2003 Southwest Drought Summit
Summary Report

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http://www.mpcer.nau.edu/megadrought/drought_summit_report/index.htm

EXECUTIVE SUMMARY

A "Southwest Drought Summit" was held at Northern Arizona University in Flagstaff, Arizona on May 12-13, 2003. The summit brought together over 200 regional experts and decision makers to assess drought impacts, integrate knowledge about the causes and consequences of drought in the Southwest, and propose sustainable strategies for the future.

MAJOR CONCLUSIONS

There was a consensus on a variety of issues that were raised during the summit. However, five recurring themes/issues emerged during the summit in both presentations and working groups.

DROUGHTS ARE NORMAL. We need to incorporate this reality into management and policy plans. An important impediment to communities incorporating this concept in planning efforts is the tendency to dismiss droughts as regular events that may last years or decades.

WET PERIODS CAN OCCUR WITHIN A DROUGHT. These periods of normal to elevated precipitation can span weeks to years, and are typical of multi-year drought periods. These "wet" breaks in a longer-term pattern hinder appropriate planning because they provide the false assurance that a drought has subsided.

INCREASED POPULATION GROWTH. The Southwest is experiencing unprecedented population growth that will not only exacerbate drought effects but will create serious problems in the future even in the absence of droughts.

LONG-TERM PERSPECTIVE. For all of the themes addressed in the summit, we lack long-term data needed to develop predictions necessary for responsible long-term plans for water and land management. Viable long-terms plans are critical to ensure sustainability.

DROUGHT EDUCATION. One of the most repeated statements made during the conference was a need to better educate researchers, managers, policy experts, and the public about drought. This includes formal k-college education as well as informal education programs.

INTRODUCTION

The "Southwest Drought Summit" held at Northern Arizona University in Flagstaff, Arizona on May 12-13, 2003 was designed to bring together scientists and decision makers with the common goal of providing a synthesis of current scientific and policy information on the issue of drought in the Southwest. Often, the scientific community views science as undervalued in policymaking, whereas policy makers find scientific information to be complex and inaccessible. The Summit sought to incorporate science into the decision-making process by giving participants the opportunity to provide input to the Arizona Governor's Drought Task Force.

The resulting summit was the formulation of an integrative and proactive strategy to address emerging water and land management issues. The summit addressed a rising concern that the Southwest has emerged from an unusual "wet" period of several decades and entered a drought period that may be the long-term norm. The environmental consequences of a change in weather patterns to a period of sustained drought in the Southwest have far-reaching policy implications for municipal and regional land and water management decision makers. Therefore, the focus of the summit was to integrate and analyze knowledge about the causes and consequences of drought in the Southwest so as to more completely and effectively address the impacts it has on the environment and society.

This goal was achieved by assessing the drought from a long-term climatic perspective, synthesizing research on the ecology and hydrology of drought impacts, which included short- and long-term predictions for Southwest ecosystems, proposing long-term strategies that may involve modifying land management and water-use policies in order to achieve sustainability. This summit complemented other regional meetings in that it covered a range of major issues associated with our regional drought, which go beyond water availability. The topics covered reflected regional expertise and interest in climate, water availabity, increased human population growth, biodiversity, invasive species, emerging diseases, and the functioning of ecosystems.

The report includes the summit agenda, a synopsis of the first day presentations, followed by the summaries of the four working group. The summaries highlight the discussions on the second day of the summit by the working groups, and their subgroups. Specifically, each group identified key issues, proposed major predictions, and assessed specific needs for managers and researchers to more effectively deal with drought issues.

The working groups were divided into Climate, Water, Ecosystems, and Biodiversity, the latter three groups were further divided into subgroups. The Water group was divided into two subgroups that addressed issues of water use and human demographics, and regional hydrologic functions. The Biodiversity group comprised four sub-groups that focused on populations, communities, plants, and animals, including wildlife species, insect outbreaks, invasive species, and diseases. The ecosystem group was divided into groups that focused on issues of rangeland/agricultural sustainability, desertification and global carbon. Researchers, policy experts, and decision makers were represented in each of these groups.

We provide two appendices in the report including a list of summit attendees with their pertinent information, and participant responses evaluating the summit. Our website http://www.mpcer.nau.edu/megadrought/drought_summit_report/index.htm contains these appendices as well as this final report and the full PowerPoint presentations and abstracts of the lectures presented at the summit by Day 1 speakers. This same material is also available on CD-Rom from Neil.Cobb@nau.edu. The Summit was organized by the Merriam-Powell Center for Environmental Research, the Verde Watershed Research & Education Program, the Southwest Strategy, University of Arizona CLIMAS, The Center for Sustainable Environments, and the USGS Southwest Biological Science Center. Financial sponsors included Salt River Project, Central Arizona Project, USGS, National Park Service, Arizona Hydrological Society, Bureau of Land Management, the Bureau of Reclamation, US Forest Service, and Northern Arizona Council of Governments.

AGENDA OF DROUGHT SUMMIT PRESENTATIONS[1]

[1]Please visit http://www.mpcer.nau.edu/megadrought/drought_summit_report/index.htm

Day One Formal Presentations: Welcome

David Ostergren, 2003 Southwest Drought Summit Committee, Kathy Jacobs, Arizona Department Water Resources, and John Haeger, President, NAU

Climate and Drought

The Current Drought in Historical Perspective.

Julio Betancourt, U.S. Geological Survey, The Desert Laboratory, Tucson, Arizona.

