Drought, early warning and climate services

Roger S. Pulwarty PhD
J. Verdin, R. Olsen, C. Hennig, V. Deheza, N. Doesken, M. Hayes, M. Hiza Redsteer, C. McNutt, M. Brewer and the NIDIS Implementation Team

Chief, Climate and Societal Impacts Division and Director, National Integrated Drought Information System (NIDIS)
NOAA
Impacts of a Changing climate

- Higher evaporation. More farm dams as surface water availability reduces?
- Greater irrigation efficiency as surface water availability reduces?
- Increased evapotranspiration due to higher temps?
- Increased demand for groundwater as surface water availability reduces?
- Higher frequency and intensity of wildfires due to higher temps and droughts?
“If we are not careful we will end up where we are going”
Climate drivers of drought-a continuum
Drought: Diverse temporal and spatial scales

Percent Area of the United States in Severe and Extreme Drought
January 1895–July 2008

Based on data from the National Climatic Data Center/NOAA

Dust Bowl Drought (1931-1940)
1950's Drought (1950-1957)
Groundwater depletion trends

(groundwater 30% of available freshwater on the planet)

1000 = one cubic kilometer of depletion per year

The future (2041-2060): where do the models agree?
What would “adaptation” address?

The threat already posed to society from today’s climate variations

Climate-sensitive development paths that might put greater population, ecosystem services, and economies at risk

The potentially high-impact but still critically uncertain additional risks presented by climate change
How do we “usually” adapt?

- Infrastructure/assets
- Technological process optimization
- Institutional and behavioral changes or reinforcement
- Crisis, learning and redesign
Event to event.......issue attention cycle

Focusing event(s) and cumulative Impacts

Preparedness

Mitigation

Response

Recovery

Development

Prevention
Focus on the critical problems: not just asking but answering the right question

“ALSO, THE BRIDGE IS OUT AHEAD”
What has led to “action”?

1. Focusing events - extremes, legal decisions etc.
2. Leadership at different levels and the public are engaged:
3. **Supported framework for collaboration between research and management**-integrated, scenarios, scenarios/gaming, communication, embedding information into practice, evaluation
4. Existing social basis or even pressure for collaboration
Are droughts different from other hazards?

2000-2004 drought in the Colorado Basin

“No systematic collection and analysis of social, environmental, and economic data focused on the impacts of drought within the United States exists today” Western Governors Association 2004

The NIDIS Act of 2006 (Public Law 109-430)

“Enable the Nation to move from a reactive to a more proactive approach to managing drought risks and impacts”

(www.drought.gov)
Three tasks under the NIDIS Act
Public Law 109-430, 2006

(I) Provide an effective drought early warning system:
   (a) collect and integrate key indicators of drought severity and impacts; and
   (b) produce timely information that reflect local, regional, and State differences;

(II) Coordinate and integrate as practicable, Federal research in support of a drought early warning system

(III) Build upon existing forecasting and assessment programs and partnerships
Drought and Water Resources: Federal Partnerships (States, Tribes, Urban, other)

Monitoring & Forecasting

Early Warning Information in support of Adaptation

Drought and Flood Impacts Assessments and Scenarios

Communication and Outreach

Engaging Preparedness & Adaptation
NIDIS Components

1. NIDIS Office
2. U.S. Drought Portal
3. Climate Test Beds/Drought
   Integrating data and forecasts
4. Coping with Drought-Grants-
   Impacts assessment and decision support research
5. Regional Drought Early Warning
   Information Systems
   Design, Prototyping, Implementation
NIDIS Governance: Executive Council

NATIONAL

NIDIS Program Office → NIDIS Implementation Team:

NIDIS Technical Working Groups

REGIONAL

Public Awareness And Education
Engaging Preparedness Communities
Integrated Monitoring and Forecasting
Interdisciplinary Research and Applications

U.S. Drought Portal

WATERSHED/URBAN/LOCAL

Regional Drought Early Warning Systems
Information clearinghouse, prototypes, and Implementation
National Level: NIDIS Knowledge Assessments (selected);
What do we know? What do we need to know?


