Science and Engineering to Address Water Resource Management Issues in Arid and Semi-arid Regions

Juan B. Valdés

Deputy Director, NSF Center for Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA)

Professor and Head, Civil Engineering, The University of Arizona

Intl. Center for Integrated Water Resources Management (ICIWaRM)

Practical Cutting-edge Technology for Water Services
Discussion and Focus on Applications in Africa

Water Science Forum 2008
State Dept., Washington, D.C.

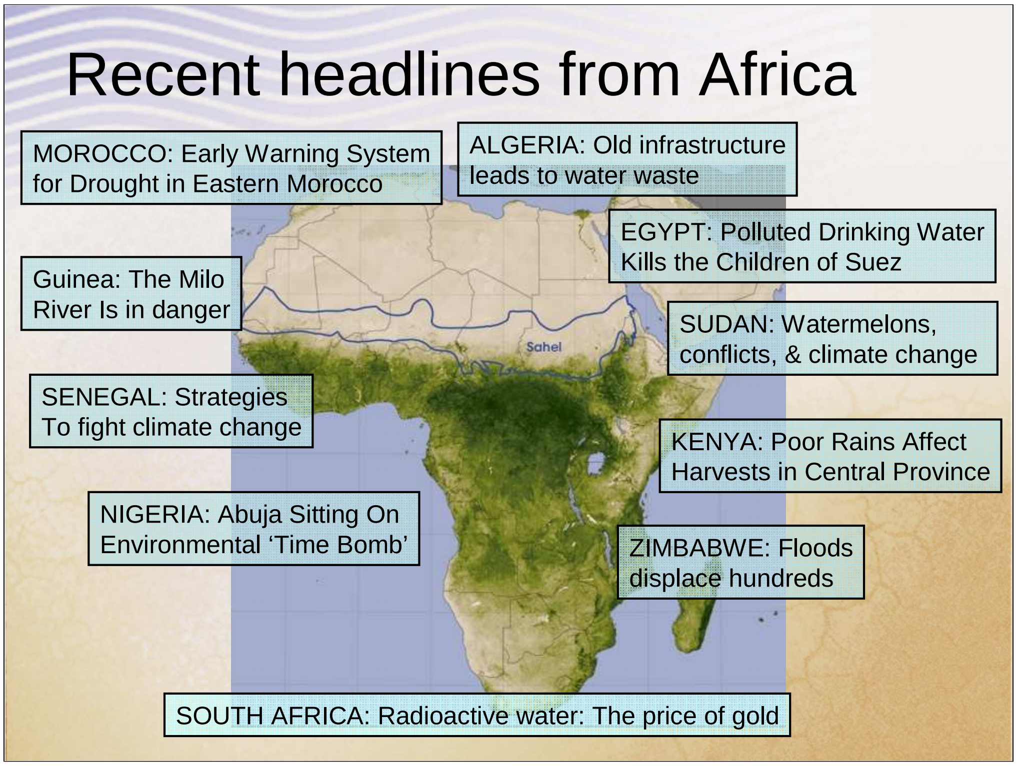
Acknowledgements

The science and technology presented here is the work of numerous individuals from many universities, research centers, and agencies, including

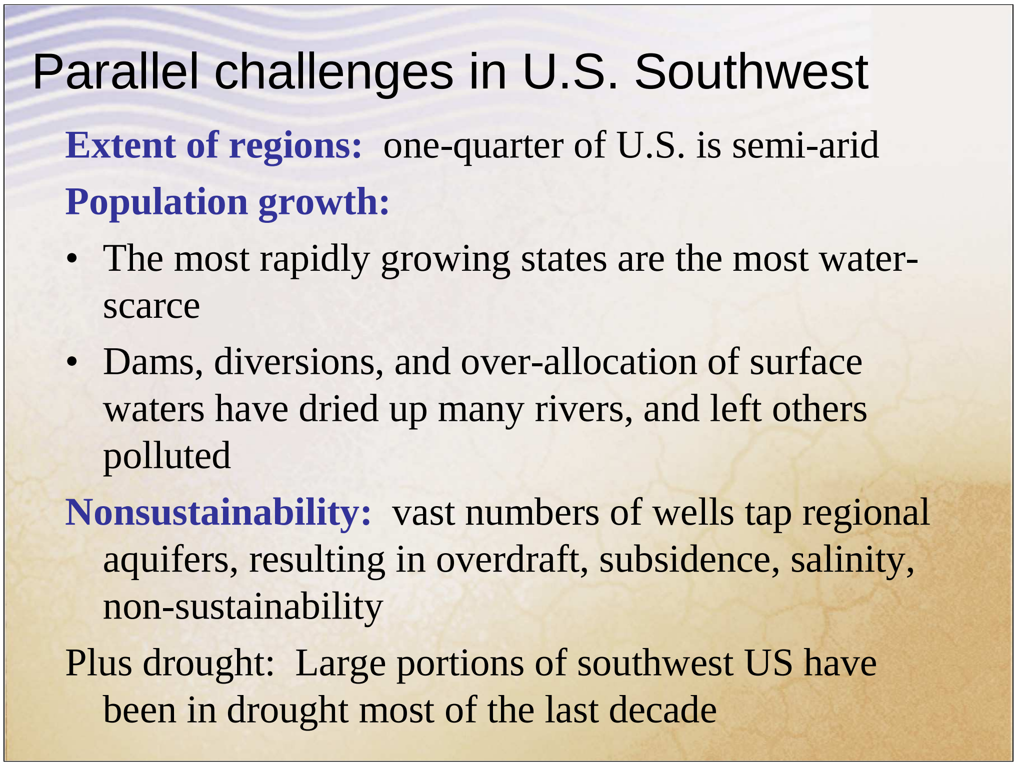
- Columbia University – Intl. Research Institute for Climate and Society
- NASA
- NASDA (Japan Space Agency)
- National Science Foundation – CUAHSI and SAHRA
- NOAA - World Data Center for Paleoclimatology
- Oregon State University
- Princeton University
- Sandia National Laboratories
- U.S. Army Corps of Engineers – Institute for Water Resources
- U.S. Dept. of Agriculture – Foreign Agriculture Service
- U.S. Geological Survey
- UNESCO
- University of Arizona
- University of California, Irvine
- University of Maryland
- University of Washington

Arid and semi-arid regions comprise 1/3 of the earth’s land surface. (Semi-arid regions are defined as areas of land that get 25 to 50 cms (10 to 20 inches) of precipitation, and usually have scrubby vegetation with short, coarse grasslands. Arid regions get less than that.) Water resource challenges include increasing populations, and nonsustainable resources.

The most rapidly growing populations are in arid and semi-arid regions. Population pressures and development are drying up rivers or leaving water unfit for most uses. In response, water users have tapped regional aquifers, resulting in overdraft and saltwater intrusion, causing reliance on nonsustainable water supplies.



Water resource challenges are particularly acute in Africa, as these recent headlines show. Flood, drought, pollution and inadequate infrastructure all contribute to denying many Africans a safe and sustainable water supply.



There are many parallels with the water situation in the United States:

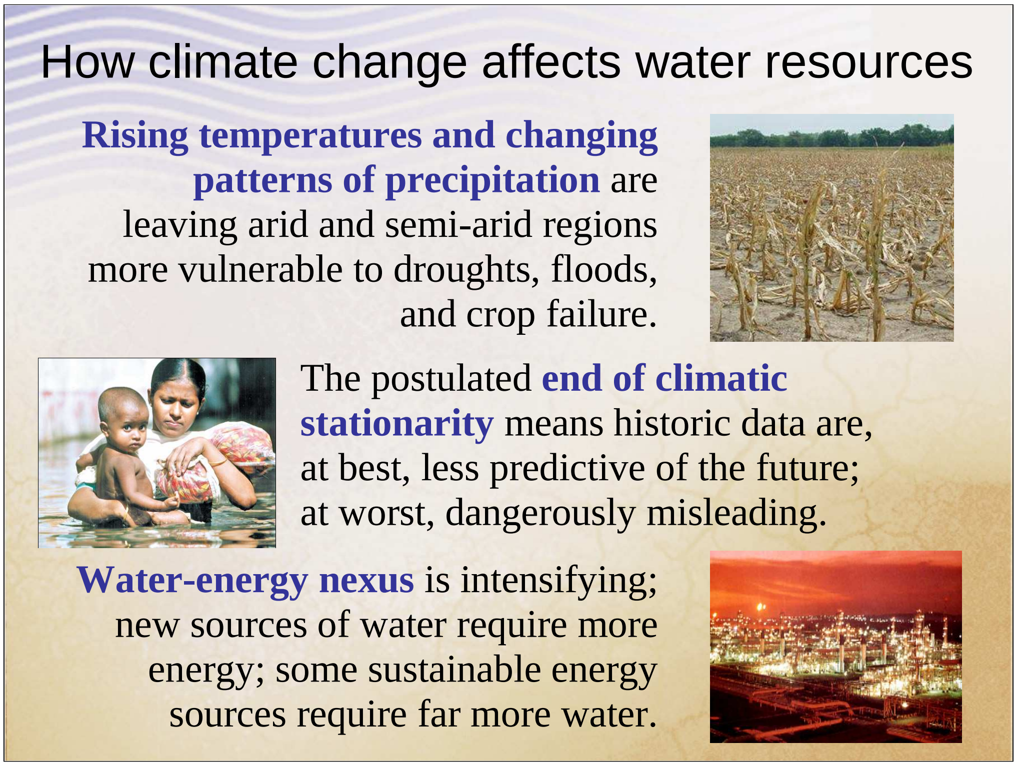
--One-quarter of the U.S. is semi-arid or arid, mainly the area west of the 100th meridian;

--The most rapidly growing areas are concentrated in the most water-scarce states;

--Dams, diversions, and over-allocation of surface water dried up many rivers; waste disposal left other waters polluted;

--Hundreds of thousands of wells have tapped regional aquifers, resulting in groundwater overdraft, land subsidence and salinity problems, leaving cities and farms reliant on unsustainable water resources;

Making this supply-demand imbalance worse, large portions of the West have been in drought for much of the last decade.



Is it really drought that is affecting the Western U.S. or is this a harbinger of climate change? The warmer temperatures, reduced snowpack and runoff, lower soil moisture levels, and reduced stream flows all are consistent with past peak water models for the western United States.

Impacts of climate change will be felt at least three ways:

--*Increasing temperatures and changing patterns of precipitation.* Soil moisture, runoff, streamflow, and groundwater recharge are being altered and often reduced, thereby reducing the reliability and sustainability of water supplies. As a result, arid and semi-arid regions are more vulnerable to both drought and flood, and consequently, crop failure.

--*The end of stationarity.* Global change researchers ((Milly et al., 2008) have postulated the end of stationarity, the fundamental assumption underlying water resource planning that the future will be statistically indistinguishable from the past. Under the progressively changing and uncertain climate now being projected by climate models, these hydrologic patterns will change. Calculations based on historical data about where the flood plain is, and what constitutes an assured water supply, may be seriously in error.

--*Water-energy nexus.* Vast amounts of water are used to produce energy, and vast amounts of energy are used to pump, transport, and treat water. The current water-energy relationships are intensifying because new sources of water are more distant, deeper, or polluted/brackish/salty, and so require more energy to purify and deliver. Some new sources of energy that reduce CO_2 emissions, such as corn-based ethanol, increase water consumption.

Key differences, U.S. vs. semi-arid world

- Over-allocation of rivers and groundwater overdraft began much longer ago in U.S.
- Impacts on water supplies, environment became apparent decades ago
- This spurred a shift away from structural solutions (dams) to non-structural approaches (improved management)
- U.S. has large, long-term investment of resources in seeking scientific, technical solutions

Despite the similarities in global and U.S. water challenges, there are important differences, and they create opportunities for the United States to contribute to improving water resource management in many areas of the world.

Over-allocation of surface waters in the western United States began a century ago; large-scale overdraft of groundwater aquifers began 60 years ago. Eventually, the costs of these early approaches to water resource development became apparent, in the form of reduced water supplies and environmental impacts. The benefits provided by natural ecosystems came to be recognized. About 45 years ago, a gradual shift began, away from dams and ditches, concrete and rebar, to more comprehensive structural and nonstructural solutions. This shift occurred earlier here in the U.S. than in most other semi-arid and arid regions.

Key questions

- What have we learned?
- Which cutting-edge technologies can be transferred to semi-arid and arid regions?
- How can these transfers be made most efficiently and effectively?

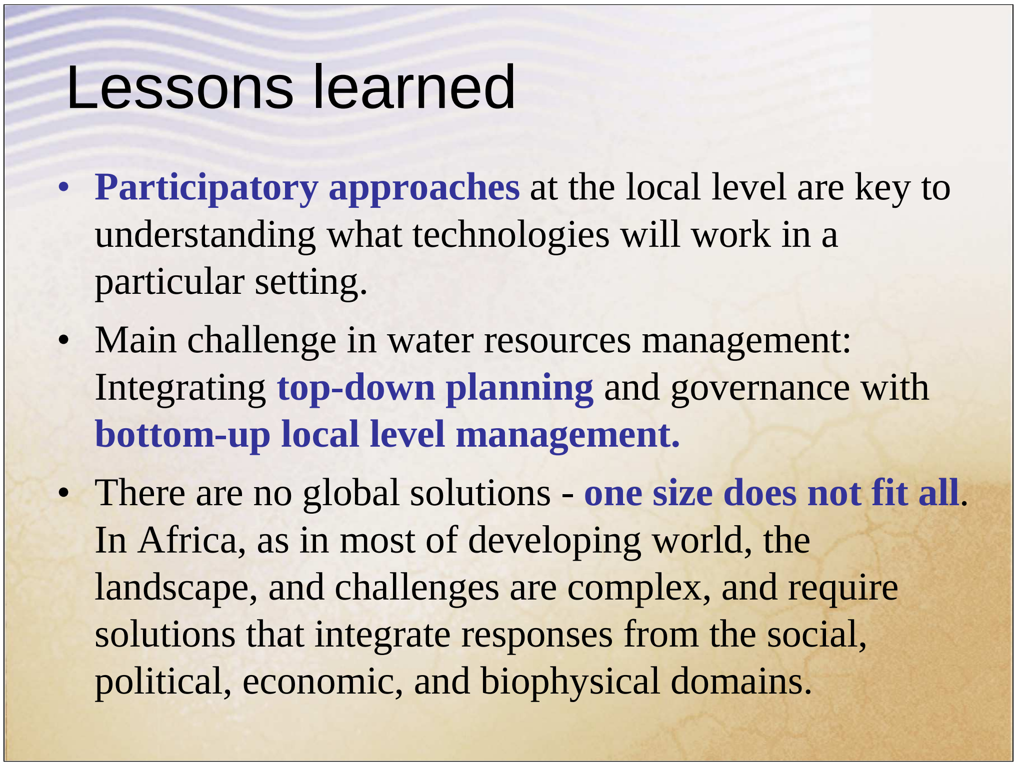
Sevilleta LTER site, central New Mexico; photo Eric Small

The U.S. has subsequently invested considerable resources in seeking scientific understandings and technical solutions to these problems. Some of this knowledge is transferable to other areas of the world. The key questions now are:

--What have we learned?

--Which cutting-edge technologies that we developed can be transferred to semi-arid and arid regions of the developing world? and

--How can these transfers be made most efficiently and effectively?



Resilience and sustainability are site-specific. Participatory approaches at the local level may be key to understanding what technologies will work in a particular setting. Adoption of technology can be affected by local cultural customs and political structures, or by lack of fit into an existing livelihood. In Sub-Saharan Africa, the introduction of superior varieties of cotton put increased pressure on local labor pools, especially female labor, and resulted in diminished child care and child nutrition.

A primary challenge in water resources management is: How can we integrate top-down planning and governance with bottom-up local level management? This topic will be addressed further today by Eugene Stakhiv.

There are no global solutions, and one size does not fit all. In Africa, as in most of the developing world, the landscape, and challenges are complex, and require solutions that integrate responses from the social, political, economic, and biophysical domains. As noted in a recent *Science* article (Brown and Funk, 2008) and follow-up by authors such as James Verdin, soon to speak (Wojtkowski, 2008), the food security problem needs more than Western agribusiness solution: it also will require good governance, appropriate interventions, safety nets, and investments during crises.