Hydroclimatology of Southwestern Droughts.

Michael Dettinger, U.S. Geological Survey, Scripps Institution of Oceanography, La Jolla, CA, and Greg McCabe, U.S. Geological Survey, Lakewood, CO.

Perspectives on Drought Impacts on Diverse Southwest Ecosystems

Drought Impacts on Functions of Hydrologic Systems.

Abe Springer and Stephen Flora (NAU, Geology)

Human Demography, Water Supply and Water Use.

Rand Decker[1], Chuck Cullom[2], Charlie Ester[3] and Tom Piechota[4] ([1]NAU , [2]Central Arizona Project, Salt River Project, [4]UNLV)

Bark Beetles, Drought and Forest Conditions in The Southwest

John Anhold and Joel McMillin (USFS/Forest Health Monitoring, Arizona)

Altered Fire Regimes and Forest Thinning in Major Biomes.

Tom Kolb and Pete Fule (NAU, School of Forestry, Ecological Restoration Institute)

Ecosystem Responses.

Paul Selmants[1], Margaret Hiza[2], Matthew Loeser[3], and Gary Nabhan[4] ([1]NAU, School of Forestry [2]USGS, Flagstaff Field Center [3]NAU, Department of Biology/Center for Environmental Studies & Education, [4]NAU Center for Sustainable Environments)

Drought Effects on Mohave Desert Shrubs.

Robert Webb, U.S. Geological Survey, The Desert Laboratory, Tucson, Arizona.

Biodiversity of Native Plants and Animals.

Tom Whitham[1] and Rick Miller[2] ([1]NAU, Department of Biology & Merriam-Powell Center for Environmental Research, [2]Arizona Game & Fish Department)

Invasive species & Vector borne diseases.

Kathryn Thomas and Charles van Riper (USGS/NAU, Colorado Plateau Field Station/Southwest Biological Science Center).

Stakeholders: Federal, State, Tribal, County and Municipal Perspectives

Bureau of Land Management. Carl Rountree

United States Forest Service/Southwest Strategy. Harv Forsgren

National Park Service. Ron Hiebert

Bureau of Reclamation. Carol Lynn Erwin

Bureau of Indian Affairs. Barry Welch

Arizona Game and Fish/US Fish and Wildlife. Rick Miller/Brenda Smith

Natural Resources Conservation Service. Michael Somerville, Don Paulus

Arizona Department of Water Resources Drought Task Force. Kathy Jacobs

Central Arizona Project. Chuck Cullom

Northern Arizona Council of Governments/Navajo County. Percy Deal

United States Geological Survey. Chris Smith

Town of Payson Water. Mike Ploughe, Scott Stratton

Drought Planning: A State, National And International Perspective On Strategies For Success.

Donald A. Wilhite, Director, National Drought Mitigation Center

The Effects of Drought on Agriculture, Food and Domestic Security.

Gary Nabhan, Director, Center for Sustainable Environments (Presented on Day 2).

Highlights of the First Day's Presentations: A Perspective From Dennis B. Fenn, USGS, Southwest Biological Science Center

1) It was recommended that communities and government use a risk management approach rather than a disaster response approach to drought.
2) The Hydro-Illogical Cycle shown by Dr. Wilhite is a good graphic that illustrates the challenges facing society in taking a long-term approach to drought preparation.
3) Numerous speakers have indicated that there are several types of drought.
   - Meteorological
   - Agricultural
   - Hydrological
   - Socio-Economic and Political

4) The Southwest has suffered drought before and we will suffer drought again in the future. The difference now is that society's degree of vulnerability has increased due to population growth and economic development in the region.

5) The question was raised about whether Arizona is now in the grips of what has been termed a mega-drought. Most speakers said it is difficult to judge if this is an accurate assessment, but some speakers said they see little to suggest we should be optimistic that the drought will end soon. Other speakers claimed some of the drivers of drought in the Southwest, as well as large hemispheric climate models, are yielding clues that suggest the drought may be losing its grip.

6) We learned that our moisture in the Southwest is the gift of three fickle magi from afar, who answer to the names:

   - ENSO – El Nińo Southern Oscillation
   - PDO – Pacific Decadal Oscillation, and
   - AMO – Atlantic Multi-Decadal Oscillation

   Sometimes these forces work together for our good; while at other times they fight it out, to our detriment.

7) Several speakers told us about the ecological effects of drought, using examples like the biodiversity bottleneck, reproductive success determinants, the boon and bane of invasive species, and zoonotic disease movers and shakers.

8) The land and water management, and regulatory agencies described how drought could complicate their agency mission, such as in setting maximum animal units for each grazing allotment.

9) We heard about how drought, federal land management agency policies in response to drought, and California's economy, are acting together to cause a significant portion of our formerly open rangeland to be sold off into 40-acre ranchettes

10) We heard about the need for monitoring protocols and better ecological information on the effects of drought. For example, what are drought indicators that might have practical application for the land manager?

11) We learned that the Colorado River is at least 25 percent over-allocated because the allocation model was based upon a 30-year wet period rather than on the more accurate long-term norms. This is now creating social conflict within the basin and a potential water crisis in several states, especially in California and Arizona.

12) Several speakers mentioned the concern that drought is synergistically acting with forest management practices in the U.S. to create more wildfires annually as well as far more destructive fires than ever before.

13) Several speakers called for the development of a list of drought plan triggers that communities and government could use in order to respond more effectively to drought events in a timely fashion.