- Drought, Climate change and Early Warning on Western Tribal Lands June 2009- Columbia, Colorado, Rio Grande, Missouri Basin tribes
  - 2010-11 Four Corners region

- WGA/WSWC Workshops on developing constituencies for NIDIS (April 2010, September 2010-Washington DC, 2011)

- Engaging Communities in Preparedness June 2011 Chicago
Impacts Assessment and Decision Support Research

- Adaptation Policies For Urban Water Resource Management-Short-Term Drought Responses And Long-Term Planning
- Socioeconomic Assessments to Build Community Resilience in Mitigating Drought
- Climate Information System to Enhance Drought Preparedness by Underserved Farmers

Reconciling projections of Colorado River streamflow under changing climate conditions

- Ensemble Hydrologic Forecasts using dynamic estimates of evapotranspiration

Drought Index Evaluation and Implementation in a Geospatial Framework Linked to Hydrologic Data Web Services
USGS 1331- Climate Change and Water Resources Management: A Federal Perspective 2009

Centers for Disease Control When Every Drop Counts: Protecting Public Health During Drought Conditions—A Guide for Public Health Professionals 2010

United Nations Global Assessment Report on Disaster Risk Reduction (GAR 2011)
Key Clearinghouse Functions: Credible, Accessible, Timely Information on

Where are drought conditions now?
Does this event look like other events?
How is the drought affecting me?
Will the drought continue?
Where can I go for help?
Coordinate existing federal, state, and local drought-related data and decision support activities (e.g., within watersheds and states)

Monitoring  ↔  Prediction  ↔  Applications Research

Integrating Tools e.g. Drought Monitor/Portal

Identifying and transferring indicators, decision support tools and innovative strategies for drought risk assessment, communication and preparedness

Proactive Planning  ↔  Impact Mitigation  ↔  Improved Adaptation
Regional DEWS Implementation: Upper Colorado River Basin

Categories of drought information users & analysis

Upper Basin down to Lake Mead

• Coordinated reservoir operations: Low flow shortage triggering criteria (Powell/Mead)

Sub-basin

• Inter- and Intra-basin transfers; Front range urban-agriculture-Changing water demand during drought

• Ecosystem health/services including recreation and tourism impacts
Colorado River Water Supply & Use

Colorado River Basin Water Supply and Water Use
10-Year Averages from 1923 to 2006

10-Year Running Average Basin Water Supply
10-Year Running Average Basin Water Use

Flow (million ac-ft/yr)

Time (Years)

1490 1540 1590 1640 1690 1740 1790 1840 1890 1940 1990

Historic Natural Flow
Paleo Reconstruction
US Drought Portal – Regional DEWS

Regional Drought Early Warning System
Upper Colorado River Basin

Area Drought Info
Select State within the DEWS
Select Other Regional DEWS

Related Information
- NIDIS Weekly Drought Webinars
- Tribal Resources
- Ongoing Research & Development

Upcoming Meetings
- To Be Determined
- TBD

Past Meetings
- UCCE Pilot Planning meeting for Federal Partners
- UCCE Scopeing Workshop
- UCCE Monitoring Gap Workshop
- UCCE Partners Update Meeting

Featured Products
- Current Conditions
- Impacts
- Forecast

U.S. Drought Monitor
November 30, 2010
West

Drought Monitor Time Series - West
% Area for west

Drought in the News

Upper Colorado River Basin
Four Corners Tribal Lands

The Drought Monitor focuses on long-term climate conditions. Live conditions may vary. See usdak escalate our summary at http://drought.usda.gov

Released Thursday, December 2, 2010
Author: R. Trine, CPC/NOAA
<table>
<thead>
<tr>
<th>Spatial Resolution/Time Horizon</th>
<th>Operational Activity</th>
<th>Decisions</th>
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<tr>
<td>Basin-wide over decades</td>
<td>Long-term Planning</td>
<td>Operating Criteria and Guidelines</td>
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<td>Basin-wide over 1-2 years</td>
<td>Mid-term Operations</td>
<td>Annual Operating Plan</td>
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<tr>
<td>Sub-basin over 4-6 weeks</td>
<td>Short-term Scheduling</td>
<td>Water and Power Schedules</td>
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<td>Single project over 1-7 days</td>
<td>Real-time Control</td>
<td>Unit Commitment Economic Dispatch</td>
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<td>Automatic Generation and Control</td>
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NIDIS Products and Services in the Colorado Basin to date

