteristics.

To build effective decision support systems, it is critical to understand the decision context within a particular sector (such as the key players and early adopters), the kinds of information they currently use and potentially could use, and the institutional constraints to decisionmaking. Additionally, the practical constraints created by politics and perceptions of risk need to be fully incorporated into the framing of knowledge systems for decisionmaking. With agricultural stakeholders, information about extra-regional and international competitors can be as important as improved science to understand local or regional conditions. In the case of Native Americans, consideration of history and ongoing legal processes, such as water rights litigation, is crucial. Moreover, certain aspects of risk tolerance are especially critical: Must a given decisionmaker avoid a single poor decision because the associated impacts could be financially devastating or have serious public health consequences—or can he or she work with long-term odds, knowing that he or she will win in some cases and lose in others? The 2000 Cerro Grande Fire in Los Alamos, New Mexico, provides a poignant example of a case where public trust for prescribed fire was significantly eroded by a single decision.[46] Expanded use of intermediaries and translators can also enhance the flow of information where scientists or agencies do not engage directly with decisionmakers. Not every researcher needs to

MEASURES OF SUCCESS

Establishing goals and objectives prior to engaging stakeholders in scientific processes is critical to successful interactions. In addition, establishing from the beginning of a project clear milestones or metrics by which to measure "success" will result in much more focused effort and timely completion. Many scientists approach potential "stakeholders" with much trepidation, because they are not sure how to engage without compromising the scientific value of their work. Having achievable and clear measures of success that focus on the engagement process itself can be reassuring in such cases.

Responses to the following questions help determine success:

In stakeholder interaction/collaboration (from the point of view of either scientists or users),

- Did participants modify behavior in response to information?
- Did participants initiate subsequent contacts?
- Were contacts/relationships sustained over time, and did they extend beyond individuals to institutions?
- Did the information change the user's perspective on the role of science in making decisions?
- Was staff performance evaluated on the basis of quality or quantity of interaction?
- Were interactions with stakeholders documented or evaluated relative to metrics for success?

In stakeholder interaction/collaboration (generally),

- Did stakeholders invest staff time or money in the activity?
- Did the project take on a life of its own, becoming at least partially self-supporting after the end of the project?
- Did the project result in building capacity and resilience to future events/conditions rather than focusing on mitigation?
- Were quality of life or economic conditions improved due to use of information generated or accessed through the project?
- Did the stakeholders claim or accept partial ownership of final products?

In the use of science in decision-making,

- Was the process representative (all interests have a voice at the table)?
- Was the process credible (based on facts as the participants knew them)?
- Were the solutions implementable in a reasonable time frame (political and economic support)?
- Were the solutions disciplined from a cost perspective (that is, is there some relationship between total costs and total benefits)?
- Were the costs and benefits equitably distributed (that is, was there a relationship between those who paid and those who benefited)?

In interdisciplinary work,

- Are there regular contacts with colleagues in other disciplines?
- Have interdisciplinary programs and lecture series been established within agencies or institutions?
- Are participants publishing integrated analyses in multidisciplinary journals or journals from other fields?
- Are participants cited in journals from other fields?
- Are research projects jointly funded with other agencies or disciplines?
- Is there a professional reward system (such as merit-pay review) that encourages activities outside the discipline?

SOURCE: K. L. Jacobs, *Connecting Science, Policy and Decision-Making: A Handbook for Federal Science Agencies* (NOAA Office of Global Programs, 2002). This box incorporates significant input from Barbara Morehouse, deputy director, Institute for the Study of the Planet Earth, University of Arizona, and Diana Liverman, director, Environmental Change Institute, University of Oxford, in an interview with authors, Tucson, Arizona, January, 2002.

be directly engaged with stakeholders. For example, climate model programmers do not need to be directly engaged with users if other participants in the "knowledge system" are ensuring that the models meet their expectations.