WORKING GROUP SUMMARIES

CLIMATE WORKING GROUP

Compiled by Gregg Garfin, Climate Assessment for the Southwest, University of Arizona

The Climate Working Group (CWG) examined issues with regard to key research, monitoring, prediction, and communication needs for the Southwest with a special focus on Arizona. Among the issues considered most important for further research and attention, was the need to investigate the mechanisms that initiate and end drought – especially persistent severe drought. The CWG recommends special attention be given to decade-scale climate variations, usually the result of long-term ocean circulation patterns. Such variations are key to understanding the timescales associated with water supply replenishment, recovery from drought, and our ability to predict sustained drought.

The CWG recommends attention and resources be devoted to monitoring drought on many spatial and temporal scales, with a special emphasis on hydrological monitoring and improving the network of high-elevation monitoring sites. In addition, the CWG recommends support of global monitoring systems, in order to improve our ability to track the persistent ocean circulation patterns that control long-term drought in the Southwest, according to the most up-to-date research available.

The CWG found that our ability to predict drought is, at present, poor. Prediction is, in part, constrained by seasonal climate variations that limit forecast accuracy in spring, for example. However, the CWG is sanguine that drought forecasts will improve as deep ocean monitoring networks are expanded, and as information about decade-scale climate variations is incorporated into forecasts. In the absence of substantial forecast skill, and in addition to the present array of available forecast tools, the CWG recommends the development of scenario tests, based on analogues from historical and paleo-climate records.

Finally, the CWG suggests increased and improved communication, a single state drought spokesperson/coordinator, for example, the State Climatologist, and improved public education on drought in order to enhance our ability to mitigate the effects of, and respond to, persistent drought in the Southwest.

Key Issues

1) What starts and ends droughts?
   - Drought inducing ocean patterns
   - Persistence in climate system
   - Long-term decade-scale climate variations
2) What could trigger a wet period?
   - Some combination of the following, which affect the position of the Jet Stream and delivery of moisture to the Southwest:

        - Positive phase of the Pacific Decadal Oscillation (PDO), Negative phase of the Atlantic Multidecadal Oscillation (AMO: an example would be cooling in the North Atlantic Ocean), El Niño
    - A consistent combination of positive PDO and negative AMO for ~3 years
    - Individual events such as El Niño are merely interruptions

3) What drought indices are appropriate for AZ?
    - Palmer Drought Indices (PDSI< PHDI), Standard Precipitation Index (SPI), Surface Water Supply Index (SWSI), Remote Sensing-derived indices
    - For effective drought monitoring and assessment, there is a need to calculate drought indices at finer spatial scales
        - For example, is a county or watershed scale more appropriate?
4) What are the ***sub-regional*** spatial patterns of precipitation?
5) There is a need for research on droughtas well as drought monitoring to continue during wet periods.

Predictions

- No predictions were offered by the working group due the limitations of forecasting, however there are some recommendations for ascertaining possible predictions in the future:
    - A more accurate 9-month forecast of ENSO-related sea surface temperatures is possible following the spring months. During the spring the ocean-atmosphere system is unstable, resulting in poor forecast skill. Forecasts can be provided by NOAA's Climate Prediction Center (CPC), and from independent Global Circulation Models (GCM's)
    - With improved ocean monitoring more accurate forecasts are possible
    - One long-term consensus forecast is possible

Scenario Testing vs. Prediction

- A distinction important to decision makers in the Southwest is that long-term drought is subject to irregular *regimes*, rather than regular *cycles*.
- Droughts recorded in the historical and paleo-climate records can be used to develop a variety of scenarios for planning.
- Decadal-scale climate information, such as that derived from records of the PDO, El Niño-Southern Oscillation (ENSO), and AMO, should be incorporated into scenario development and testing.
- It is important that researchers provide explicit confidence statements with regard to scenarios and scenario testing.

Possible Scenarios

- Re-evaluate management decisions from recent drought years.
  - For example, if we had 100% foresight about 1999-2002 drought, could certain management decisions have mitigated the effects of drought?
- Mega-drought Scenarios – what would happen if the Great Drought (1200-1300's) occurred today?
- What are the implications of Arizona-only droughts versus more regionally extensive droughts?

Research Needs

- Assess and Implement Solutions to State/Regional Monitoring Gaps
  - Arizona requires soil moisture monitoring network of at least 25-30 stations
  - Maintain funding for stream gauges, groundwater monitoring, and climate stations; high elevation precipitation/snow monitoring stations
  - Update key tree-ring records
    - Need 2002 to establish a more effective baseline for State/Regional
    - Monitoring gaps
  - Incorporate remotely sensed data in order to fill in spatial gaps, especially with regard to summer PPT
- Global Monitoring is necessary to help assess the status of climate patterns that affect the Southwest.
  - Non-tropical ***deep ocean*** monitoring
  - Support NOAA (CLIVAR) - have plans to increase instrumentation
  - Be ware that better monitoring and forecast tools may be available in the near future
  - Our understanding of climate is improving

Outreach & Communication Needs

- Improve public understanding through outreach programs.
  - Make published research available to managers and decision makers; encourage & improve such efforts
- Have a state drought spokesperson.
  - For example, a state climatologist
- Get the attention of federal forecast/climate agencies to focus on SW issues.
  - For example, decadal-scale drought

- Increase communication among and between disciplines .
  - For example, climatologists and economists

WATER WORKING GROUP

Compiled by Margot Truini[1], Abe Springer[2], David Ostergren[3]

[1]USGS, Flagstaff Field Office, [2]Northern Arizona University, Department of Geology, [3] Northern Arizona University, Center for Environmental Science and Education

Although the focus on droughts is usually on a lack of precipitation, this decrease in precipitation has consequences for hydrologic systems on and below the surface of the Earth. Drought leads to a decrease in recharge to aquifers through reductions in: (1) aerially distributed recharge, (2) focused recharge, (3) waste water return flows, (4) irrigation return flow, and from (5) increased evaporation and transpiration. The typical response of humans to a hydrologic drought is to: (1) pump more groundwater at existing wells to make up for loss of surface water, (2) drill more boreholes to augment supply, (3) remove riparian vegetation to decrease transpiration, (4) implement conservation practices, and/or (5) develop alternative water supplies.