• New watershed-based drought indicators and triggers used in the Upper Basin
• Improved linkages between climate and streamflow modeling during drought
• Spatial analysis of water demand during drought
• Low flow impacts database for 164 NWS forecast points
• UCRB Community Colorado Basin-specific Drought Portal
• Weekly Drought and Water Outlook webinars/early warning discussions with resource managers in the UCRB
• Engaging underserved communities
Revision of the Plans to meet drought requirements of the State Natural Hazard Mitigation Plan, as well as FEMA and EMAP

NIDIS role

• Development of indices that incorporate current surface water conditions and a forecast component

• Assessment of trigger points and responses

• Weekly Early Warning Webinars
  (coordinated with River Forecast Center briefings)
Colorado River Interim Guidelines - Time to think-A Robust Solution?

- Operations specified through the full range of operation for Lake Powell and Lake Mead
- Encourage efficient and flexible water use and management in the Lower Basin through the Intentionally Created Surplus (ICS) mechanism
- Strategy for shortages in the Lower Basin\(^2\), including a provision for additional shortages if warranted
- **In place for an interim period (through 2026) to gain operational experience**
- Basin States agree to consult before resorting to litigation

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2. Mexico water deliveries are not directly effected by these guidelines (US/DoI Bureau of Reclamation)
Year 2 Actions

Prototyping/gaming: Given better data and information coordination, would responses have been improved for past events? Assess:

1. Value of improved information using past conditions
2. Responses for projections/ scenarios (seasons, decadal, change)
3. Develop EWS Fora
4. Feedback on priorities (e.g. data gaps) to Executive Council
Native Nations in SW are major land managers

- 6 million acres/ 242kha of land
- held in trust by the US for American Indian tribes and Alaska Natives
- Reservations and tribal lands are >25% of land in AZ
- Confronting same climate trends, need same info, but context is different
  - cultural ties to landscape
  - federal trust relationship
  - widely variable capacity
Kayenta, AZ
2004

Margaret Hiza
Redsteer USGS
Recent Landscape changes

**LOCAL NEWS**

Multiple crashes due to wind and dust along I-40

*More Phoenix Local News*

09:21 PM Mountain Standard Time on Thursday, March 26, 2009

azfamily.com

WINNSLOW – A dust storm shut down Interstate 40 in the High Country for several hours.

It was closed in both directions east of Flagstaff near Winslow. Department of Public Safety officials say wind gusts up to 60 miles-per-hour have hit the area, blowing dust and causing multiple car crashes. The freeway was reopened at about 7:30 p.m.

DPS says if you see a dust storm approaching...

**USGS**

Assessment of sand dunes and the affects of climatic variation on dune mobility in Navajo Land

Sand dunes are sensitive indicators of climate change, including precipitation and moisture balance, and serve as indicators of global warming. They become active during periods of drought or by increasing temperatures in the desert, when the dunes are growing and changing, and are affected by wind and dust storms. The degree of sand mobility can be predicted based on the ratio of sand in the soil to vegetation, precipitation, and temperature.

If you calculate the sand mobility index using the formula: Sand Mobility Index = (Precipitation - Evaporation) / Moisture Content, the values can be divided into the following categories:

- High Mobility: Sand mobility index > 1.5
- Moderate Mobility: 0.5 < Sand mobility index < 1.5
- Low Mobility: Sand mobility index < 0.5

The sand mobility index can be influenced by human activities such as land use changes, infrastructure development, and water management practices.
Landscape changes - Drought Early Warning on Tribal Lands in the Four-Corners Region

(Nature, 2009)
Co-produced Scenarios: Navajo Lands

Through conversations before and during workshops, the team identified the most important and most uncertain climate drivers that will affect conditions over the next 40 years. These were combined in the following matrix. (Also note that temperature increase was a ‘given’ so it applies in all scenarios.

**Shrubland**

Ecosystem becomes more susceptible to annual grass invaders. Fate of pines and other trees uncertain. Soil erosion increases. Faunal composition changes.

Flash floods entering caves more often

Native grassland replaced by shrubland and exotic annuals

Ponderosa pine communities more susceptible to catastrophic fires due to decreasing summer precipitation

Changes seen as part of normal variability

Other management issues dominate

Streams more intermittent, trees dry out

Increased evaporation decreases plant productivity somewhat; ecosystem change occurs, but more slowly and/or to lesser degree than in other scenarios.