Interdisciplinarity & Collaboration

Researchers also recognize the need to work at the river **basin scale** in **multidisciplinary** teams that focus on real-world, **stakeholder-relevant** problems.

And we have a duty to:

- help **train** the present and future generations of water professionals
- **build capacity** by providing access to information, consulting, and building coordinating alliances.

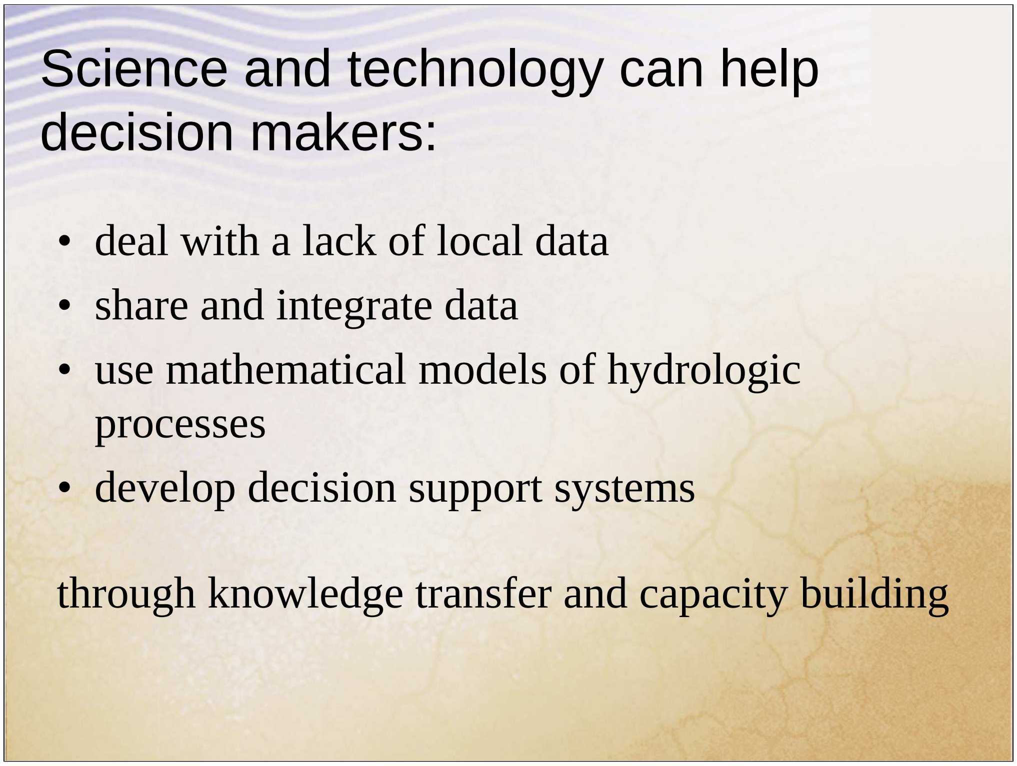
Photo: USACE Institute for Water Resources

Researchers now recognize the need to learn to work in multidisciplinary teams. focusing our research on real-world, stakeholder-relevant problems at the catchment scale. Water research is no longer informed merely by a hydrologic or engineering perspective, but benefits from the insights and knowledge of economists, biologists, geochemists, atmospheric scientists, and many other disciplines.

To further management practice and policy making throughout the developing world, we have a duty to:

--help train the present and future generations of water professionals

--build capacity by providing access to information, consulting, and building coordinating alliances.



Science and technology can help decision makers and water managers:

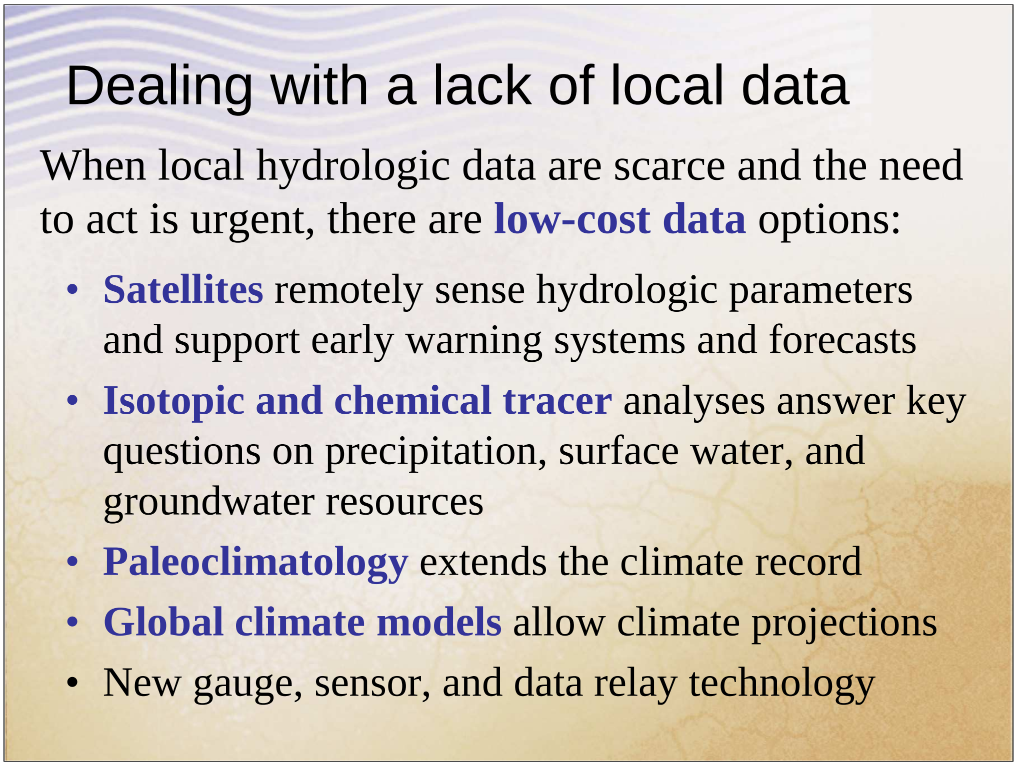
--deal with a lack of local data

--share and integrate data

--use mathematical models of hydrologic processes

--develop decision support systems

through knowledge transfer and capacity building.



When local data are scarce, there are numerous low-cost data options:

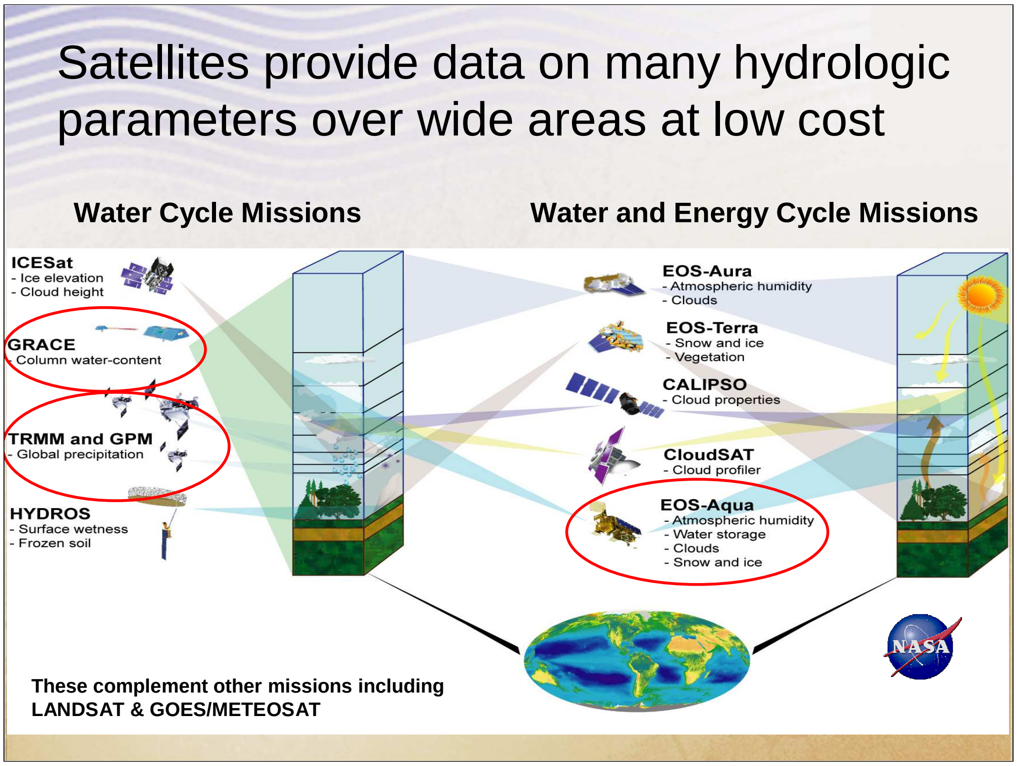
Satellites remotely sense hydrologic parameters and support early warning systems and forecasts

Isotopic and chemical tracer analyses answer key questions on precipitation, surface water, and groundwater resources

Paleoclimatology extends the climate record

Global climate models allow climate projections

New gauge, sensor, and data relay technology can help, and will be discussed later during the Water Forum.



Space age satellites that look down on Earth have significantly increased our understanding of the planet in general and its water resources in particular. They can provide data on many hydrologic parameters over wide areas and at low cost. Shown are the recent U.S. missions to understand the hydrologic cycle.

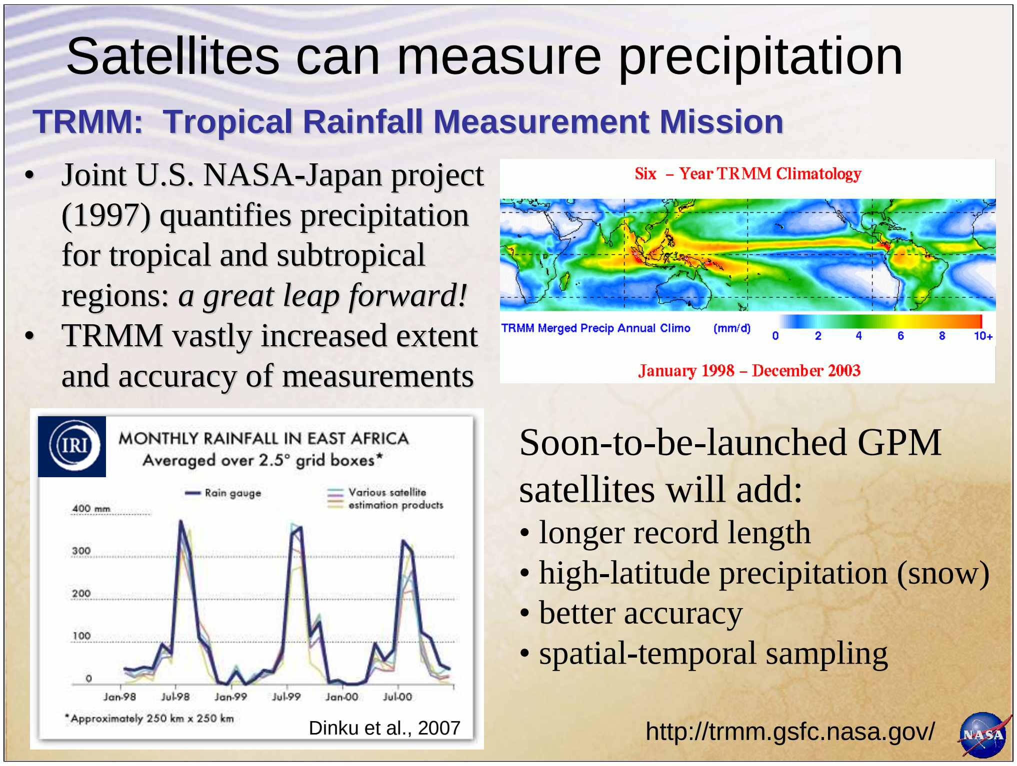
Some of the questions for which space sensors may provide information are:

--When and where is precipitation occurring? What are the amounts of precipitation? How is precipitation partitioned into runoff? Into evaporation? To infiltration?

--How much water is stored in the terrain?

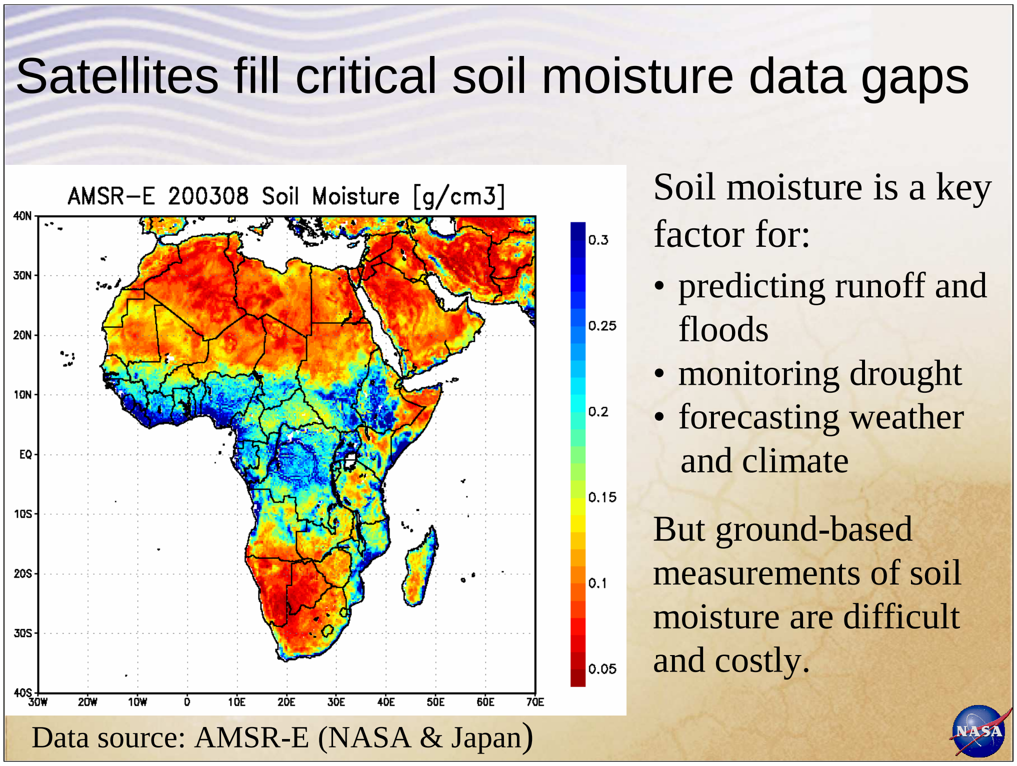
--What are the soil and vegetation conditions? Is drought a concern now or in the near future?

--How much water is available in reservoirs and lakes used for agriculture?



To increase understanding about global water, NASA initiated a research program to measure precipitation from space under its Mission to Planet Earth program. As a result, the Tropical Rainfall Measuring Mission (TRMM), a collaborative mission between NASA and NASDA (Japanese space agency), was launched in 1997 to measure tropical and subtropical rain.

TRMM is still providing valuable information on precipitation in the tropics and has become the primary satellite in a global set of satellites to observe and study precipitation characteristics and variations. Motivated by its success, NASA and NASDA are planning a new mission, the Global Precipitation Measurement (GPM) mission which will greatly enhance the ability to use the information provided for hydrologic applications such as water balance and real-time forecasting of streamflow.