Hydrologic drought impacts soil water and groundwater in many ways. It leads to a loss of groundwater and soil-water storage. This causes water levels in wells to be lowered and an increased depth to water in riparian areas with less water available for the plants to transpire. It also leads to a decrease in aquifer discharge. This will cause a decrease in base-flow in streams and lakes, decreased spring discharges, and decreased aquatic habitat in streams and lakes. Other impacts are increases in the risks from land subsidence and saltwater intrusion.

The U.S. Geological Survey began a system of monitoring stream discharge in the late 1800's on many streams in the U.S. There are now continuous gages on over 7,000 streams, but a lack of stations with records of more than 30 years and a growing loss of gages on the smallest, unregulated streams, make it difficult to observe the impacts of drought on base-flow. In response to the drought of the 1930s, the USGS began monitoring water levels in a network of wells. Generally, this program has a more complete and extensive record in the Eastern U.S. than in the Western U.S. Some states use these wells as part of their drought management strategy.

Because of the lack of direct hydrological measurements of the impacts of recent droughts, it is useful to look at the hydrological impacts of land-use management to understand potential impacts on hydrological systems. There are good examples of changing agricultural practices and changing forest management practices to use as surrogates to understand the changes we might anticipate from drought. Also there may be animal taxa, such as spring snails, that may be very useful habitat indicators of long-term vegetation patterns, to understand drought on longer time scales.

The water in the Colorado River is fully subscribed, which will only exacerbate future drought conditions. There are a variety of demand tensions, including unprecedented population growth in the Southwest that need to be understood in order to develop viable plans for the

region. International and Native American water rights claims/settlements need to be resolved and/or considered in drought plans that explicitly involve water use. There are supply tensions among political entities in the region that will have a major impact on dealing with basin wide drought. Sensitivity of snowpacks to climate forcings will be an important consideration in predicting future water availability. On-going water resource planning remains crucial for our future. Drought can exacerbate the potential for reactionary and politically motivated water planning. Systematic, basin wide natural resource planning that incorporates technical, policy and social knowledge is crucial for successful panning. For example, the Chesapeake Bay Program is a multi-state, multi-campus, multi-disciplinary program that exemplifies successful natural resource planning and management. This is one potential model that the Southwest should consider, in order to ensure that we are successful in developing future water supplies without compromising natural resources and quality of life for some communities in order to supply other communities.

Key Issues

1) There is a public perception that the resource is unlimited.
   - The notion that one might have to pay higher water fees, but there is plenty of water to go around right now without a lot of thought towards the future
2) There is a need for adequate land use planning.
   - Real estate planners, golf courses
3) Conversion of agricultural land to residential land.
   - Apparently, residential land use uses more water then the previous agricultural uses of the land
4) A desire to preserve "the rural way of life" despite its current conflict with maintaining or creating sustainable conditions.
5) Impacts on hydrologic processes (recharge/storage)
   - Increased runoff where trees and plants have been removed from the land cover, allowing water to keep moving over the land instead of going into the ground
   - Increased Fire and
   - bark beetle infestations
6) There exist short-term institutional barriers to water movement.
   - Conservation practices
7) There is a need for better communication/outreach/interaction on water shortage/supply.
   - Devise approaches to educating people on how to conserve water, where the water comes from, who is sharing the water with them, and why they should conserve
8) Urban/rural polarization must be reduced.

- Devise better communication between the urban and rural communities with regards to water use, water needs (i.e. livestock needs versus filling your swimming pool). The larger voting body is typically urban and thus rural needs and issues may be overlooked.

9) Regular stakeholder involvement in is needed more in the planning process.
   - Allow greater public participation

10) Greater communication of hydrological issues to land managers is needed along with promoting greater public participation.

11)

12) The problems that arise with water availability in relation to a growing population must be taken into account.
   - The growing population means more wells pulling out more water. How many wells can we put in the ground and on what evidence is this water use based? Can a community establish a population number, based on the water availability, beyond which there can be no more growth?

13) Need to evaluate the impact of drought on watershed scale, point monitoring (e.g., single wells) is not adequate.
   - An example of this is wells drying up in Parks, Arizona

14) Further study of groundwater/surface-water interaction is necessary.
   - Is ground water being withdrawn from wells near a flowing river impacting the river stage?
   - For example, Chino Valley and the Verde River, or the Little Colorado River Basin

15) How will the dynamics of drought and decreased snow pack impact water availability?
   - For example, increased temperatures
   - Less snow means less recharge to ground water or run off to Lake Powell. How does this affect water use in communities?

16) It is necessary for many different constituents to understanding the water budget.
   - Regional understanding of where the water from the tap is coming from. Learn how to communicate this to water managers and communities to help conserve water and/or limit growth

17) There needs to be centralized management and planning authority.
   - Make sure all parties involved are making informed decisions based on sound information

18) A greater understanding of supply and demand is necessary.
   - How much water is available and who needs it?