**Novel Ecosystem**

Climate changes quickly to something like southern SW U.S. and species migration limited. Water table drops; streams go from perennial to intermittent or gone. Soil erosion increases. Many fauna may not be sustainable.

Period of frequent, intense fire followed by decrease in fire because of lack of fuel

Tough decisions regarding above-ground mission

**Mixed-grass Prairie**

**Duration and Frequency change little**

**Drought**

**Severity**

Patterns shift – more winter precipitation relative to summer

**Patterns change little**

**Extreme Droughts become far more common**

**Extreme heat events – camp fire bans**

Decreased water availability

Park culls half of the bison herd – limits on carrying capacity

Forest is more restricted by moisture than currently. Megafauna capacity decreases because forage production is lower. Water table drops; spring and stream flow decreases or ceases, depending on location.

**Shortgrass Prairie**

**Patterns shift – more winter precipitation relative to summer**

**Patterns change little**

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ACF Corps Dam Watersheds

Water supply

Energy

Agriculture

Near-shore

The ACT and ACF River Basins

Apalachicola-Chattahoochee-Flint Basin
Regional Drought Early Warning Systems

Highlighted-first round prototypes;
Non-highlighted-second round Regional DEWS

Hydrologic Unit Boundaries

- Columbia River Basin
- Colorado River Basin
- California
- Great Plains
- Great Lakes
- Missouri
- Oklahoma
- Tennessee Valley
- Chesapeake Bay
- Southeast

Pacific Ocean (No Data)

Hydrologic Unit Boundary Types:
- digit delineating unit
- digit accounting unit
- digit subregional unit
- digit regional unit

Puerto Rico/Virgin Islands
The development phase or regional drought early warning information systems:

- Allows for existing barriers to cross-agency collaboration to be addressed
- Innovations and new information to be introduced and tested, and
- The benefits of participation in design, implementation and maintenance to be clarified

Mature prototypes become the regional system. Lessons become more likely to be successfully transferred within or to other as yet underserved regions.
Identifying appropriate partners, stakeholder representatives

- Setting goals/priorities, and involving partners in problem definition
- Using professionals from relevant agencies etc. to build common ground
- Producing collectively authored gaps assessments and agreement on the way forward
- Building longer term collaborative partnerships
- Tradeoffs-Decision quality vs decision acceptability
California- Recent drought impacts

- Reduction in hydropower generation
- Rural homeowners with fractured rock wells in need of deepening
- Insufficient vegetation to support livestock
- Large cutbacks-State Water and Central Valley Projects deliveries
- Rationing-small coastal groundwater supplies
- Fire risk
- Mandatory water conservation

Maximum extent Water conservation
“We would cite the National Integrated Drought Information System (NIDIS) as one example of how federal agencies can work together and with states ……NIDIS is not perfect yet– but it demonstrates key elements of how….to deliver actionable information to end users and decisionmakers”

Western Governors letter to CEQ-Response to CEQ Adaptation Interim Report  May 21, 2010
NIDIS as prototype: Informing climate services development

“If we don’t get NIDIS right, we can’t get a national climate service right”

Kelly Redmond, Western Regional Climate Center

6th Drought Monitor Forum
Austin, TX Oct. 7-8, 2009
Need for exchange of experience and learning among different basins

How is awareness of slow onset problems in the context of seasonal to decadal-scale variability and longer-term change developed?

How are adjustments and adaptations being designed, implemented, and evaluated?
NIDIS-Transferability

- FEWSNet
- GEO Water Resources
- Mediterranean/Iberian Peninsula
- Australia (MDB/Colorado)
- India NIDIS
- Caribbean Basin
- US-Canada PNW
- GIDIS-
Global Drought Monitoring Conceptual Framework
The “Services” Challenge

Identify user requirements
Conduct research

Develop applications and capacity
Integrate knowledge and products
Deliver information
Data quality control

MONITORING/FORECASTS

DEVELOPMENT
(Assessments, int.products)

PROTOTYPING
(Scenarios, Applications)

DELIVERY/MAINSTREAMING

Relative status of information

STATIC.................................. EMERGENT/DYNAMIC
Watershed transitions

Transitions from applications to adaptation:
Social-structural and spatial-temporal, resource management
Limits of co-production