Soil moisture is a key hydrologic factor for:

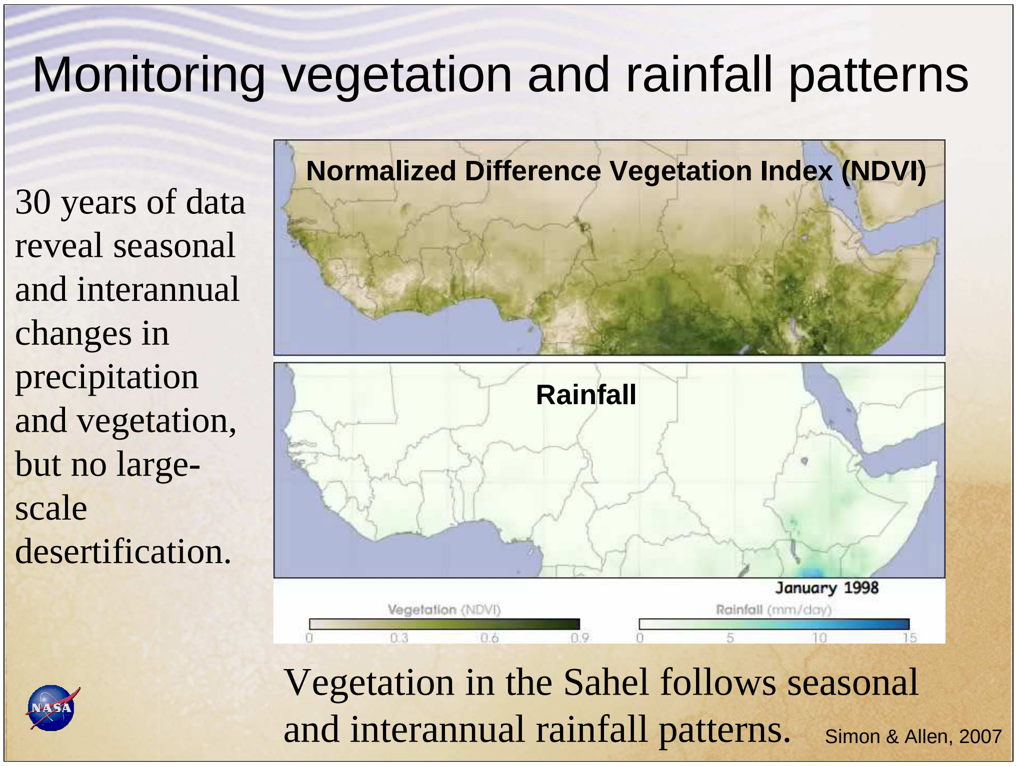
--predicting runoff and floods

--monitoring drought

--forecasting weather and climate

Ground-based measurements of soil moisture are difficult and costly, but satellites fill critical soil moisture data gaps.

The Aqua satellite-borne Advanced Microwave Scanning Radiometer for EOS (AMSR-E, http://wwwghcc.msfc.nasa.gov/AMSR/data_products.html), developed jointly by NASA and a network of international researchers, is a tool that provides soil moisture estimates—crucial for the maintenance of land vegetation and agricultural crops-- and other hydrologic information by detecting faint microwave emissions from the Earth's surface and atmosphere. AMSR-E can also measure water vapor, liquid water in clouds, precipitation, and other parameters, at a resolution that varies from 6 to 57 km. AMSR-E's monitoring of soil moisture globally should permit, for example, the early identification of signs of drought episodes.



Satellites can also provide data on vegetation change and rainfall patterns, revealing seasonal and interannual changes. This provides an improved perspective for distinguishing desertification, which is permanent and irreversible, from shorter-term changes.

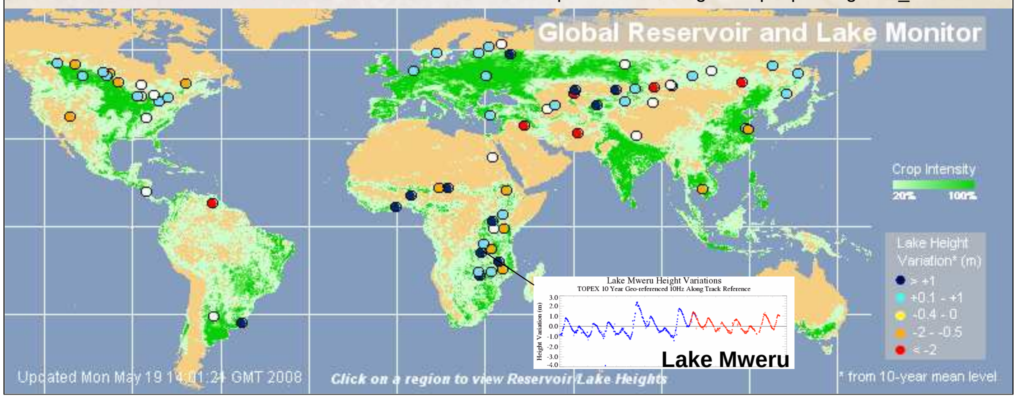
The animation, from NASA's Earth Observatory website (http://earthobservatory.nasa.gov/Library/MeasuringVegetation/measuring_vegetation_2.html), shows seasonal and interannual changes in vegetation and rainfall for the Sahel from January 1998 to June 2005. This is a segment of a larger database, which covers a 30-year period.

NDVI is calculated from the visible and near-infrared light reflected by vegetation. Maps and animation by Robert Simmon and Jesse Allen, based on GIMMS and TRMM
data,“ taken from Riebeek, H., Defining Desertification, Earth Observatory, NASA, January 3rd 2007, url:
http://earthobservatory.nasa.gov/Study/Desertification/printall.php

Monitoring reservoir and lake levels to predict crop yields

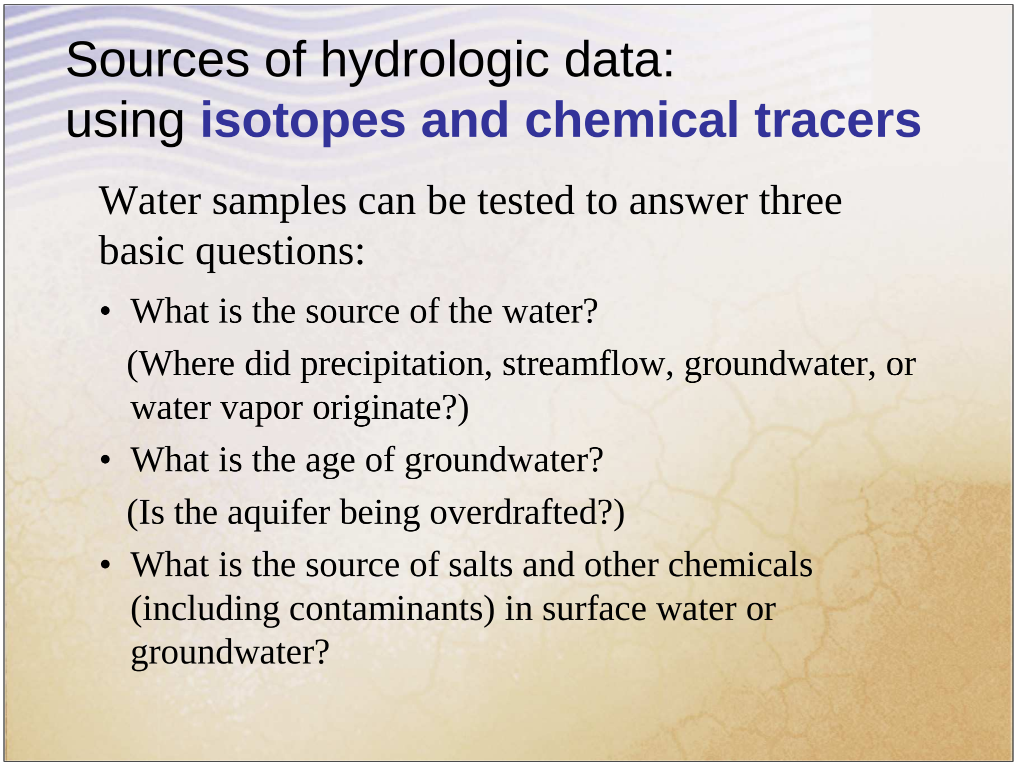
A joint project of NASA & USDA uses radar to measure the elevation and water stored in 100 reservoirs and lakes around the world that supply irrigation water.

www.pecad.fas.usda.gov/cropexplorer/global_reservoir/



Satellite sensing can also monitor reservoir and lake levels. This facilitates system-wide planning and improved water management decisions for allocating water, locating regional droughts, or improving crop production estimates for irrigated areas. Data products on water surface elevation are available on a website. This is a joint project of the U.S. Department of Agriculture's Foreign Agriculture Service, NASA, and the University of Maryland [www.pecad.fas.usda.gov/cropexplorer/global_reservoir/].

The Global Reservoir and Lake Monitor provides estimates of surface water storage by routinely monitoring height variations in 100 lakes and reservoirs around the world, allowing users to quickly assess surface water supplies. All targeted lakes and reservoirs are located within major agricultural regions.



Another way to get local data on water resources is by analyzing chemical tracers and isotopes. The International Atomic Energy Agency has worked intensely in developing these tracers and methods for isotopic analysis and in applying them to water resources. Water samples can be tested to answer three basic questions:

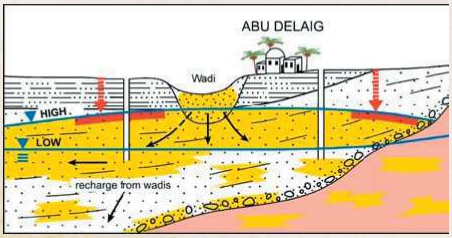
--What is the source of the water? (Where did the precipitation, streamflow, groundwater, or water vapor originate?)

--What is the age of groundwater? (Did it take hundreds or thousands of years to reach the aquifer through infiltration? If so, is the aquifer being overdrafted?)

--What is the source of salts and other chemicals in surface or groundwater? (For example, do they come from natural geochemical processes or were they introduced by humans?)

Isotopes can measure groundwater recharge

Chemical and isotopic tracers were used to measure groundwater recharge during flood events from Wadi Hawad, a tributary of the Nile, near Shendi, Sudan.



The UNESCO G-WADI network and SAHRA provide materials, resources, short courses and case studies to strengthen the capacity to manage water resources in arid and semi-arid areas.

Villagers from Abu Delaig draw water recharged from the wadi from a traditional shallow well. Photo: M. Edmunds

The flashy and unpredictable nature of precipitation in semi-arid regions makes the measurement of rainfall and surface runoff extremely difficult. Conventional, physical means for recharge estimation are often inappropriate, and in any case with large errors involved. In this case study at Wadi Hawad, near Shendi, Sudan, chemical and isotopic results are used to demonstrate where and how recharge is taking place and to consider the wider implications for water resources development in similar regions of the Sahel. (Edmunds, 2005)

Sources of hydrologic data: **paleodata**

Where the climate record is short or lacking, proxy data (tree rings, ice cores, sediment deposits, fossils, etc.) can extend the record back thousands of years to answer:

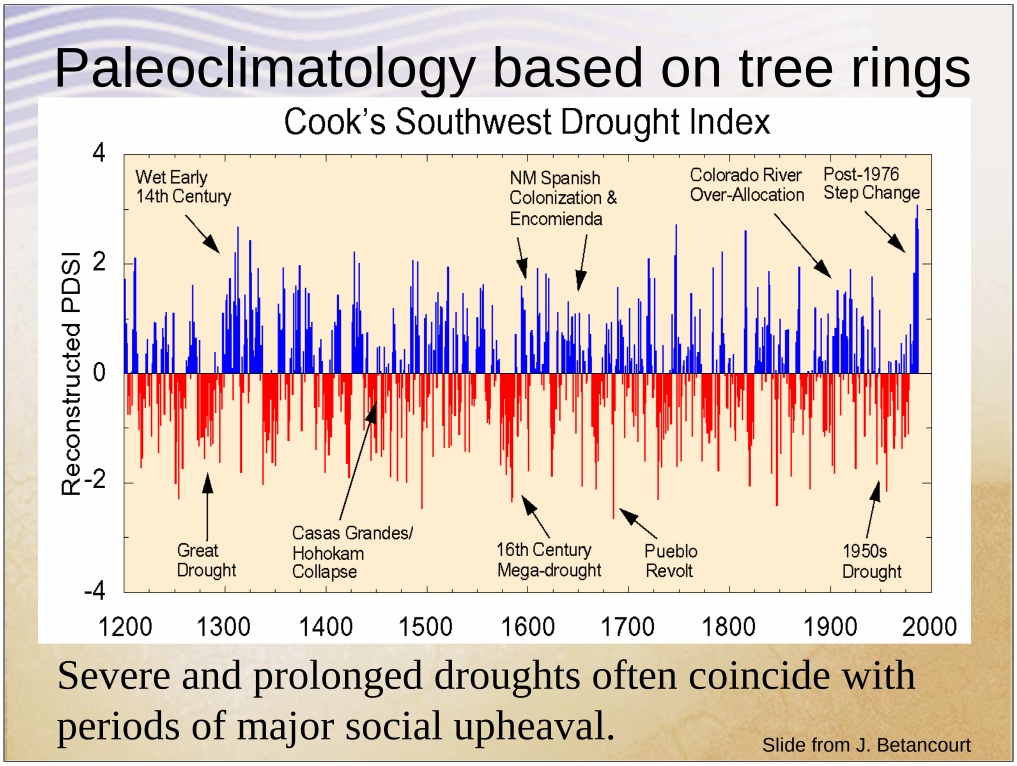
- How frequent or severe are floods and droughts in an area?
- Has drought occurred frequently in the area or is the recent drought unusual?
- Do temperature changes represent historic variability or is the climate changing?

Climate and hydrologic variability are critical factors in the appropriate management of water resources. Even in developed countries the length of the instrumental record is not long enough to allow a more accurate understanding of this variability. Paleoclimatology, the study of climate taken on the scale of the entire history of Earth, uses proxy data such as tree rings, ice cores, sediment deposits, and fossils to extend the instrument records by thousands of years. Some questions paleoclimatology can answer are:

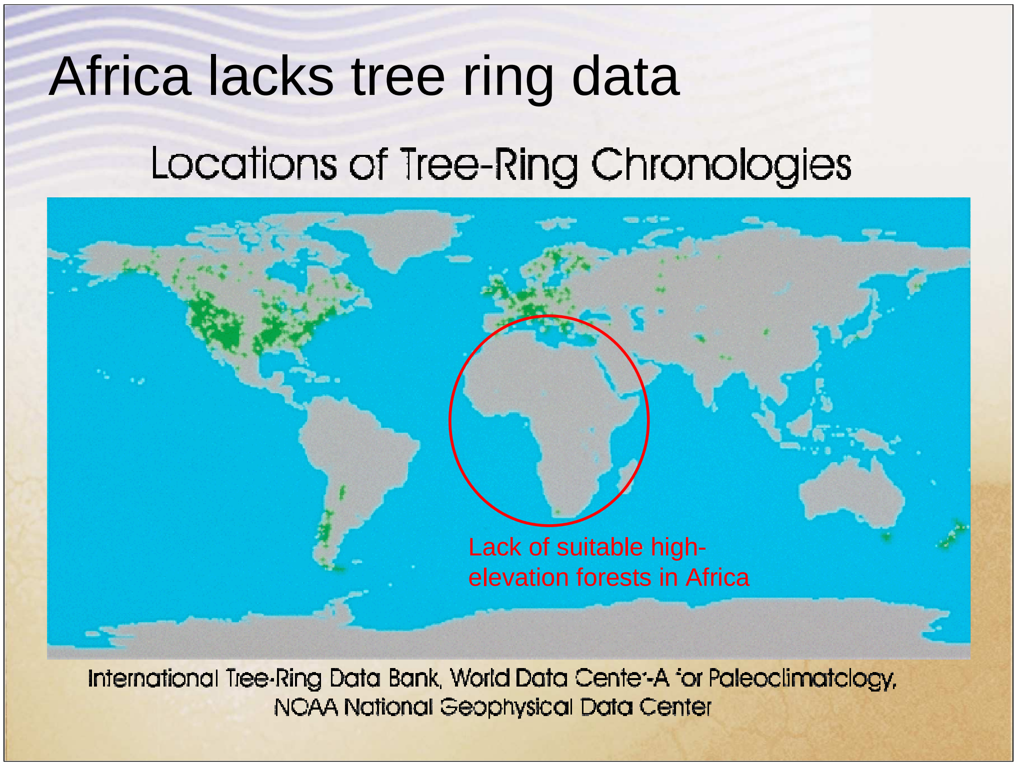
--How frequent and severe are extreme events (such as droughts and floods) in the region of interest?

--Is the current drought an example of something that occurs frequently or it has not happened in the past record?

--Do recent temperature changes represent the historic variability or do they indicate a change in the climate?