19) How does location affect water availability in certain communities?
   - upstream vs. downstream

- water rights issues, water quality issues

20) More accurate information/indices are needed.
    - Make sure the parameters and conditions under which the data were collected are well understood
    - For example, long-term versus short-term surface water gauging data; or tree ring data; or paleo-climatic data)

21) Time scales for the information being collected and used in planning must be taken into consideration.
    - Same concerns and suggestions as for #19

22) The integrity of spring, seep, and riparian ecosystems must be protect and preserved.
    - Make sure riparian ecosystems are not adversely impacted by human needs

23) Protection of endangered species is necessary.
    - Protection of the ecosystem(s) in which the species lives

Predictions

- Droughts are normal and will continue.
    - Understanding that drought is part of the climatic cycle whether caused by anthropogenic or natural causes
- Less snow pack will decrease recharge to aquifers and reduce surface water availability.
    - Fits into understanding the water budget and how drought affects the water used by a community and/or decisions made by City water managers
- Increased evapotranspiration (i.e., water transpired by plants) will occur with increases in temperature.
    - Evapotranspiration removes a lot of water from a system. More plants lead to an increase in water loss
- Aquifers will continue to be drained regardless of drought conditions.
    - Communities ignore drought conditions and continue with the same level of water usage as in non-drought conditions
- Policy links must be made between groundwater and surface water.
    - Communities have to be pro-active and learn about the hydrologic connection between groundwater and surface water and make sound water use decisions based on this understanding
- The increase in population will result in an increase of ground water pumping.

- There will be an increase in sedimentation in existing reservoirs due to the impacts of fire in watersheds.
    - Surface water runoff in areas where foliage has been removed by fire or other means will increase the salinity within the reservoirs from increases in the sediment being carried in with the water and diminish the water quality
    - Decrease storage
    - Decrease in water quality
- Changes in channel morphology will occur.
    - Down cutting and/or aggradations
    - Apparently, either process can occur in times of drought
- Groundwater usage and pumping will increase as it is no longer possible to create new surface-water reservoirs.

- Rivers, streams and washes will be negatively impacted by the continued loss of discharge from the groundwater systems due to a increased water use and a lack of recharge. This condition will be aggravated by the impacts if pumping in rivers and streams, and base-flow will be especially problematic near pumping centers.

- A greater use of alternative water supplies will need to occur.
    - Recycled water, reclaimed effluent, and captured water, for example, storm water
    - Gray water
- Water quality will continue to decline as wastewater is a soup of unregulated compounds.
    - Know what is in your reclaimed/recycled water and which uses are reasonable
- We will work together---the population will respond.
- We will protect rivers, plants, animals.
- A change in the economic paradigm must occur so that growth is not the only valid indication of the future health of our country.

Manager Needs

- Define the triggers and thresholds of drought for clarification and identification purposes.
    - Through dependable scientific means identify ways to measure aspects of the hydrologic system that clearly declare drought conditions
- Make data readily accessible as well as understandable, and easy to interpret.
- Researchers must produce information and materials in a timely manner.

- Create a comprehensive, integrated spring monitoring program.
    - Identify vulnerable springs
    - Establish monitoring program
- Assess hydrologic needs and concerns at the geographic scale of watersheds.
- Know and understand redundant water supplies, especially in rural areas.
- Understand transient nature of water budgets and associated processes.
    - Recharge
- Generate better GIS information for hydrologic planning/models for floodplains and watersheds.
-
- Define appropriate baseline conditions/trends, triggers, and thresholds of drought.
- Create a comprehensive, integrated, monitoring program in real time in designated monitoring wells.
    - Determine well sites that are unused, to collect water level data, which can be used to determine the health of the ground water system
    - Identify vulnerable aquifers
    - Establish monitoring program
- Increase resources for proper management.
- Incorporate cultural information into hydrologic system management.
- Estimate returns on previous investment in research.
    - Make sure the manager understands what will happen if they do not invest in gaining knowledge about the hydrologic system they depend on for water

- Need to support long-term monitoring.
    - Managers often provide funding for short time period, but scientists understand and need long term monitoring to provide information for at least some solutions
- Participation in Drought Task Force and subgroups is required.
- Create an organizational framework that would facilitate communication among researchers, managers, and other stakeholders.

Researcher Needs

- Increase in allocation of resources, including funding that are adequate and sufficient, towards drought research.
- Make data from land and water managers accessible to help guide research efforts

  - Knowing past & present land uses (e.g., grazing, timber sales) would be helpful for directing research, or placing it in appropriate context

- issues.
- Management planning documents and policy papers need to incorporate more results from studies. Researchers need to know how the results of their research will be disseminated. Despite researchers voluntarily compiling their results for managers, they are not always incorporated into management plans.
- Government and agency support for long-term studies. Land management plans and funding agencies need to invest at least some resources in long-term monitoring and research in order for early detection of drought impacts and initiation of drought mitigation plans.
- Scientists must have a forum for collaboration with stakeholders, managers, and others.
- Scientists must build relationships with managers and take time to interact with them.
- Prioritize research.
- Responsibilities must be delineated.
- Scientists must participate in the AZ Drought Task Force and in each subgroup.

BIODIVERSITY WORKING GROUP

Compiled by Peter Price, Neil Cobb and Kitty Gehring
Northern Arizona University, Department of Biology, and Merriam-Powell Center for Environmental Research.