Social-ecological
Path dependence
Organizational boundaries
Joint monitoring and joint fact-finding
Risk governance

- Ensure political authority and policy coherence
- Decentralize step-by-step and incrementally
- Develop a culture of partnership
Knowledge “of” a process is not equal to knowledge “in” a process.
Challenges

- Develop strategic responses to crises: foreseeable, impending, actual; and
- Provide implementable options to critical actors for decision-making

A systemic view would involve assessing:

- Impediments to the flow of knowledge among existing network components
- Policies and practices that can give rise to failures of the component parts working as a system
- Opportunities for and constraints to learning and institutional innovation
Visit the Global Assessment Report 2011 online:
www.preventionweb.net/gar
Moving beyond impacts reports—Engaging communities, resources managers in a changing climate

(Federal data, NDMC, RISAs, RCCs, State Climatologists….. NIDIS)

Integrated Climate, Ecosystems, Hydrology: Technical Info & Data + Watershed, state, tribal, local: Experience & Knowledge = Decision Support

Climate information: Needs, usability, evaluation
Entry points for proactive Planning—triggers and indicators

Enabling adaptation: Best available drought risk & water supply information Input to drought planning, preparedness and adaptation
THANK YOU!
BACKUP SLIDES
I. Choose Climate Context

- **Paleoclimate Proxies:** reconstructed runoff (Q)
- **Instrumental Records:** observed weather (T and P) and runoff (Q)
- **Global Climate Projections:** Representing various GCMs, forcings → bias-correction, spatial downscaling

II. Relate to Planning Assumptions

- Supply Variability
- Demand Variability
- Operating Constraints

III. Conduct Planning Evaluations

- System Analysis, Evaluate Study Questions (related to Resource Management Objectives)
Challenges in a changing climate

Assessing progress for each element of planning and implementation

(i) Capacity and coordination

Priorities for early adaptation action, including land use planning, building design, emergency planning, local infrastructure provision and green space management

(ii) Decision-making

- Monitoring decision-making is not straightforward
- Wide range of organisations that are relevant to adaptation,
- Sources of evidence here will include: Analysing how climate change is considered in decisions on regionally significant infrastructure projects, in local planning policies and in local development decisions.

(iii) Timeliness of action

- depends on regional/local circumstances-surprises
- cost-effectiveness of adaptation measures
- implementation monitoring and evaluation
Summary

Principal Elements of Drought Risk Reduction Framework

Policy & Governance
- Political commitment and responsibilities

Risk & Early Warning
- Vulnerability analysis, impact assessment, and communication

Mitigation & Preparedness
- Application of effective and affordable practices

Awareness & Education
- A well-informed public and participatory process

Local reality
- Community participation
- Political commitment
- Sustainable livelihoods
<table>
<thead>
<tr>
<th>Vulnerable Sector/activity/group</th>
<th>Magnitude</th>
<th>Rates of Change</th>
<th>Persistence and reversibility</th>
<th>Likelihood and confidence</th>
<th>Distribution</th>
<th>Potential for Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic sectors (Water, Ag, Tourism etc.) Communities at risk</td>
<td>Situation of existing Levels of vulnerability for different magnitudes of change, especially thresholds, relative to temperature, precipitation or the other critical parameters that create the vulnerability</td>
<td>Critical rates/steeper response curves that affect vulnerability</td>
<td>Likelihood that the vulnerable sector will be affected by an irreversible impact and whether it is likely to persist</td>
<td>Overall confidence and likelihood, but state confidence also with any specific figures or points.</td>
<td>Distribution of impacts – both physically and socially within countries (not in a simple developed/developing dichotomy).</td>
<td>Capacity for adaptation. Is adaptive capacity sufficient to delay or prevent adverse impacts and at what cost.</td>
</tr>
</tbody>
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WGII & Leggett and Pulwarty
**Mission:** Implement a dynamic, accessible, authoritative drought information system