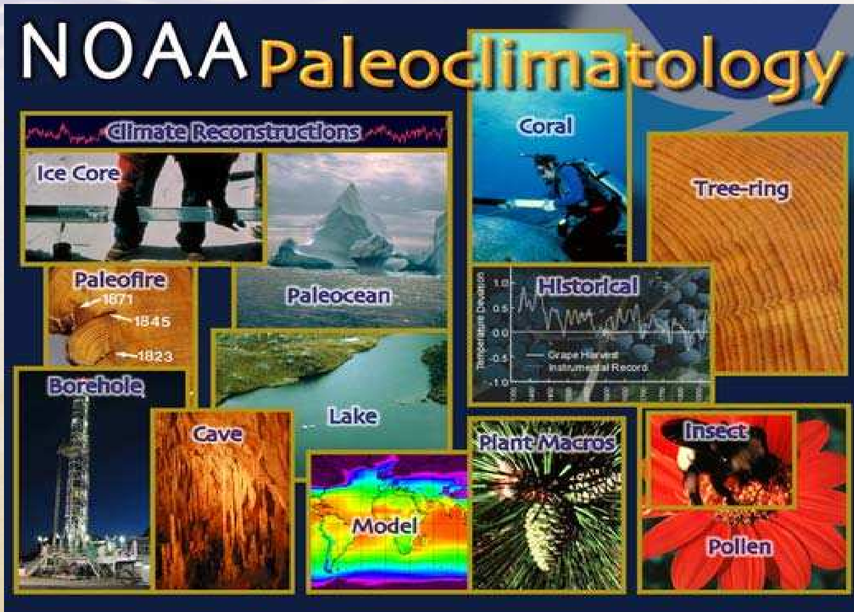


What were the impacts of significant climatic events on societies in the past? Paleoclilmatology also reveals interesting relationships of climate and human events. This drought chronology, based on the tree ring record and a reconstructed Palmer Drought Severity Index, shows a correspondence of periods of significant social upheaval and drought in the Southwestern United States.



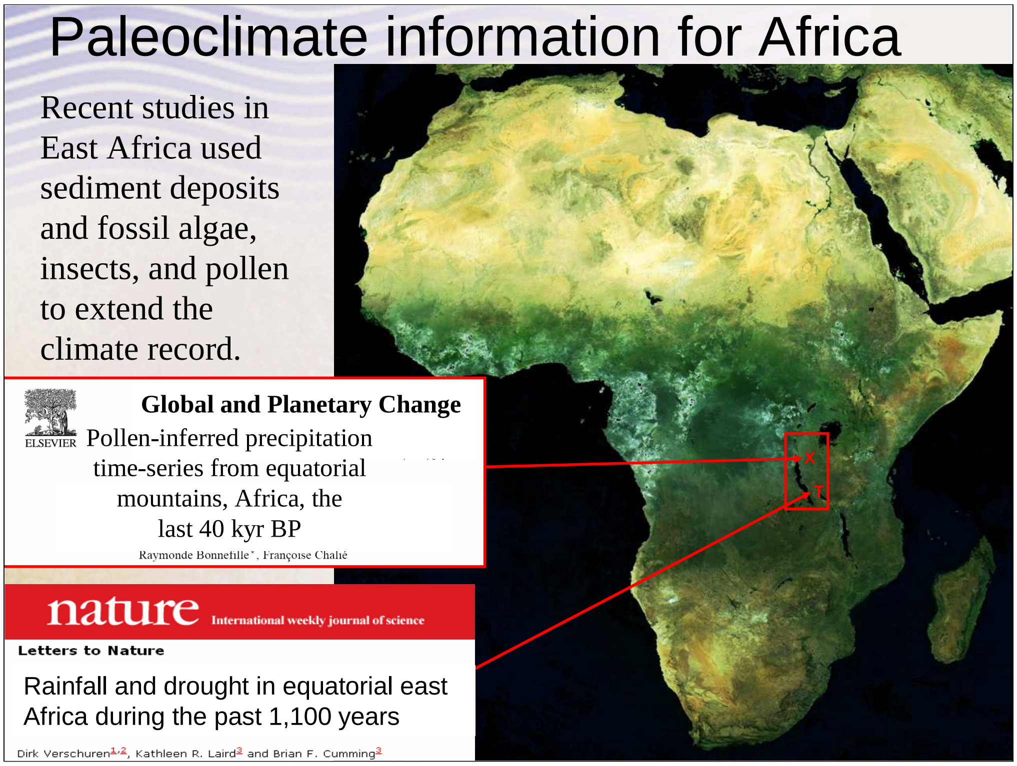
Tree ring data have predominantly been used in paleoclimatic reconstructions for North America and Europe, and to some extent in South America. But a lack of suitable high-elevation trees in Africa makes this a poor fit for climatic reconstructions in that continent. But other paleodata sources are available.

...but paleodata are available from many sources



World Data Center for Paleoclimatology, www.ncdc.noaa.gov/paleo/paleo.html

In addition to tree rings, paleoclimatology studies ice sheets, sediment deposits, and fossils to determine the past state of the climate system on Earth to better understand natural climate variability. Scientists have studied these records over large parts of the globe. A significant amount of paleoclimatic data is available through the World Data Center for Paleoclimatology at: www.ncdc.noaa.gov/paleo/paleo.html.



The climatic record of Africa has been limited because standard dating tools such as tree rings and ice cores have limited applicability in tropical regions. But recent studies have been filling in the paleoclimate record:

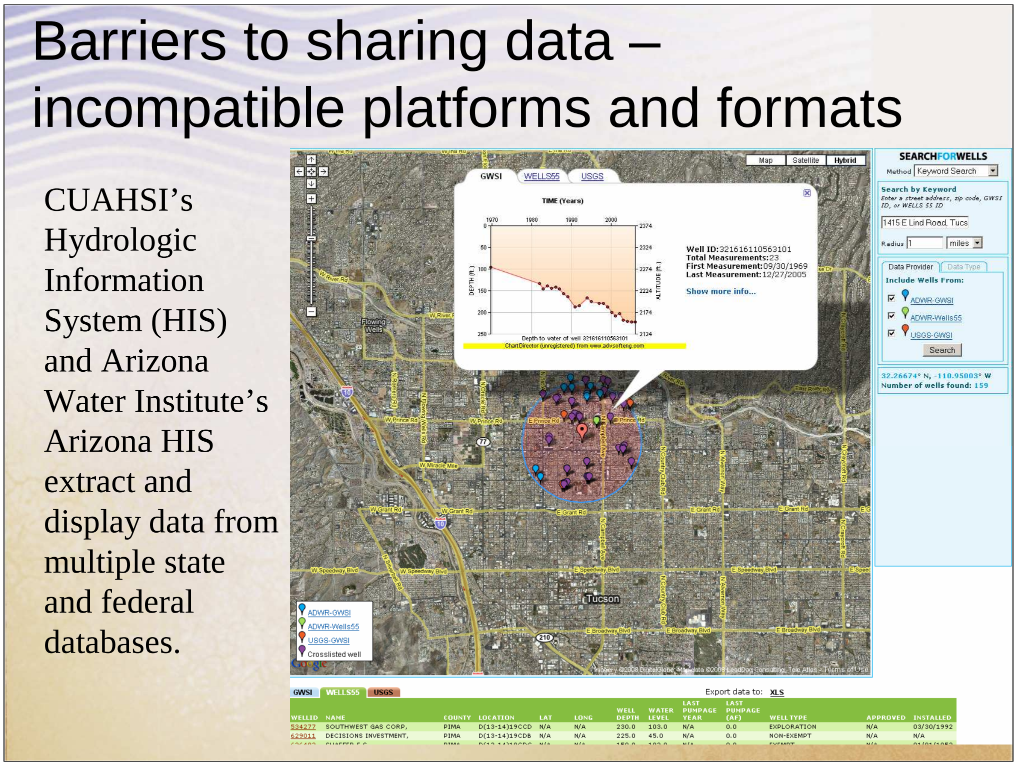
--The precipitation in central east Africa was reconstructed from fossil pollen to 38,000 BC (Bennefille and Chalie, 2000)

--For another region in equatorial east Africa, lake levels and salinity fluctuations were reconstructed for the past 1,100 years, from sediment deposits and algae/insect fossils (Verschuren, 2000)

Science and technology can help decision makers:

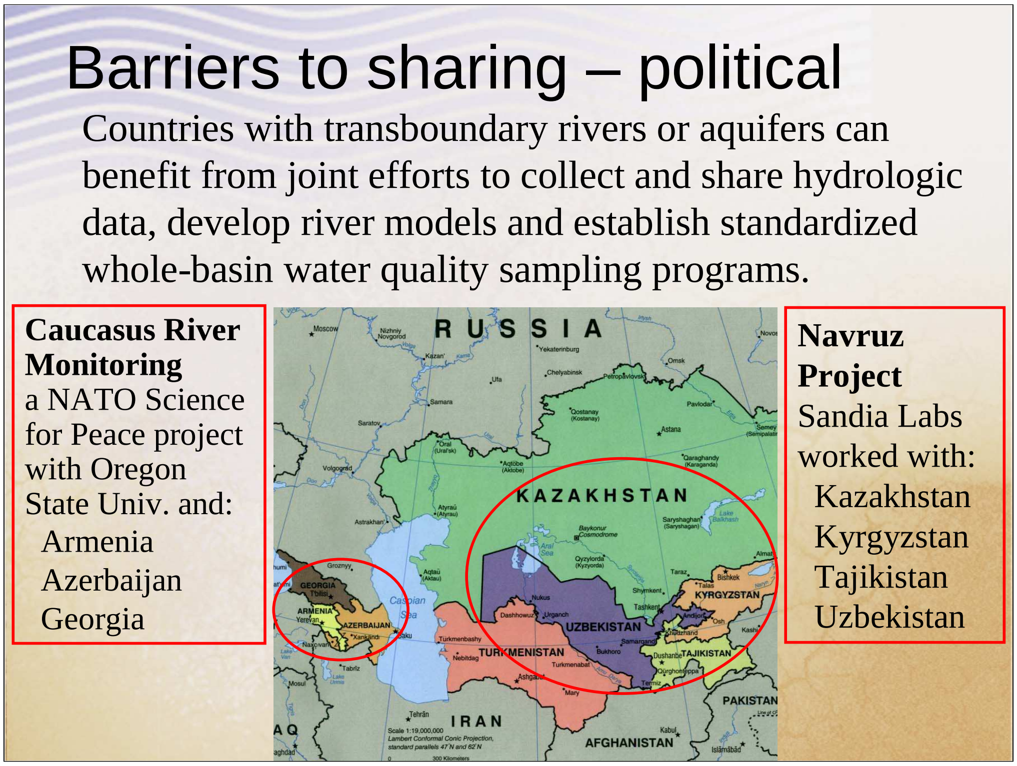
- deal with a lack of local data
- share and integrate data
- use mathematical models of hydrologic processes
- develop decision support systems

through knowledge transfer and capacity building



One major barrier to data sharing is the incompatibility of computer platforms and database formats used by the many agencies that gather hydrologic information. Concerns regarding data security and integrity also have proven to be stumbling blocks. Past proposals to deal with this problem generally failed, because they required agencies to abandon their current database structures and adopt a uniform structure.

A promising new approach to data sharing allows all agencies sharing data to retain their current database software and formats, preserving database integrity and security. Web services respond to data queries by accessing data from a variety of platforms and databases, and visualize the data using maps, graphs, and tables. The NSF-supported Consortium of Universities for the Advancement of Hydrological Sciences, Inc. (CUAHSI) has developed a Hydrologic Information System (HIS) that taps water data from seven federal agencies and a number of research sites; the Arizona Water Institute has supported development of a state analog, the Arizona HIS.

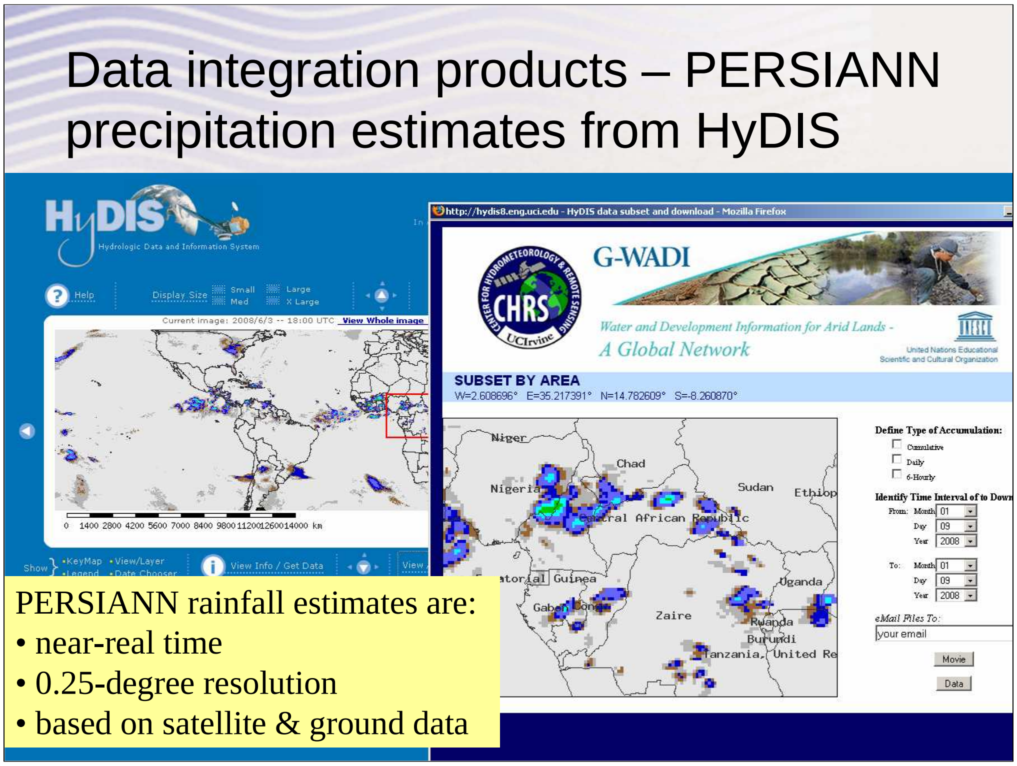


Another major barrier to data access in much of the world is the reluctance of agencies and organizations to share data, for a variety of reasons. Barriers to data sharing are particularly acute when they involve transboundary rivers or aquifers. Countries that share water resources can benefit from joint efforts to collect and share hydrologic data, develop river models, and establish standardized whole-basin water quality sampling and testing programs.

Two examples of successful international data cooperation:

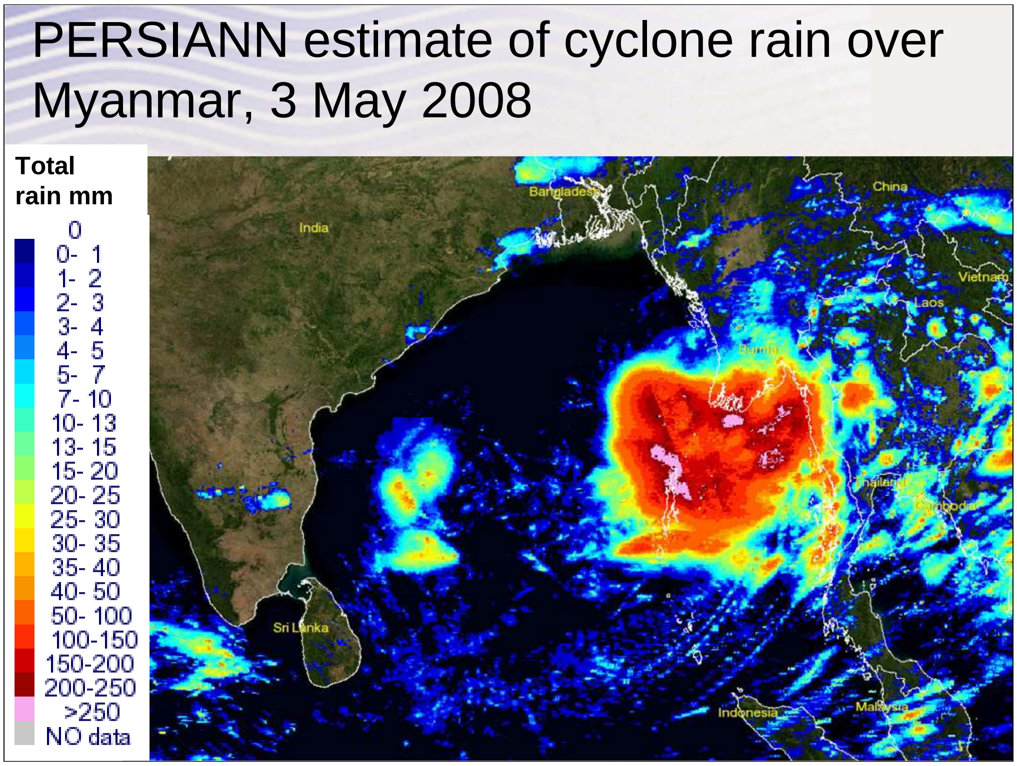
The **Navruz Project** is a cooperative, transboundary river monitoring project involving rivers and institutions in Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan. Facilitated by Sandia National Laboratories, this project (Passell et al., 2008) employed former nuclear weapons scientists in monitoring, data collection, data sharing and modeling of rivers through standardized, whole-basin sampling and analysis to identify radioactive materials that had been mined, fabricated, transported, and stored during the time of nuclear proliferation. Participants have identified sources and hot spots and are incorporating results into models for water resource managers to use. The project has improved communication and cooperation among Central Asian nations, furthering regional stability. See https://waterportal.sandia.gov/centasia/documents/Barber%20et%20al.%202004.pdf

The **South Caucasus River Monitoring** project, led by Michael Campana at Oregon State University, involves scientists from Georgia, Armenia, and Azerbaijan in addressing common problems related to municipal, agricultural, and industrial pollution of the shared Kura and Araks rivers. Solving these problems helps to further social and economic development in the region and resolve political instability in a region that would be worsened by water disputes. This effort became a NATO Science for Peace project. See http://www.kura-araks-natosfp.org/



Having access to raw data is not sufficient for most applications; data integration products are needed that make use of the different datasets to provide a final product. Some examples are PERSIANN and the climate reanalysis efforts underway in the United States and Europe.

The Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine created HyDIS and PERSIANN (http://hydis8.eng.uci.edu/persiann/), two systems that work together to fill the need for more accurate representation of precipitation, from torrential rains to localized monsoon rains, at a very high resolution and with much more accuracy than radar. Radar depicts atmospheric moisture but does not accurately show where the precipitation is falling to earth and cannot be used over the ocean.

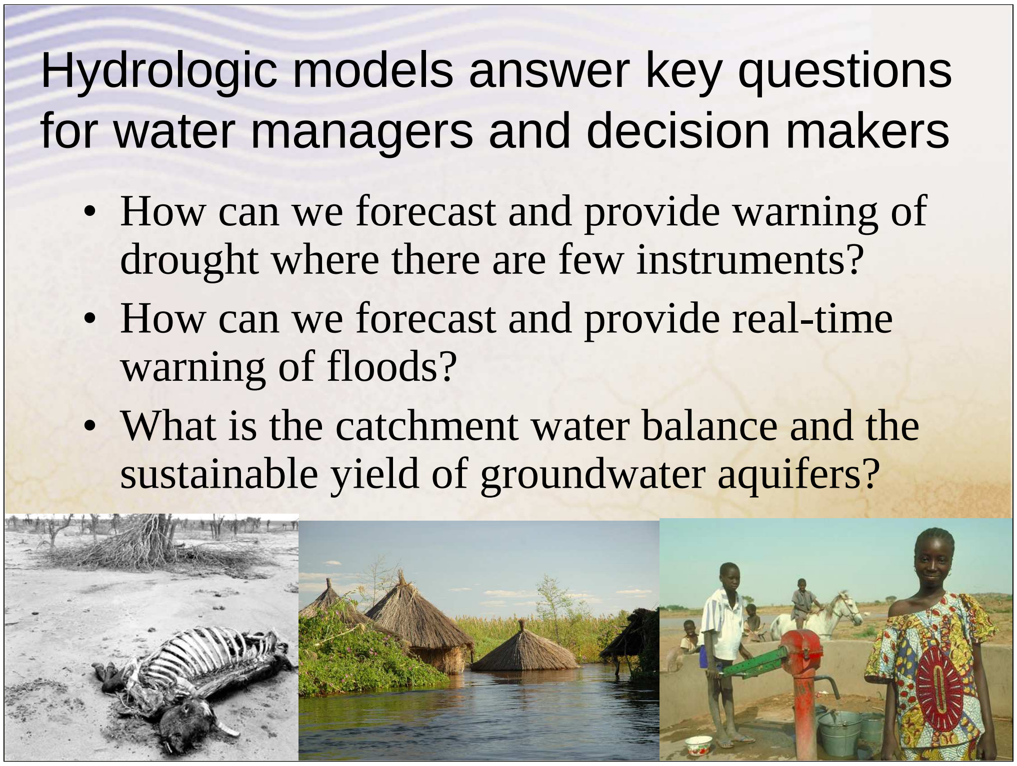


Satellite remote sensing, numerical regional climate modeling, and computer visualization can give near-real-time representations and estimates not just of precipitation, but other meteorological data such as temperature, humidity, and winds. The image shows the estimated precipitation associated with Cyclone Nargis, which struck Myanmar May 3, 2008, as captured by PERSIANN.

Science and technology can help decision makers:

- deal with a lack of local data
- share and integrate data
- use mathematical models of hydrologic processes
- develop decision support systems

through knowledge transfer and capacity building



The information provided by the sensors and models already described are used in hydrologic models that mathematically represent the water balance in a river catchment. Hydrologic models provide water resources managers and decision makers with a clearer understanding of components of the hydrologic cycle and the impact that actions, both human-caused and natural, have on this balance. The models provide further information to answer the following questions:

--How can we forecast and provide early warning of drought conditions (their magnitude and spatial extent) in areas where there are few ground sensors?

--How can we forecast and provide early warning of floods, their magnitude, and spatial extent?

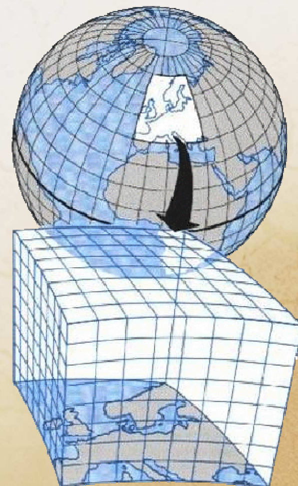
--What is the catchment water balance and the sustainable yield of groundwater aquifers?

GCMs provide critical inputs for predicting climate changes

Global Climate Models (GCMs) model the dynamics of:

- atmosphere
- ocean
- land surface
- vegetation

Understanding the energy exchange is important in simulating past and predicting future climate.



www.uib.no/People/gbsag/bcm.html

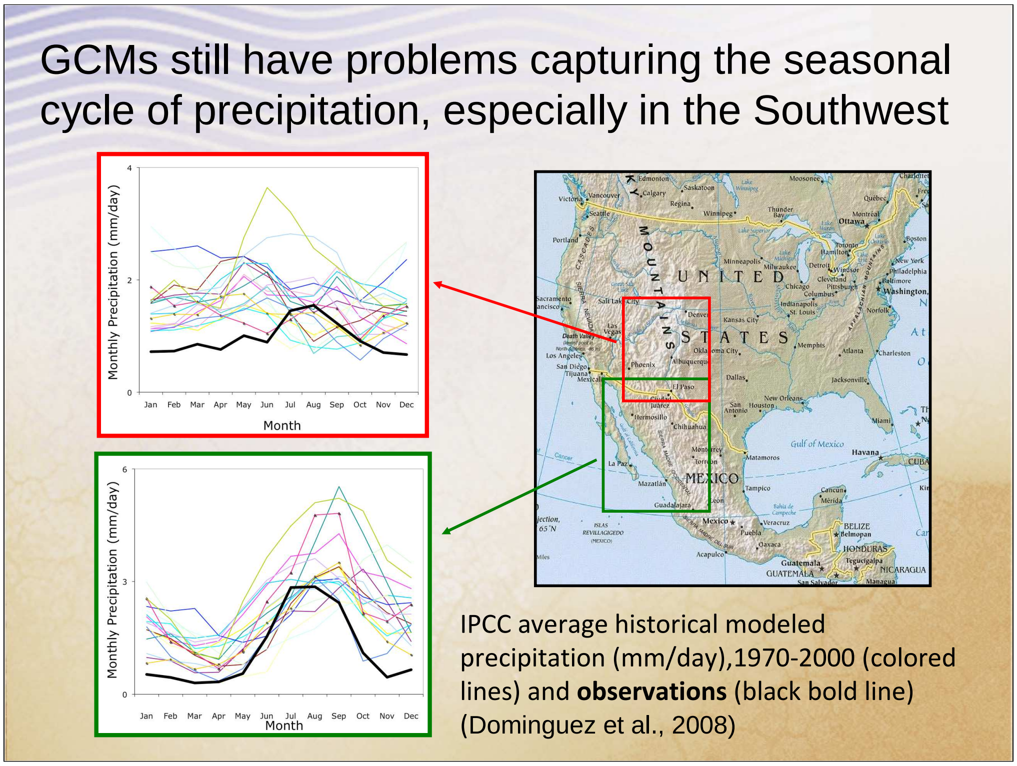
Global Climate Models (GCMs) provide critical inputs for predicting climate changes. GCMs are computer models that can simulate the Earth's past and future climate, accounting for the dynamics and energy exchange among land masses, oceans, and the atmosphere (also energy from the sun and losses to outer space). Understanding this energy exchange is important in understanding and predicting climate: the oceans store the earth's heat, which drives wind and atmospheric circulation, which in turns controls climate.

Some of the questions that GCMs can address are:

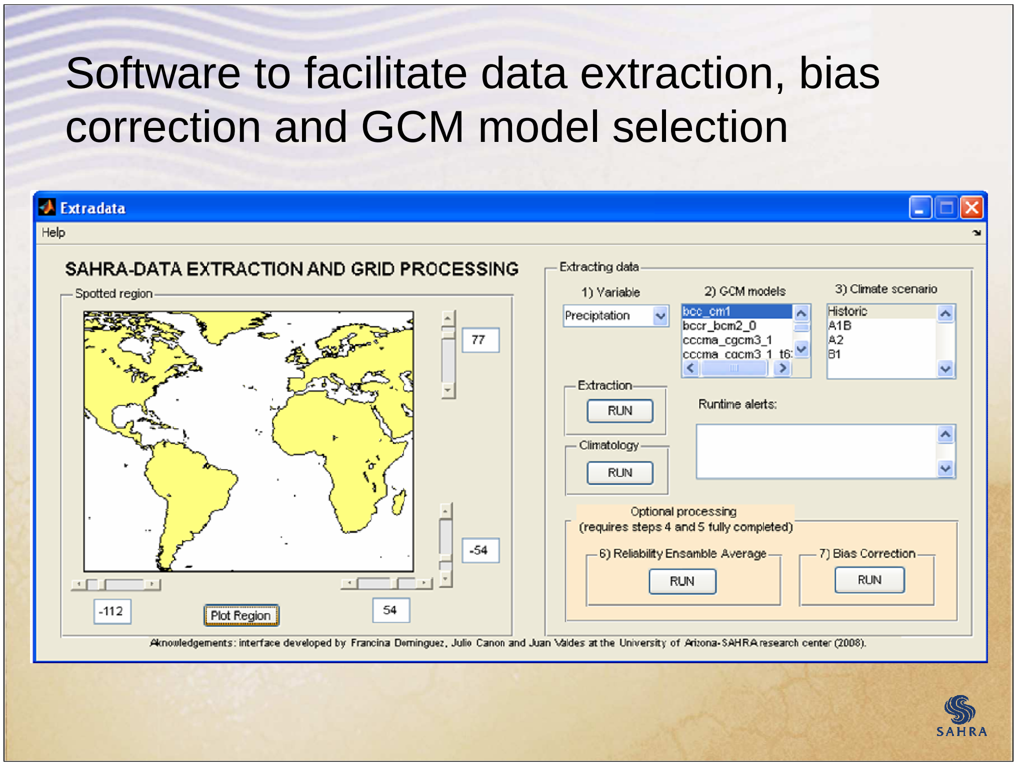
--What is the precipitation, temperature, and evapotranspiration in different parts of the planet?

--How can movements of air, energy masses in the globe be quantified?

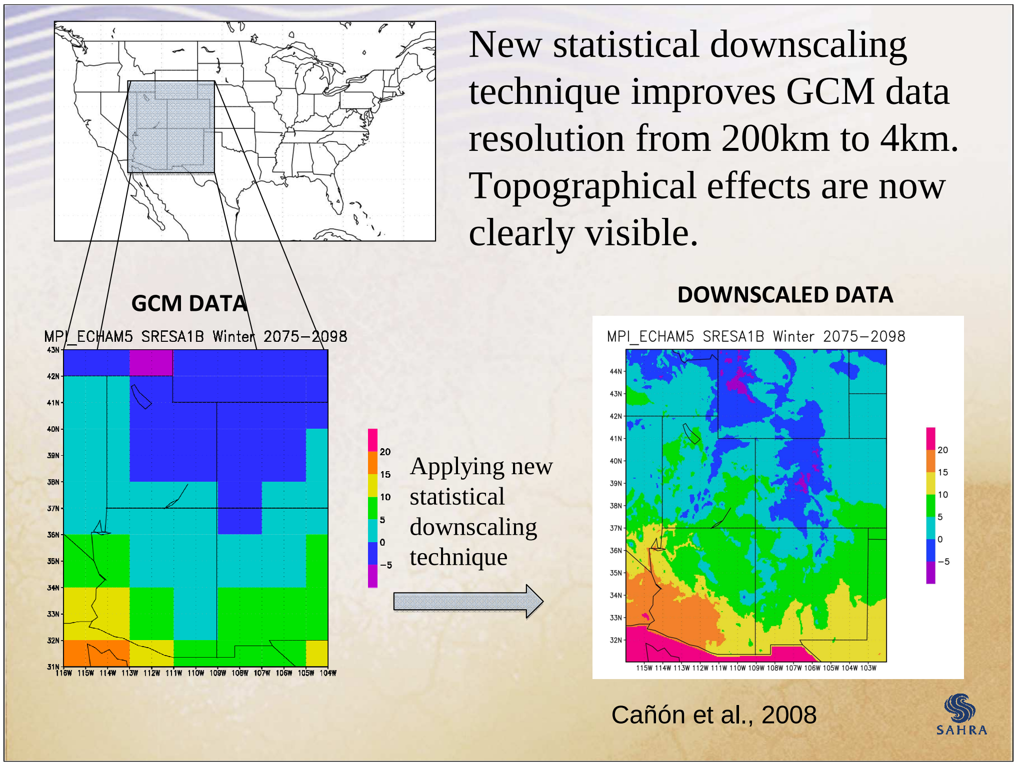
--How will the planet respond to increased greenhouse gases, and changes in vegetation cover?



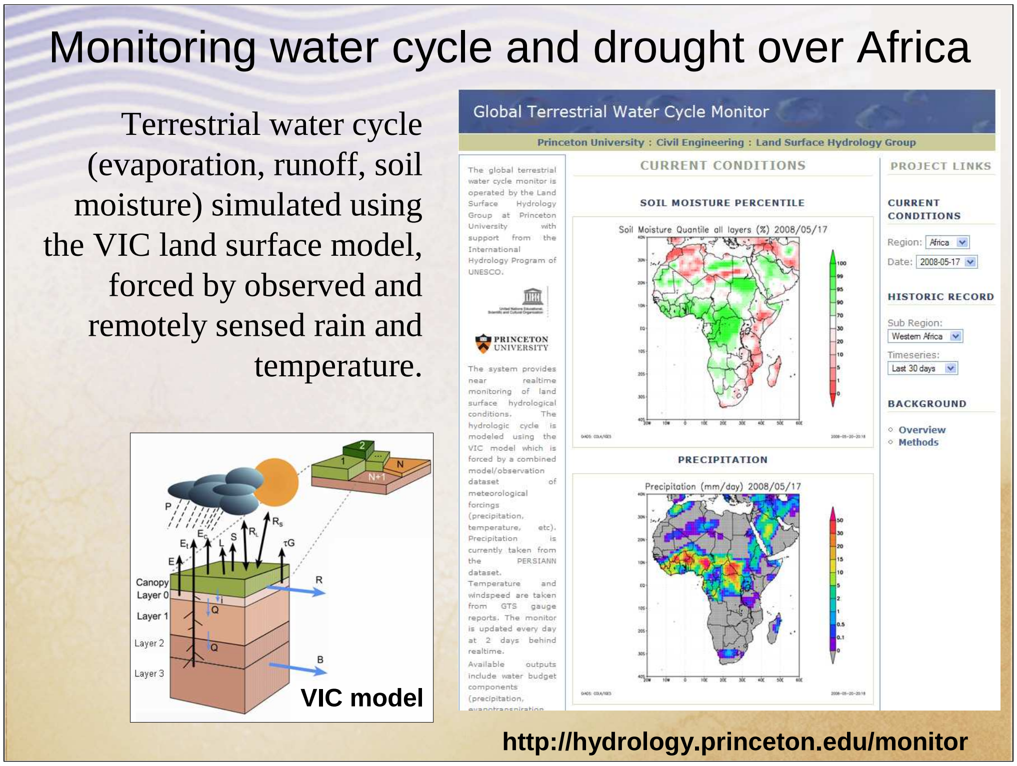
Global climate models still have problems capturing the seasonal cycle of precipitation in some areas of the world, particularly the southwestern United States, which is a transition zone for the North American monsoon. The top graph shows, in colored lines, the modeled historical precipitation for the Southwest, as compared with actual observations (the black line). In comparison, the region just south of this, shown in the lower graph, is fairly well represented by global climate models.