Causing change to occur in operational or policy environments, especially where there is substantial precedent, requires the people working in these environments to be willing to move away from the status quo. This implies some willingness to take personal and professional risks and some ability to get others to follow. Particularly in federal agencies, many people who make policy decisions are appointed and may not have the opportunity to develop long-term relationships with those who generate scientific information. This represents a particular challenge in getting scientific information used in high-level policy decisions. In contrast, CLIMAS has found that operational policy staff and research staff are likely to be in place for longer periods of time in agencies, providing better opportunities to develop the relationships necessary to integrate research and decisionmaking. In other contexts, a top-down approach might be necessary to overcome resistance to change and skepticism about poorly understood data, such as the results of long-term forecast models or global climate scenarios. Determining the most appropriate approach depends on institutional culture as much as institutional capacity and expertise.

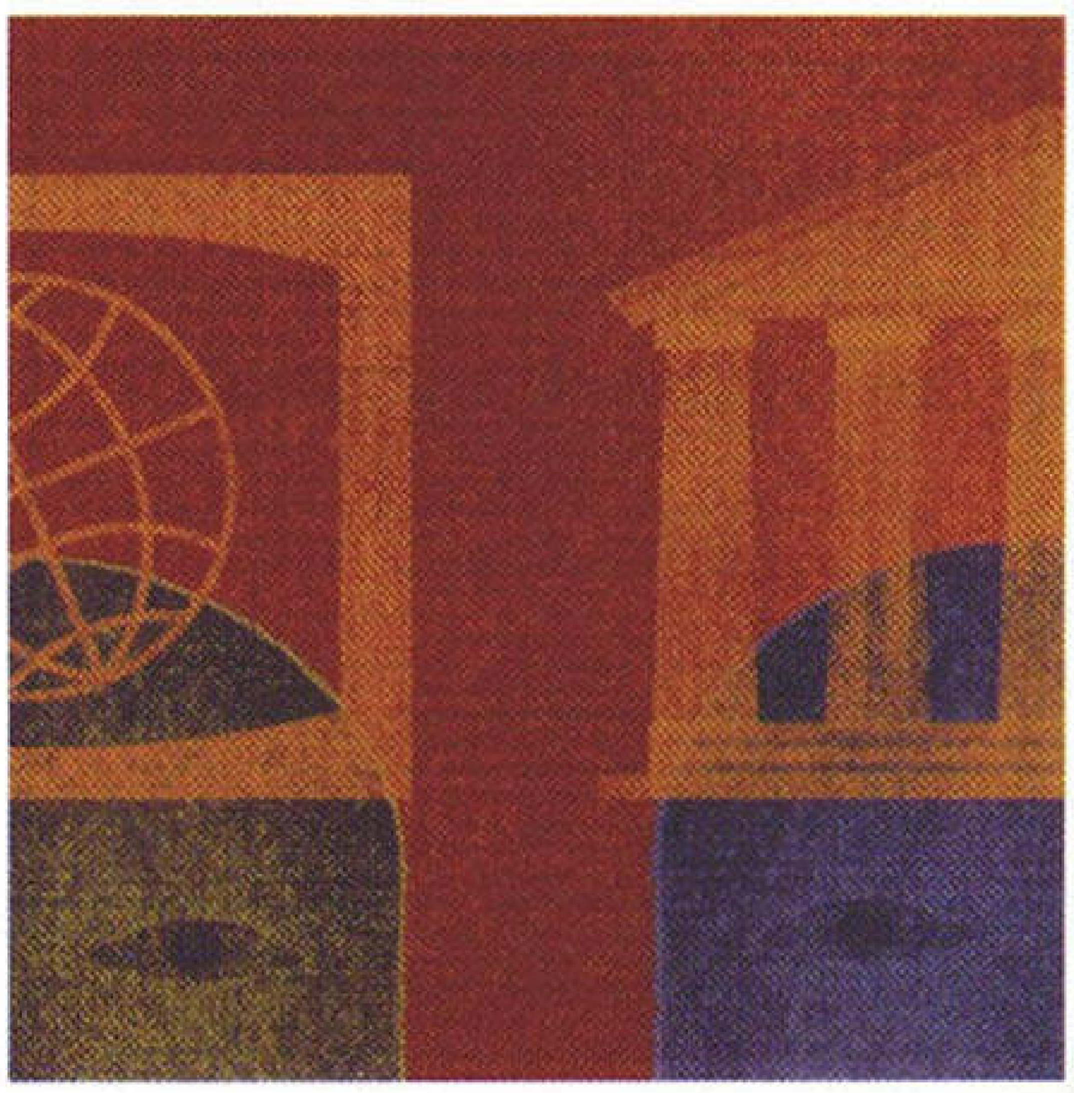
Building relationships is the key component in bridging the gap between climate science and decisionmakers.