The Biodiversity Working Group examined several areas of interrelated interest that were highly relevant to drought issues. Concerns about loss in biodiversity is relevant because of the direct impact of drought on plants and animals and the added pressure of human activities exacerbating the problem of drought for plant and animal species.

The areas of focus by the working group were native plant and animal populations, species, and communities, with a complementary but separate focus on key wildlife species. The other areas of focus were the role of drought in promoting insect outbreaks, invasive plant species, and diseases affecting humans and wildlife. Here we summarize the predictions and issues regarding biodiversity and provide some recommendations for mitigation biodiversity losses, including population reductions of key wildlife and plant species at risk.

Key Issues

1) Species at risk – threatened and endangered species
   - We need to know the species that are impacted by drought, those that are at the southern end of their range, those that exploit temporary water holes and small springs, and those that utilize other species susceptible to drought, such as herbivores

2) Habitat types at risk (fragmentation and conversion) along with keystone/dominant species
   - There will be increasers and decreasers in response to drought. The proportion in each of these categories will likely depend on the length and severity of drought
   - Predictions are needed on the response of many species. Keystone species are defined as those species that greatly impact the ecosystems in which they live (i.e. productivity, biodiversity) well beyond their biomass, e.g. ants
3) The problems of invasive species and several diseases are likely to increase
   - Detection protocols are needed to reduce movement and colonization of invasive species in new areas. Monitoring programs need to provide early warning of the existing of emerging diseases.
4) The scale of studies and interactions affect perceptions on the importance of drought
   - Highly mobile animals may be less impacted than immobile plants and poor dispersers such as snails and fish. Conversely, large animals might be more impacted than small animals. Wildlife species, insects and plants will respond to drought in different ways, which we need to understand
5) Long-term and short-term effects are important to understand
   - This will require long- term studies and the establishment of a data bank with any relevant long-term data generally available. Shortage of long-term studies, experiments and monitoring of permanent plots is a disadvantage for understanding the consequences of drought. Existing data sets should be exploited
   - There are few sources of funding designated to support the long-term integrated aspects of drought
6) Education at all levels, from bio-political to management and cultural
   - Paradigm shifts will be necessary for any activity that could have major impacts on biodiversity during droughts. Such activities and policies include grazing and grazing rights, home water use, irrigation, grey water, storage of run-off, promotion of efficiency and general water conservation
7) Priorities need to be set, scenarios developed and general planning established to interface society, research, management and policies
8) Socioeconomic priorities need to be debated and resolved, including outdoor recreation, promotion of planning for urban development or its restriction, farming, sports, natural areas and wilderness. Protection of property and sensitive habitats against fire will be essential
9) The role of temperature as a factor explaining insect outbreaks and invasive species needs to be considered. Although we focus on precipitation during droughts, increased temperatures can play an important role in promoting pest outbreaks.

Predictions

- We predict several changes will occur in the biodiversity of plants and animals. One of the biggest concerns is that sensitive species will go locally extinct. These will include species that are the most directly dependent on water resources such as springs. Populations of most species will be more likely to move north in latitude or up elevational gradients to areas that fulfill needs for sufficient water and reduced temperatures. Contraction of geographic range may be common as large areas become too stressful for reproduction and survival. Drought-adapted species will increase in abundance and/or expand their range. Thus, there will be different responses to drought, both in the short term and long term. Some species will increase in abundance and distribution while other species will decrease. Examples of species include:
  - Short-Term Response
    - increasers – bark beetles, invasive plants, generalist species, bark foragers
    - decreasers – threatened and endangered species, specialists, many wildlife species
  - Long-Term Response
    - increasers - invasive species, some wildlife (depends on habitat shifts)
    - decreasers – bark beetles and bark foragers, specialists
- Resetting of succession. Death of dominant plants and fire will set plant community succession back to earlier stages, for example from forest to weedy annuals. Drought may result in terrestrial plant succession succeeding aquatic habitats
- Existing refugia may decline or be lost. Sky island habitat will shrink, and aquatic and moist habitats will decline, perhaps resulting in unsustainable populations of residents
- Foci of interactions concentrate around limited water resources, leading to greater competition and potential for spread of diseases
- Bottlenecks develop in space and time. As size of populations decrease to critical levels, genetic bottlenecks result and establishment of new and viable populations is greatly limited

Common Needs for Managers and Researchers

- Priority lists for planning, including identifying species of concern, habitats of concern, and how their viability depends on water conservation, and land use practices
- Setting socioeconomic priorities such as outdoor recreation, private property use and hunting.
- Long-term data sets from experiments to monitoring of species distributions and abundances, plant and animal community structure, and response of key species to drought
- Network of long-term protected plots representing all southwest habitat types, including control plots, for extended observation of communities, interactions and responses to drought
- Monitoring criteria and protocols for standardized data collection and directly comparable results