<table>
<thead>
<tr>
<th>NOAA Produces:</th>
<th>With Our Partners:</th>
<th>Used By:</th>
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<tbody>
<tr>
<td><strong>Monitoring and Forecasting</strong></td>
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<tr>
<td>U.S. Drought Monitor</td>
<td>USDA, National Drought Mitigation Center</td>
<td>USDA, state and local governments</td>
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<td>U.S. Soil Moisture Monitoring</td>
<td>DOE, USDA (NRCS)</td>
<td>USDA, agricultural producers</td>
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<tr>
<td>Normalized Difference Vegetation Index</td>
<td>USGS, NASA</td>
<td>USAID (FEWS NET)</td>
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<tr>
<td>Crop Moisture Index</td>
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<td>Ensemble Water Supply Forecasts</td>
<td>USDA</td>
<td>USBR, USACE, state water management agencies, local district water managers</td>
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<tr>
<td>Soil Moisture Anomaly Forecast</td>
<td>USDA (NRCS)</td>
<td>USDA, agricultural producers</td>
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<td>Products Informing Risk Assessment and Management</td>
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<tr>
<td>Concluding projections of future Colorado River stream flow in a changing climate</td>
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<td>USBR, USGS, University of Washington, University of Colorado, University of Arizona, University of California-San Diego</td>
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<td>USBR, state and local water providers, reservoir managers, Water Conservancy Districts</td>
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<td>USGS Circular 1331: Climate Change and Water Resources Management: A Federal Perspective</td>
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<td>Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation</td>
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<td>Colorado Water Conservation Board, University of Colorado, Western Water Assessment RISA</td>
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<td>Colorado water planners, State Climatologists</td>
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<td>Managing Threatened and Endangered Salmon in Low Water Conditions</td>
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<td>USBR, CA Department of Fish and Game, CA Department of Water Resources, University of California Davis, Humboldt State University</td>
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<td>NMFS, CA Department of Fish and Game, CA Department of Water Resources, Pacific Fisheries Management Council</td>
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<td>Assessing Drought Indicators and Triggers</td>
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<td>USGS, USDA (NRCS), Colorado Water Conservation Board, Colorado State University, Utah State University, University of Wyoming</td>
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<tr>
<td>USGS, USDA, USBR, water planners/providers, reservoir managers, State Climatologists</td>
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</table>
Type I: Those that are well-known cases from the past where a threshold was reached and the management challenges are explicit. What lessons are available to learn that are already well documented?

Type II: Those that are emerging now and often feature aspects of accelerating change or where the accumulation of small change appears to lead to some large change in management or policy response.

Type III: Those that present very large scale, system-wide challenges. Type 3 cases are examples where we know the system well enough, or the science well enough, to think that we really ought to be concerned, that there is an important tipping point/or threshold out there.
Drought Preparedness for Tribes in the Four Corners Region Workshop

April 8-9, 2010, Flagstaff, Arizona

Tribal perspectives on critical issues

Local Knowledge & Drought: How do we incorporate local knowledge?

What are current vulnerabilities and impacts tied to drought and climate change?

Critical drought-related information needs on tribal lands in Four Corners region

Improved monitoring emerged as the highest priority near-term need
Revisiting past events with key basin and local decisions

Weekly drought situation assessments-webinars presented by key resource reps. (coordinated by State Clim. and RFC)

Information inputs into existing drought and water resources preparedness and adaptation plans

- Gaming scenarios on sensitivity, projections, potential surprises-short-term adjustments-long term risks
- Modifications of existing plans-prioritized actions
Connecting geospatial and temporal water resources data

Digital Watershed

USGS NWIS Streamflow

NHDPlus

NOAA NCDC and ASOS

NRCS Snotel

David Maidment, U Texas
CUAHSI HIS Custom Drought Index Server

Data Products and Services
- Web Map Based Display of Index
- WaterOneFlow Web Service(s) for inputs and outputs
- GIS Data Services
  - WMS, WFS, WCS
  - Digital Watershed
  - Drought Index Results

CUAHSI
D. Tarboton
J. Horsburgh
Utah State University

Data Processing and Index Calculation
Drought vulnerability GIS database that represents relationships among water users and their respective sources of water supply
Data Mining for Water Availability, Ecosystem Change, and Services

Projects

Portal development sponsored by USGS Climate Effects Network and NIDIS

Publications

People
Vegetation Drought Response Index (VegDRI)

✓ Hybrid Drought Index that Integrates:
  - Satellite-based observations of vegetation conditions
  - Climate-based drought index data
  - Biophysical characteristics of the environment

http://drought.unl.edu/vegdri/VegDRI_Main.htm

(Source: Wardlow, 2008)
Progress has been impressive... with more tools on the way!
Drought information and Resource Management: optimizing risk reduction