The presence or absence of a leader or "champion" within stakeholder groups or agencies may make the difference in successful integration of new information. Identifying people with leadership qualities and working through them will facilitate adoption of new applications and techniques. The importance of leadership in initiating change cannot be overestimated, although connections with on-the-ground operations employees and data managers are also important to facilitate information exchange. New (recently hired) professional water managers have been found to be more likely to take risks and deviate from precedent and "craft skills" that are unique to a particular water organization.[47]

Finally, many changes in policy and use of technology occur in response to actual or perceived crises, when there tends to be greater political pressure to respond and sometimes more opportunity for investment in adaptation. Drought-planning activities are a significant example of this. Because it is virtually inevitable that there will be future droughts and floods and other environmental hazards that affect decisionmakers, stakeholders, and the availability of money for mitigation and adaptation, preparing to use these situations to the best advantage is a useful strategy. This could mean having constructive alternatives or suggested legislation ready for a future "opportunity." In addition to crises caused by natural hazards, crises can be caused by regulatory changes and abrupt changes in funding. For example, in the Pacific Northwest, California, and New Mexico, scientific opinions associated with implementation of the Endangered Species Act (ESA) have significantly impacted existing water allocations, in some cases by trumping existing priority water rights—and, in turn, causing major economic dislocation. In other cases, habitat conservation plans developed under ESA have derailed potential crises and provided an avenue for constructive evaluation of options that would not previously have been considered.

The pace of environmental change and population growth in the western states, particularly in the Southwest, demand thoughtful, well-informed decisionmaking with relatively short lead times. Decisionmakers are rethinking assumptions about the reliability of major hydrologic systems—such as the Colorado River—to deliver water to a burgeoning population in the face of severe sustained drought and increasing temperatures. In the past five years, the western states have also seen an increase in catastrophic high-intensity fires and fire suppression costs. Solutions to conflicts relating to climate-driven environmental issues at the nexus of water, fire, irrigated agriculture, and endangered species, for instance, require multi-decisionmaker processes and the best science available. Thus it is urgent that the process of integrating science into decisionmaking be accelerated to encourage adaptation and foster environmental and social sustainability.

Long-term issues, such as water resource and land use management,



require a long-term investment to ensure public access to key information. Efforts to increase the likelihood that research results and products will be used by decisionmakers help promote the integration of science into the decisionmaking process—to the benefit of research and policy.

Policy benefits from the development of research and science programs and applied decision support tools that are tailored to society's needs. Society has invested billions of dollars in climate research, and gains from this investment can only be realized if the results of that research reach decisionmakers in a timely fashion and in a format that is easily understood by decisionmakers.

Moreover, academic scientists are frequently stereotyped as a community of individuals who are out of touch with the "real world." The research community benefits tremendously from interactions with decisionmakers when the interactions generate interesting and challenging research questions about how the world works and results that benefit society. The more research is grounded in sophisticated "real world" notions about how decisions are made, the greater the credibility of scientists—and, in the best situations, society improves its adaptive capacity.

The grand challenge for environmental and social sustainability is for our leaders and decisionmakers to become far more nimble at management that adapts to rapidly changing social and environmental conditions as well as to our geometrically increasing ability to generate new science and disseminate information. Improving the communication between scientists and decisionmakers—and getting scientists and a wide array of decisionmakers to collaborate—is an effective and exciting step to sustainable environmental management.

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17. Ibid.; and *Forecast Evaluation Tool (Beta-Test Version 1.0)*, http://hydis4.hwr.arizona.edu/ForecastEvaluationTool/.

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