New software developed at the University of Arizona can help correct bias by taking into account large-scale climate oscillations such as those resulting from the El Niño Southern Oscillation. For further information, email jvaldes@u.arizona.edu.



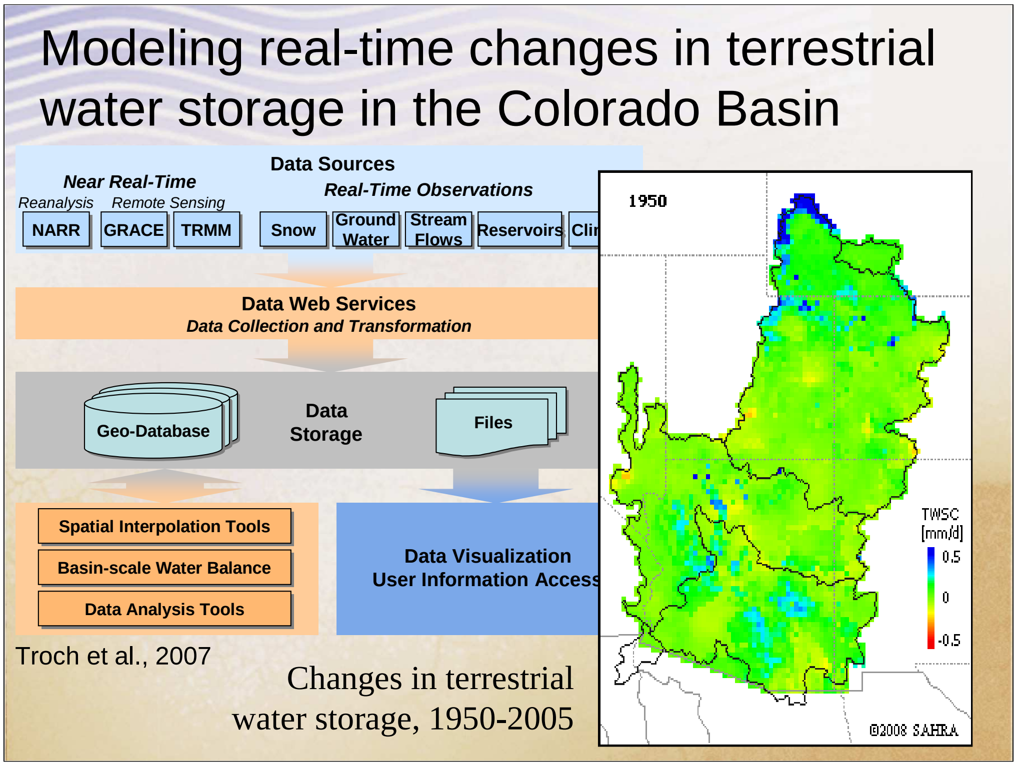
Using historical climate data and climate model scenarios from the IPCC, which take into account topography and large-scale climate fluctuations, future climate can be projected on a regional basis, with very promising results. This methodology can be transferred anywhere in the world, and is particularly useful in regions affected by large-scale patterns such as the El Niño Southern Oscillation (ENSO), which affects both East Africa (where conditions become wetter than normal) and south-central Africa (where conditions become drier than normal).



Researchers at Princeton University have developed an experimental method to monitor drought, based on large-scale hydrologic modeling, which provides near-real-time monitoring of the global terrestrial water cycle. Products include monitoring and visualization of current conditions for soil moisture, precipitation, temperature, wind, evaporation, runoff, baseflow, soil moisture at three levels, and snow, for Africa and the entire globe, along with the historic record for the last decade. UNESCO supported the African part of the project. The products are available at *hydrology.princeton.edu/monitor/*.

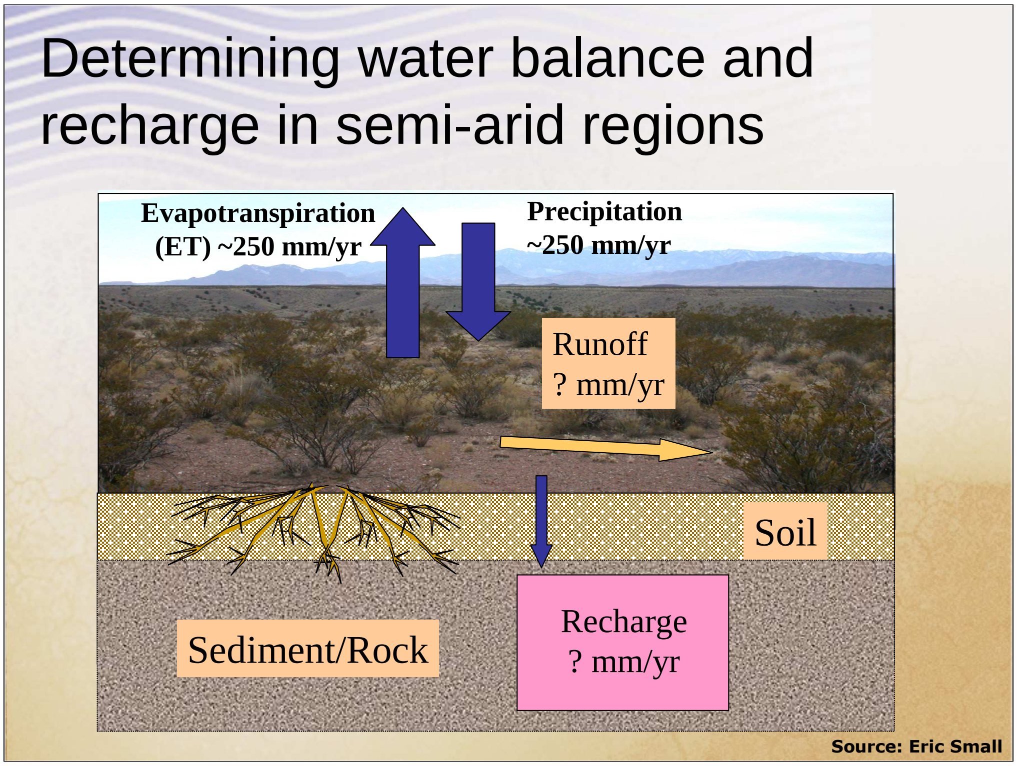
This effort uses 50-year simulations of terrestrial hydrology combined with observational datasets. Such simulations offer a way of analyzing historical soil moisture over large time and space scales in the absence of direct observations. This type of modeling helps to allow early forecasting of drought in many parts of the world, such as Africa, where large-scale observations of hydrologic variables are lacking (Sheffield et al., 2006).

The National Integrated Drought Information Service (NIDIS) and the International Institute for Climate and Society (IRI) also have extensive projects that address climate forecasts and outlooks, particularly for droughts. Details on these products will be presented by James Verdin of the U.S. Geological Survey.

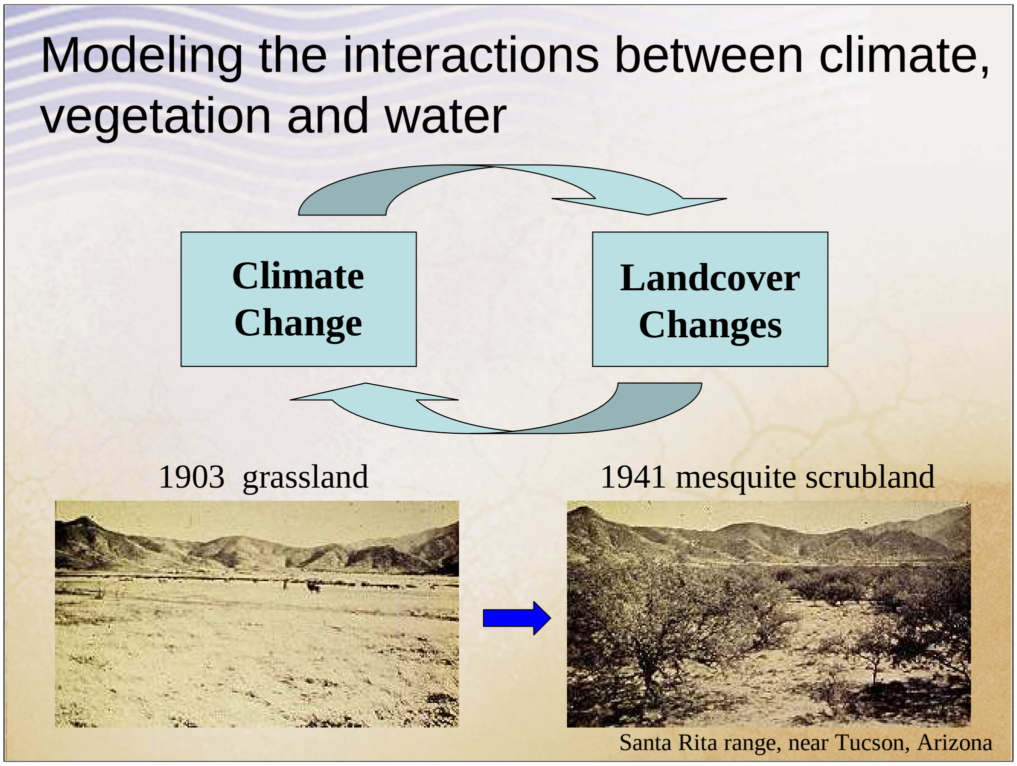


As mentioned before, satellites can provide information on the location and magnitude of water sources that are not readily available, due to the lack of ground measurements in developing countries. A group at the University of Arizona is the first to use GRACE satellite data to develop a real-time system to monitor terrestrial water storage (TWS) at the scale of large river basins (Troch et al., 2007). TWS consists of surface water, snow, soil moisture, groundwater, and water vapor. Better estimates of TWS will greatly enhance our ability to predict streamflow at seasonal and annual time scales.

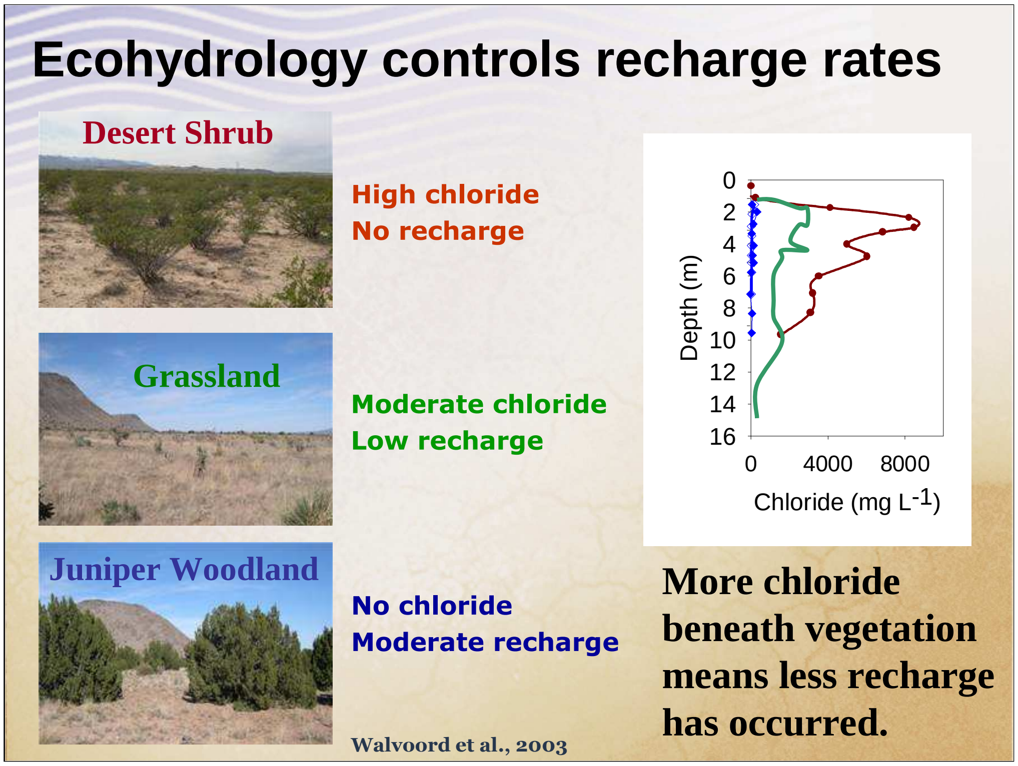
The TWS monitoring system uses data web services to automatically pull several data sets into a geographic database. After processing the data into the proper formats, the data are stored, then coupled with the different models to estimate TWS dynamics. The data are collected daily and models are run every two weeks to provide biweekly estimates of TWS changes. The animation shown is from a database that covers the years 1950 to 2005. Red areas show reductions in stored water, while blue areas show increases.



To improve water resource management at the catchment scale, one needs to understand hydrologic inputs and outputs, expressed as a basic water budget. Understanding how much water is lost to the atmosphere as water vapor, through evaporation and transpiration, allows us to understand how much is gained (or recharged) in an aquifer and determine a sustainable yield for pumping groundwater. In arid and semi-arid regions, nearly all of the precipitation is lost to the atmosphere through evaporation and transpiration, with very little recharge.



A great deal of research has focused on how climate change and resulting changes in precipitation and temperature will affect land covers. SAHRA has investigated the other half of this relationship: how these changing land covers will alter the partitioning of precipitation into plant evapotranspiration, runoff, streamflow, and groundwater recharge.



Chloride accumulations in soil cores from beneath different land cover types reveal how much recharge has occurred.

As climate change alters vegetation, the vegetation alters the amount of groundwater recharge that occurs.