**Hydropower Decision Calendars**

**Municipal & Industrial Decision Calendars**

**Aquatic Ecosystems Decision Calendars**

**Outdoor Recreation Decision Calendars**

**Agriculture Production Decision Calendars**

**Reservoir Management Decision Calendar**

**Water Year Planning**
- Next Water Year Planning
- Provide for late Summer/early Fall irrigation while maintaining target flows
  - Next water year runoff unknown, reserve water until February snowpack data
  - Winter season precipitation forecast for Fall release decisions
  - Winter releases based on Jan/Feb snowpack data
  - Winter/Spring forecast for Winter release decisions
  - Peak Flow Augmentation --- fill curve
  - Summer season forecast for Peak Augmentation planning
  - Week 2 forecasts for Peak Augmentation
  - Peak Flow Augmentation releases
  - Plan releases for Summer irrigation & hydropower
  - Week 2 forecasts for Summer irrigation & hydropower release decisions
  - Provide for Summer irrigation & hydropower needs while maintaining target flows

**Calendar Months:**
- Aug
- Sep
- Oct
- Nov
- Dec
- Jan
- Feb
- Mar
- Apr
- May
- Jun
- July
- Aug
- Sep
- Oct
Regional Drought Early Warning System
Upper Colorado River Basin

Given better data and information coordination, would responses have been improved for past events? Assess:

1. Value of improved information using past conditions
2. Responses for projections/scenarios (decadal, climate change)
3. Feedback on priorities (e.g. data gaps) to Interagency Executive Council
Managing in a changing climate:
Adaptation needs

(1) Understand adaptation as being driven by crises, learning and redesign- Role of “surprises” in shaping responses

- Human action in response to projections is reflexive
- Key drivers, such as technological innovation and change, are unpredictable with great accuracy on scales that matter for regional and local decisions-both pressures and solutions
- The system may change faster than the models can be recalibrated, particularly during turbulent periods of transition-Projections may be most unreliable in precisely the situations where they are most desired
- Inactions, actions and consequences
Adaptation needs-

(2) Early warning systems for critical thresholds across climate time and space scales: **Extremes in the context of change**

(3) Derive risk profiles and a portfolio of measures for each location/unit of analysis, identifying the broader economic, social and environmental benefits of each measure along with its cost.

Methodological developments:

- Cost-effectiveness - costs of action and of inaction
- Technological Efficiency: Drivers of adoption
- Renewables: Viability and offsets
- Evaluation: Infrastructure vs emergent events
Science for adaptation -
Sustain a collaborative framework between research and management -

Engage both leadership and the public
Scenario planning to address problem-definition and characterize multiple uncertainties

Prioritize and select climate adaptation and resilience measures and revise periodically (extremes, variability and change) and development

- Assumptions - e.g. climate knowledge, forecasts of socio-economic trends and drivers of growth
- Effectiveness - Short-term adjustments/coping that constrain or enable longer-term risks
- Benefits - adaptation in support of development goals
- Limits - to adaptation e.g. ocean acidification
Definition of the core set of data, information and information technologies needed to maintain the minimum acceptable level of stewardship in the management of water resources and water infrastructure.
CO Basin EWS

Existing mandates, decision cycles, and organizational capacities to guide implementation of the pilot-workshops, interviews, reports

- Colorado Division of Water Resources (CDWR)
- Colorado State Climatologist
- Colorado River Water Conservation District (CRWCD)
- Colorado Water Conservation Board (CWCB)
- CU – Western Water Assessment, CIRES, and CADSWES
- Denver Water Board
- Northern Colorado Water Conservancy District (NCWCD)
- Wyoming State Engineer
- Wyoming State Climatologist
- Utah State Climatologist
- Western Regional Climate Center

- National Center for Atmospheric Research (NCAR)
- National Drought Mitigation Center (NDMC)
- USDA: Natural Resources Conservation Service
- USFS: Region 2
- USBR: Eastern Colorado Area Office, Great Plains Region, Office of Policy and Programs, Research and Development
- USGS: Colorado Water Science Center, Central Region, Grand Canyon Monitoring and Research Center
- NOAA: Earth System Research Laboratory, National Centers for Environmental Prediction, National Climatic Data Center, National Weather Service