- Acceleration of permitting processes to conduct critical studies for understanding how drought impacts populations, and plant and animal communities
- Improved information exchange between researchers and managers
  - Meetings, conferences and online research forums necessary for researchers and managers to effectively respond to one another's needs
- Review and synthesis of scientific information needs to be conducted on an annual basis through interdisciplinary research/management teams
- Historical photographs, remote sensing, databases should be incorporated into current drought-specific data so that we can better ascertain how habitats have changed over time (historic photos) and across the Southwest (remote sensing), as well as how they might impact different land management practices (existing databases)
- Development of predictive models and scenario modeling to better understand how sensitive species, dominant species, and biodiversity will be impacted across spatial and temporal scales
- Identification of sensitive habitats and environments and the reduction of impacts by increased active management during drought
- Management for movement and range extension of exotics, invasives, disease and vectors of disease. Disease transmission dynamics will change with drought conditions, which need to be anticipated
  - e.g., How is an emerging disease like West Nile virus impacted by drought?
- Management at multiple scales. Management needs to be concerned with genetic, population, community, ecosystem, landscape, bioregion and global scales
- Management as if every year is a drought year, at least for species and communities at risk so that they are buffered during droughts, which are unpredictable
- Conflict recognition and resolution. Predictions and management plans are necessary to resolve inevitable conflicts of interest when shortages occur

ECOSYSTEMS WORKING GROUP

Compiled by Matthew Loeser
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The Ecosystems Working Group (EWG) identified the effects of drought on rural ecosystems, including reduced food security, lost economic vitality, and diminished environmental sustainability. The drought of 2002 in combination with consecutive years of dry conditions has had extensive negative effects on the rural lands and people of Arizona. The EWG predicted that the 2002 drought will have long-term effects on rural communities and that state resources should be invested in mitigating the effects of future droughts. In particular, the EWG recommends a statewide research program that would identify priority areas for monitoring and subsequently serve as a warning system for imminent threats.

The EWG predicts future droughts will produce many of the same negative effects of the 2002 drought on rangelands and agriculture because regional mitigation plans do not exist. Rural economic security would be bolstered by further economic diversification as well as emphasis on managing our natural resources for drought-readiness. Successful preparedness will depend on an educated public, particularly on the issues of natural resources and food production. We recommend the creation of a drought-focused educational outreach program for rural and urban communities.

In summary, the EWG supports a pro-active approach to drought and its effects on rangelands, agriculture, and desertification. It was our estimation that cost-savings, in both economic and environmental terms, would greatly exceed the costs of initiating a drought-readiness program.

Key Issues

1) Plans for managing land must consider and address a range of drought conditions even before drought occurs.
   - Agencies need established criteria upon which to judge the severity of a drought and then apply appropriate mitigation efforts
2) There is a need for planning across boundaries so that efforts will be effective and appropriate for political, urban, and rural constituents.
   - Drought commonly crosses political boundaries, but agencies struggle to work across those same boundaries
3) Identify common goals between environmental and agricultural sustainability.
   - Resource managers would benefit from an enumeration of the shared goals of constituents
4) Raise awareness about the connection between plants and animals and rocks, water, soils.
   - The public should be better educated on the interrelationships of hydrology, geology, and biology
5) The deferral of ecological debts on public land has been institutionalized.
   - Pay now or pay later
   - The public should be informed as to the trade-offs that exist in management actions
   - Failing to act now or without some level of conservation of water may be limiting options in the future
6) There is a need for rapid measurement tools to allow for de-stocking & restocking of livestock.
   - In some parts of Arizona, livestock die-offs occurred due to a lack of understanding of the severity of the drought. Managers need tools to inform their decisions

7) The measurement of ecological changes must be ongoing to put drought in context.
   - Resource managers rarely have information on ecological dynamics that occur at multi-century time scales, let alone multi-decadal scales. We need scientific information to put ecological change in context
8) There must be monitoring at the landscape and/or watershed scale.
   - Effective monitoring requires an assessment of the appropriate scale. We recommend a large-scale approach
9) Monitoring protocols need to be standardized. Standardization of monitoring protocols
   - Different agencies apply different monitoring protocols which makes inter-agency collaboration difficult
10) There is a need to identify thresholds/triggers of major ecological change.
   - There is a growing awareness that ecological change often occurs once a threshold has been crossed. Can we identify drought thresholds for the ecological communities of Arizona?
11) The impacts of drought on agriculture needs to be assessed, including any subsequent changes in the industry's feedback to the economy.
   - There needs to be an assessment of the costs of drought based on its effects to Arizona's agriculture
12) The impacts of ranchland being converted to subdivisions due to economic pressure needs to be explored and addressed.
   - Drought conditions can push ranching families into selling land for development that may have negative consequences for ecosystems
13) Strategies for dealing with an increased water demand as the result of the urbanization of farmland need to be developed.
   - As farmland becomes developed, more water is consumed. Communities may wish to apply growth boundaries
14) The economic viability of rural communities during drought needs to be explored and addressed.
   - Diversification: Drought conditions highlight the need for a diversified income, but rural people may need support to diversify
   - Forest health
15) There is a need for public outreach to educate citizens about drought and what an appropriate response to it should be.
   - More informed citizens would lead to more effective decisions
16) Seek a common understanding of land management goals among all stakeholders
   - Resource managers would benefit from an enumeration of the shared goals of constituents

17) Education and outreach is needed to reconnect society with the land and food production.
    - Over the last 100 years the American people have become further and further separated from their source of food. This separation limits the ability of the people to make informed decisions regarding the security of their food

18) There is evidence of frequent, low-intensity fires in Southwestern ponderosa pine forests prior to Euro-American settlement. The disruption of this fire regime in the late 1800's, and large increases in tree density since then, are irrefutable.
    - Increasing fuel loads and drought in Southwest ponderosa pine forests cause large, synchronous crown fires

Predictions

- An export of soil will cause state changes in plant communities.
    - Drought tends to lead to increases in soil loss through erosion which may lead to the following ecological responses
        - Higher proportions of woody vegetation
        - Increased desertification