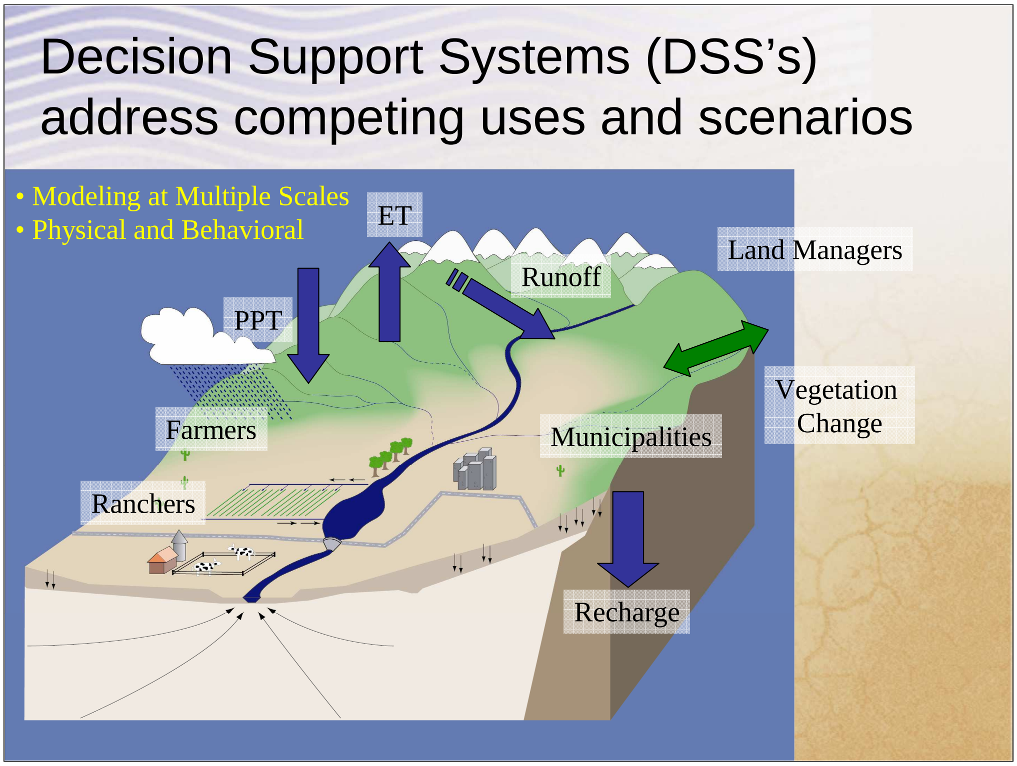
Science and technology can help decision makers:

- deal with a lack of local data
- share and integrate data
- use mathematical models of hydrologic processes
- develop decision support systems

through knowledge transfer and capacity building

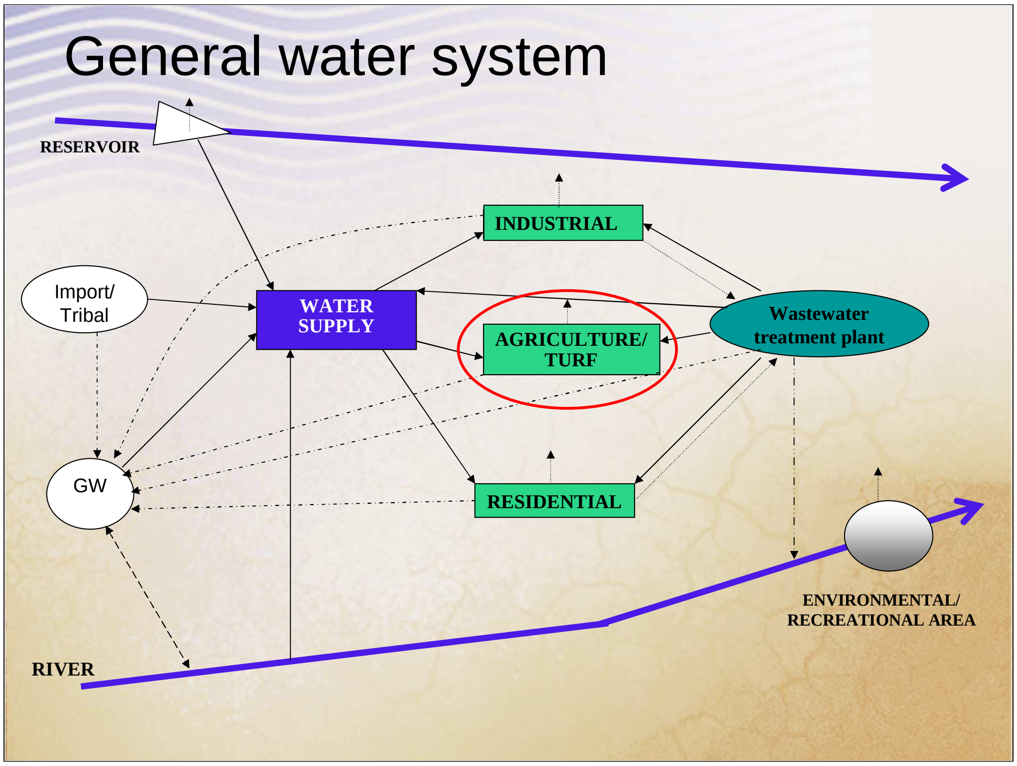
Problem: competing demands on limited resources

Water resources problems are perceived differently by different populations and interest groups, who have competing needs for the water resources, such as farmers, manufacturers, recreationists, and environmentalists. Decision support systems (DSSs) can bring together competing groups to help them address and resolve these problems.



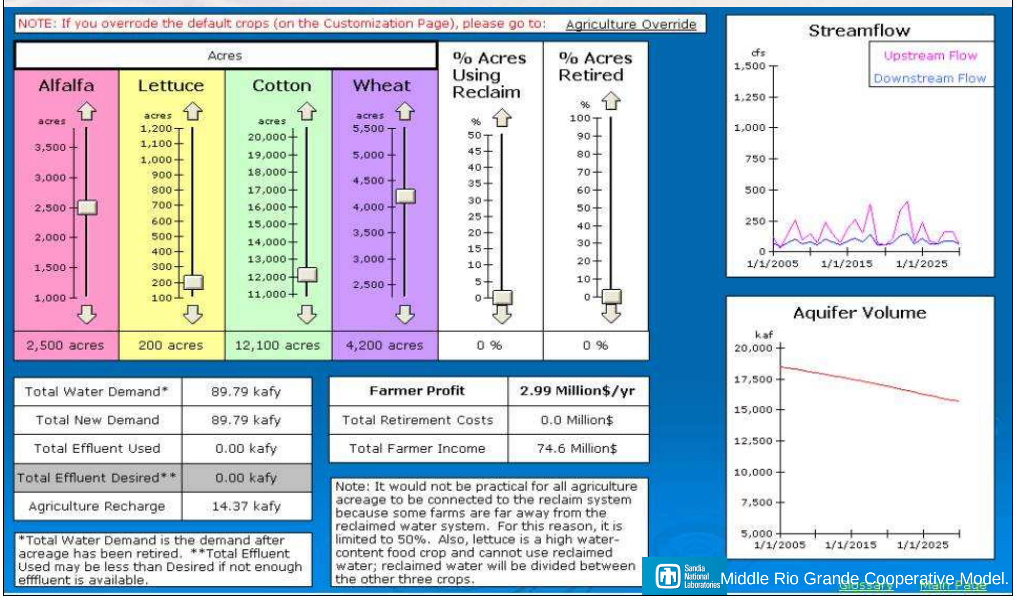
DSSs are computer-based tools that allow stakeholders to evaluate options, as in water management, based on a variety of plausible scenarios. DSSs help both scientists and the stakeholders they serve focus data collection and research on real-world information needs and applications. They also integrate research results from multiple studies in ways that are useful to water managers. DSS models, along with broad stakeholder involvement, fairness in representation, and an open process and significant science inputs, enable collective sustainability. The process can produce increased understanding - both social and ecological - among stakeholders, as well as lessons learned in the process. (Serrat-Capdevila et al., 2008)

The complexities of water management planning in the Middle Rio Grande led to the development of a water resources model to assist in community-based planning for a three-county region centered on the Rio Grande.



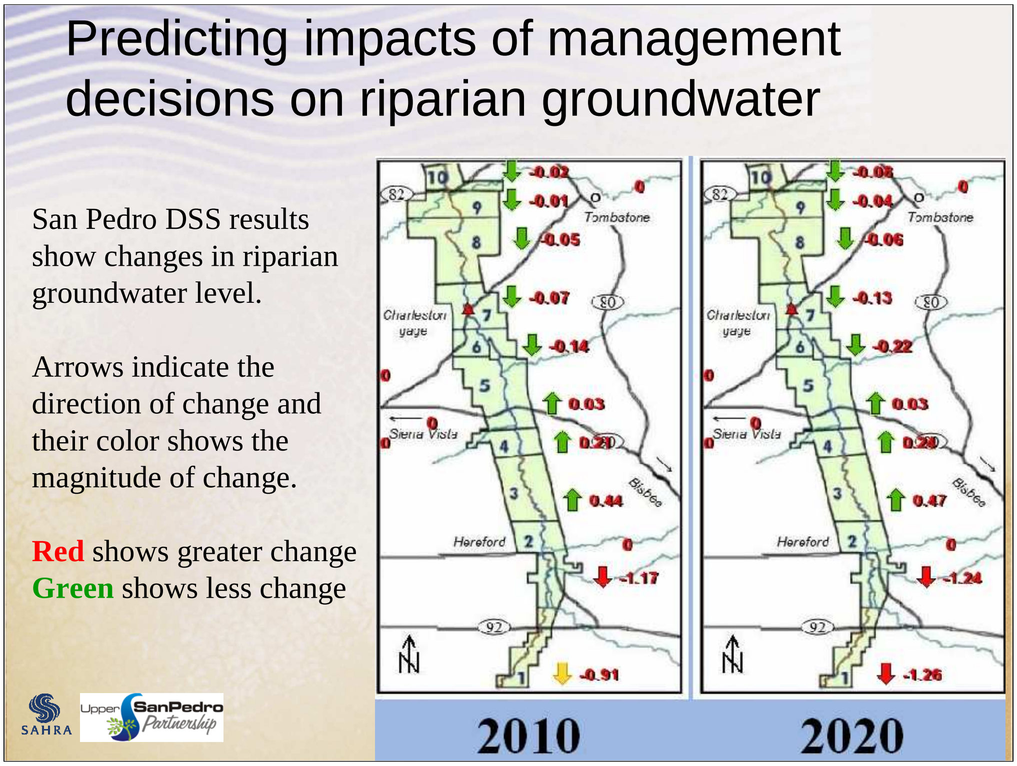
The overall structure of a dynamic simulation model reflects the underlying physical reality. Here, boxes and circles represent water demands and water sources, while arrows represent flows of water. Let's focus on the agricultural demand sector.

Tradeoffs and long-term impacts of water-use decisions in agriculture



Within a particular area of interest, DSSs allow close examination of the impacts of particular water-use decisions.

Shown here is a segment of a DSS that looks closely at agricultural concerns. By manipulating the slider bars, the user can see how policy variables such as crop choice and water source can impact streamflow, recharge to the aquifer, and their crop yield and profits. For more information, see Tidwell, V.C., H. D. Passell, S. H. Conrad and R. P. Thomas (2004) System dynamics modeling for community-based water planning: Application to the Middle Rio Grande, Journal of Aquatic Sciences 66:357-372



A long-standing scientific collaboration between the UA and the Upper San Pedro Partnership (USPP) led to the development of a DSS model that had significant stakeholder involvement. USPP is charged with developing a plan to ensure the long-term sustainability of the San Pedro River in southern Arizona and includes representation by municipalities, state and federal agencies, NGOs, environmental organizations, and water districts. The DSS fulfills the need of the USPP to handle large amounts of information and evaluate different water conservation measures, management strategies and policies in a user-friendly way. Results of the impacts of different development scenarios for the regions have been evaluated by the DSS and will allow development of a formal plan for maintaining the riparian corridor and habitat, by assessing recharge alternatives among other development scenarios. For more information, see: Yalcin D. and K. Lansey (2004) Evaluation of Conservation Measures in the Upper
San Pedro Basin, in Critical Transitions In Water And Environmental Resources Management, ASCE, pp. 1-9

Shown are San Pedro DSS results that illustrate changes in riparian groundwater level under a particular management scenario. Arrows indicate the direction of change and their color shows the magnitude of change. Red represents greater change, and green smaller change.

Fouta Djalon region of Senegal Basin; photo by Aleix Serrat-Capdevila

The methodology developed in the San Pedro DSS is being extended to Africa through a new partnership between the University of Arizona (UA) and the Organisation pour la Mise en Valeur du Fleuve Senegal (OMVS), an organization including Mali, Mauritania, Senegal, and Guinea to manage the Senegal River Basin to promote self-sufficiency in food, improve the income of the local populations, and preserve the natural ecosystems.

An interdisciplinary team of physical and social scientists from the UA working closely with experts and institutions from OMVS member states will use the latest technologies to assess climate and hydrology dynamics; environmental change (land use/land cover); irrigation; public health; socioeconomic change; and natural resource management. The UA program review on climate and hydrology includes variations in seasonal and inter-annual rainfall regimes and overall climate change impacts on the hydrology of the Senegal River Basin, using global climate models and IPCC scenarios.

Science and technology can help decision makers:

- deal with a lack of local data
- share and integrate data
- use mathematical models of hydrologic processes
- develop decision support systems

through knowledge transfer and capacity building

Knowledge transfer and capacity building can be achieved through:

- Information sharing
- Hydrologic modeling tools
- Short courses and workshops

Many initiatives and programs are underway to facilitate the rapid transfer of new scientific understandings and cost-effective cutting edge technology to water professionals and other decision makers in arid and semi-arid regions. These include:

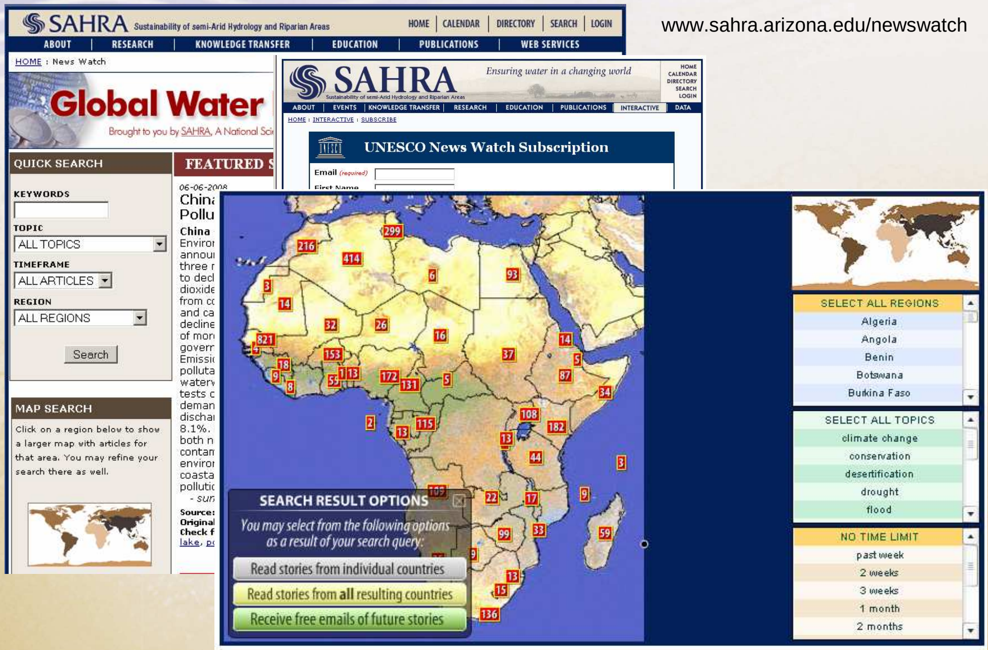
--information sharing

--hydrologic modeling tools

--short courses, workshops, and other training

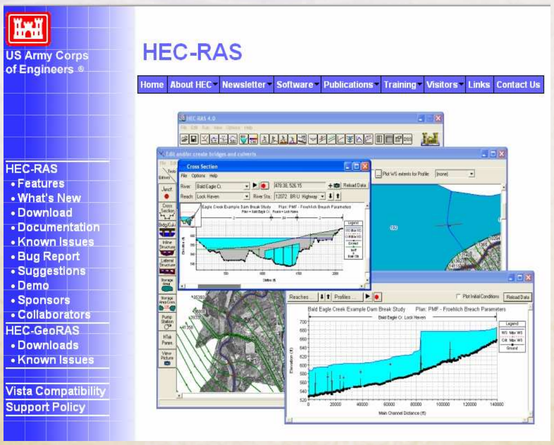
Information sharing: Global Water News Watch

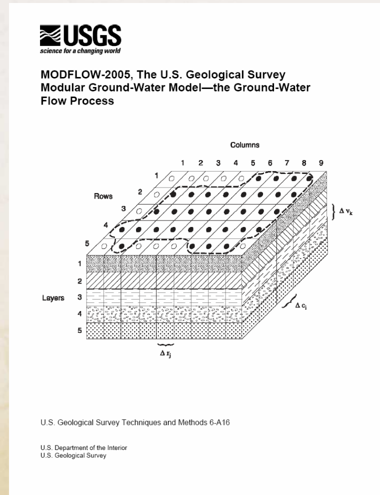
www.sahra.arizona.edu/newswatch



Websites and email services can facilitate the transfer of information. UNESCO's G-WADI program and the SAHRA Center have teamed up to provide current water-related news and information through Global Water News Watch. This web-based service continuously monitors nearly 200 sources of news, reports and information, in seven languages, and provides summaries and links. Over 17,000 articles in the database can be searched by key word, topic, region, and publication date. Water professionals can subscribe to the G-WADI Water News Tracker and receive customized email newsletters covering only those topics and geographic areas of interest to them.

Hydrologic modeling tools: public domain software from US agencies





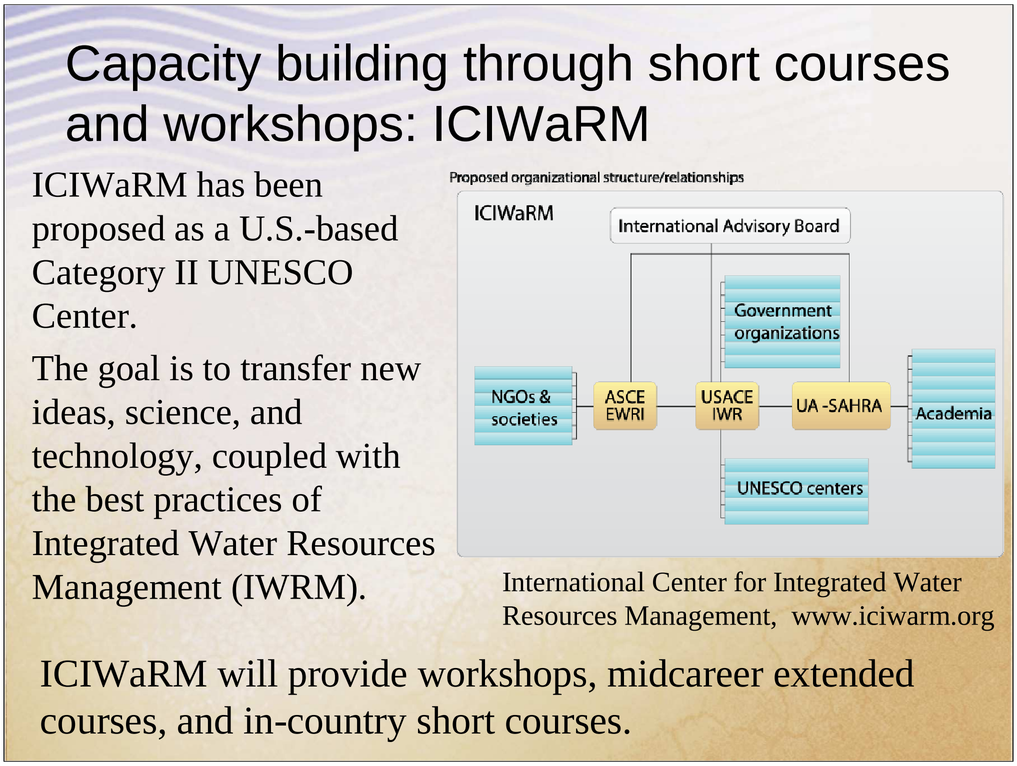
www.hec.usace.army.mil/software/hec-ras/

water.usgs.gov/nrp/gwsoftware/modflow2005/modflow2005.html

There is a large and dynamic market for hydrologic modeling tools, many of which command high prices. But some of the most widely used and trusted modeling environments are developed and distributed freely by U.S. agencies, including the Army Corps of Engineers (USACE) and the U.S. Geological Survey (USGS), and they have become the state of the practice in many countries.

The Hydrologic Engineering Center (HEC) at USACE's Institute for Water Resources develops water resources models and associated utilities, and makes them available to the public through free downloads. Two widely used modeling products are HEC-RAS and HEC-HMS, which respectively allow river analysis and examine precipitation-runoff processes.

USGS has developed diverse software applications relating to groundwater flow in the saturated and vadose zone, pumping tests, contaminant transport, geochemistry and remediation, stream aquifer linkages, and rainfall-runoff processes. ModFlow is the most widely used application for groundwater modeling purposes, with far-reaching capabilities in terms of problem-setting applicability.



A new U.S.-based Category II Center has been proposed as part of UNESCO's International Hydrology Program. This International Center for Integrated Water Resources Management, or ICIWaRM, led by USACE IWR, the American Society of Civil Engineers, and SAHRA, will focus on practical, experience-based water management training and capacity building for developing and emerging countries as well as post-disaster/conflict nations and regions. Some of the topics which the Center will address include:

--integrated water resources management and sustainable development in arid and semi-arid zones

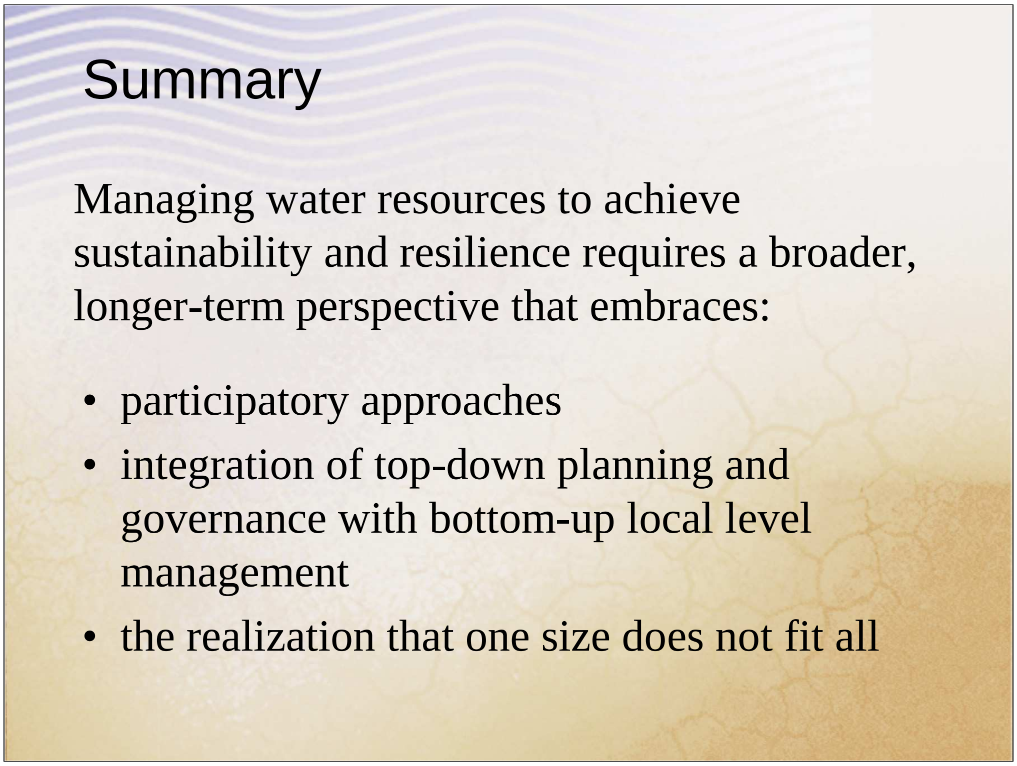
--infrastructure development and related engineering design standards and procedures

--capacity building, development, and training

--water policy, governance, and institutional aspects

--water security

The principal purpose of a Category II UNESCO Center is to serve as the most effective means of transferring new ideas, science, and technology and integrating them with the current best management practices associated with IWRM. This will be accomplished in part through short courses and training.

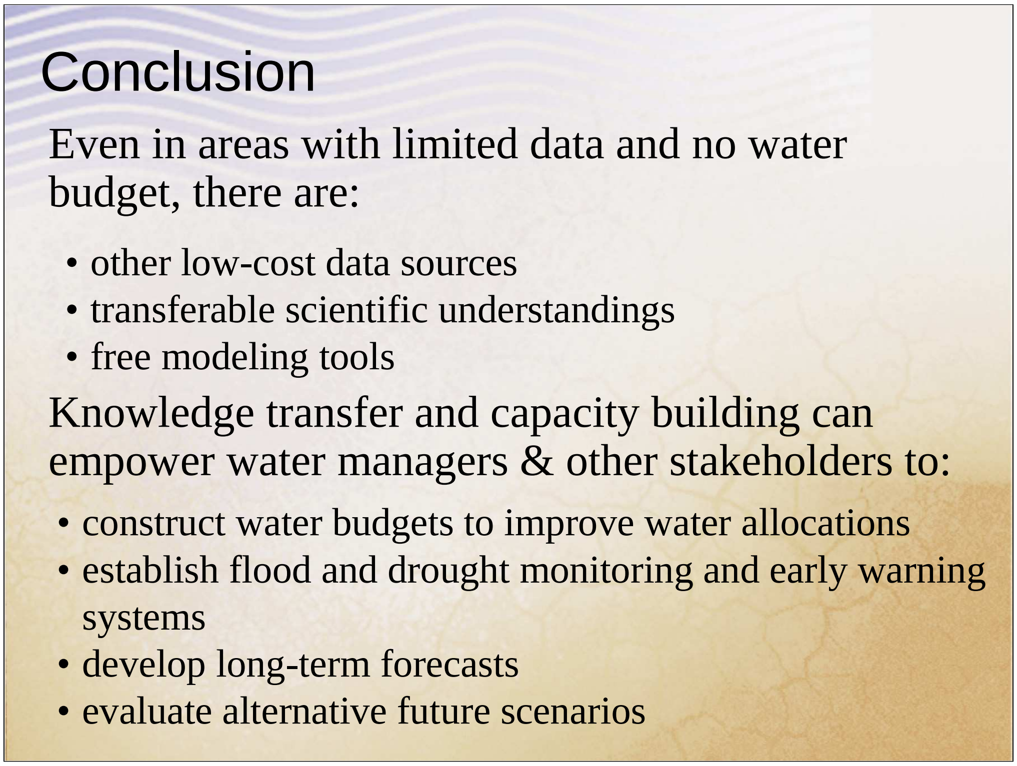


To achieve sustainability and resilience in the management of water resources requires a broader, longer-term perspective that embraces:

--participatory approaches

--integration of top-down planning and governance with bottom-up local level management

--the realization that one size does not fit all



Even in semi-arid and arid areas with limited data and no water budget, there are low-cost data sources, transferable scientific understandings, and free modeling tools.

Knowledge transfer and capacity building can empower water managers & other stakeholders to:

--construct water budgets to improve water allocations

--establish flood and drought monitoring and early warning systems

--develop long-term forecasts

--evaluate alternative future scenarios


Final thought: Many of the scientific advances and cutting-edge technologies that the US has developed to aid water resource managers in the semi-arid SW can be effectively used elsewhere. And we have a good start on building the infrastructure to disseminate it.
For more information, contact:
Juan B. Valdés
jvaldes@u.arizona.edu
SAHRA
www.sahra.arizona.edu
Photo: J. Overpeck

References

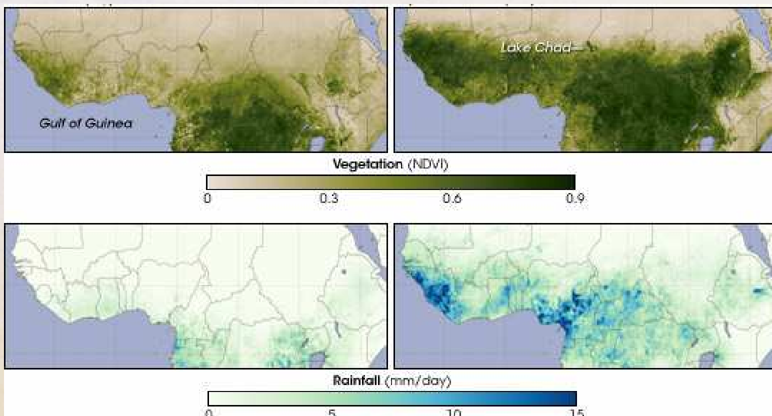
- Bonnefille, R., and F. Challie, Pollen-inferred precipitation time-series from equatorial mountains, Africa, the last 40 kyr BP, 2000, *Global and Planetary Change, 26*(103): 25-50.
- Brown, M.E., and C.C. Funk, 2008. Food security under climate change, *Science, 319*: 580-581.
- Cañón, J, F. Dominguez, and J. Valdes, 2008. Downscaling climate variability associated with quasi-periodic climate signals: A new statistical approach, submitted to *Climatic Change.*
- Dinku, T., P. Ceccato, E. Grover-Kopec, M. Lemma, S.J. Connor and C.F. Ropelewsk, 2007. Validation of satellite rainfall products over East Africa's complex topography. *Intl. J. Remote Sensing, 2*8(7), 1503-1526.
- Dominguez, F., J. Cañon, and J. Valdes. IPCC-AR4 climate simulations for the Southwestern US: the importance of future ENSO projections, submitted to *Climatic Change.*
- Edmunds, W.M., Recharge in wadis, 2005. Case study available at http://www.gwadi.org/casestudies/Edmunds.pdf
- Hoerling, M., and J. Eischeid, 2007. Past peak water in the Southwest, *Southwest Hydrology, 6*(1): 18-19, 35.
- Hogan, J.F., F.M. Phillips, S.K. Mills, J. Hendrickx. J. Ruiz, J.T. Chesley, and Y. Asmerom, 2007. Geologic origins of salinization in a semiarid river: the role of sedimentary brines, *Geology, 35(*12), 1063-1066.
- Kummerow, C., J. Simpson, 0. Thiele, W. Bames,A.T.C. Chang, E. Stocker, R.F. Adler,A. Hou, R. Kakar, F. Wentz, P. Ashcroft, T. Kozu, Y. Hong, K. Okamoto, T. Iguchi, H. Kuroiwa, E. Im, Z. Haddad, G. Huffman, B. Ferrier, W.S. Olson, E. Zipser, E.A. Smith, T.T. Wilheit, G. North, T.
- Krishnamurti, and K. Nakamura, 2000. The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit. *J. Appl. Meteor.,* 39: 1965-1982.
- Meko, D.M., C.A. Woodhouse, C.A. Baisan, T. Knight, J.J. Lukas, M.K. Hughes, and M.W. Salzer, 2007. *Geophys. Research Letters, 34,* L10705).
- Milly, P.C.D., J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D.P. Lettenmaier, R.J. Stourffer, 2008.Stationarity is dead: Whither water management? *Science, 319*(5863), 573-574.

References (cont.)

- Passell, H.D., V. Solodukhin, S. Khazekhber, V.L. Pozniak, I. A. Vasiliev, V.M. Alekhina, A. Djuraev, U.S. Salikhbaev, R. I. Radyuk, D. Suozzi, and D.S. Barber, 2008. The Navruz Project: Cooperative, Transboundary monitoring, data sharing and modeling of water resources in Central Asia, in *Nuclear Risks in Central Asia*, ed. B. Salbu and L. Skipperud, Springer Netherlands, pp. 191-199.
- Serrat-Capdevila, A., Browning-Aiken, A., Lansey, K., Finan, T. and J.B. Valdés, 2008. Increasing socio-ecological resilience by placing science at the decision table: The role of the San Pedro Basin Decision Support System Model (Arizona), submitted to *Ecology & Society*.
- Serrat-Capdevila, A., J.B. Valdés, J. González Pérez, K. Baird, L. J. Mata, T. Maddock III, 2007. Modeling climate change impacts - and uncertainty - on the hydrology of a riparian system: the San Pedro Basin (Arizona/Sonora), *J. Hydrology 347*: 48-66, DOI 10.1016/j.jhydrol.2007.08.028.
- Sheffield, J., Goteti, G., and E.F. Wood, 2006. Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling, *J. Climate, 19*(13): 3088-3111.
- Simon and Allen,
- Simpson, J., C. Kummerow, W.-K. Tao, and R.F. Adler, 1996. On the Tropical Rainfall Measuring Mission (TRMM) satellite, *Meteorol. Atmos. Phys., 60*: 19-36.
- Troch, P.A., M. Durcik, S. Seneviratne, M. Hirschi, A. Teuling, R. Hurkmans, S. Hasan, 2007. New data sets to estimate terrestrial water storage change. *EOS, 88*(45): 6.
- Verschuren, D., K.R. Laird, and B.F. Cumming, 2000. Rainfall and drought in equatorial east Africa during the past 1,100 years, *Nature, 403*(6768): 410-414.
- Walvoord, M.A., F.M. Phillips, D.A. Stonestrom, R.D. Evans, P.C. Hartsough, B.D. Newman, and R.G. Striegl, 2003. A reservoir of nitrate beneath desert soils, *Science, 302*(5647): 1021-1024.
- Wojtkowski. P., M.E. Brown, C.C. Funk, J. Verdin, and G. Eilerts, 2008. Ensuring food security, *Science, 320*: 611-612, DOI: 10.1126/science.320.5876.611.

Normalized Difference Vegetation Index & Rain

March 2004 (dry) September 2004 (wet)



Vegetation in the Sahel follows seasonal rainfall. In March, during the dry season, rainfall and lush vegetation don't extend north of the Gulf of Guinea. September brings rain and vegetation into the Sahel as far north as the northern edge of Lake Chad.