- Changes in land use practices are contingent on changing behavior.
  - Human behavior may be more limiting to changing land use practices than scientific knowledge
- Frequency of large synchronous crown fires will likely increase in the future because present fuel loads and future increases in fuels overwhelm current capacity for fuels reduction treatments.
  - Effects of these large synchronous crown fires include: increased opportunities for invasion by exotic, noxious weeds; massive soil erosion; flooding; damage to down slope riparian areas; deforestation for decades to centuries; degradation of aesthetics; degradation of recreation opportunities; and many others
  - Heavy crown damage to ponderosa pine reduces tree resistance to bark beetle attack, and may promote landscape scale beetle outbreaks
- Heavy ponderosa pine mortality from bark beetles, an effect of the 2002 drought, will likely affect fire incidence and behavior, but data is scarce. A hypothesis is: As long as dead needles remain on the dead trees the hazard for an intense crown fire is high. When the needles fall to the ground the probability of an intense crown fire decreases, but increases for a low-intensity ground fire until they deteriorate. When the dead trees fall, the probability of crown fire is nil, and the residence time of ground fires should increase because of more slow-burning fuels.
- Severe drought decreases herbaceous productivity and diversity, with the following possible effects: increased soil erosion, increased opportunities for exotic plant invasion, reduced energy transfers through food webs, lower NPP and carbon sequestration, altered food webs , and less animal forage.
- Thinning causes small, ephemeral increases in down slope water runoff and drainage; effects diminish as vegetation recovers.
- Landscape scale thinning in the future will be limited by the high costs of treatment, low wood value, and lack of regional markets; inadequate resources for quick NEPA has been suggested as a constraint. Solutions include: 1) coordinated/consistent wood supply, 2) incentives to stimulate local markets/biomass energy, 3) “super NEPA” teams, 4) large state/federal subsides/public works programs.

Manager Needs

- An increase in rapid and statistically reliable monitoring techniques that are also inexpensive is needed.
- Resource managers need to know what and how to monitor drought conditions.
- Research must begin to emphasize the value of practical applications.
- Academic research should be encouraged to achieve both basic and applied results.
- Grazing management/planning systems should be based on research and account for climate.

- Resource management needs to create management plans that do not assume a consistent climate.
- An adequate response to drought will require the effort of more people and funding.
  - Better monitoring of rangeland, determining forage production
  - Established protocol for decision making due to drought
- Planning should take into account the beneficial effects of thinning on ponderosa pine water uptake and growth are most pronounced in drought years; thinning ameliorates effects of drought on tree stress.
- Thinning is recommended to reduce ponderosa pine tree density in order to increase tree resistance against bark beetles and reduce crown fire occurrence
- Need to resolve potential conflicts among different users (i.e. recreation versus wildlife) in order to better plan and manage land across administrative boundaries.
  - An example of this is the Hopi – Navajo boundary
- Policymakers need to be informed on the consequences of developing rural land.
  - Preventing desertification of woodlands and savannahs as a practical matter over large areas
  - A region-wide plan should be developed for limiting desertification and its negative effects
  - Getting criteria for drought management into land use plans for federal agencies
- Drought management plans should exist at every level of government, from cities to the federal level.
  - Rethinking grazing practices/management and partnerships
    - For example, individual vs. common allotments
- Rapid response to drought will be more effective than a post-mortem approach.
  - Giving people options for what to do with their livestock
- Political decisions should recognize ecological constraints.
  - Ongoing ecological changes putting drought in context:
    - Grassland to woodland
    - Effects on water
    - Effects on resource availability (forage)
    - Effects on economic viability
  - Good ways of identifying onset and relief of drought

Researcher Needs

- Researchers need to know the questions to which the resource managers are seeking answers.
- More funding and involved people are necessary.
- Rapid measurement tools to allow for de-stocking and restocking of livestock are needed.
- The ongoing measurement of ecological changes is needed to put drought in context.
- Monitoring at landscape and/or watershed scale is necessary.
- Monitoring protocols must be standardized.
- Thresholds and triggers of major ecological change need to be identified.
- Much less is known about effects of thinning and fuels treatments on pinyon-juniper woodlands than ponderosa pine forests. Current thinning experiments in P-J offer research opportunities.
- Resource managers need early warning tools.
  - Primary goal of managing grazing
  - Identify thresholds/triggers of removing grazing or resuming grazing
    see previous comments
  - Analysis needs to recognize effects on the watershed scale
    see previous comments
  - Need to provide information from the 2003 drought summit and other sources to people to ensure an educated public

Outreach and Communication Needs

Creative solutions are needed to balance ecological and economic sustainability must be generated.

- Arizona should invest in an active research program in this arena

The state needs to share a responsibility in the resolutions of cross-political boundary conflicts.
urban-rural interface issues , for example, development impacts on water resources

Grazing practices should incorporate drought planning.

Changing emphasis from drought mitigation to management early on in drought

Livestock owners, especially those on tribal lands, need more options in drought conditions.

- Restoration strategy

A restoration strategy should be developed for ecological communities when drought periods end.

- Incorporating/recognizing other uses than domestic livestock as impacts to range:
  - OHV's
  - Oil and gas
  - Wildlife demands on forage
- Information in needed on drought recovery in order to allow use that was curtailed due to drought, particularly grazing.
- Political pressures versus ecological reality must be addressed.

- Drought education should be ongoing, even in drought-free times.

APPENDIX I

Links to Day 1 PowerPoint presentation and abstracts/outlines converted to html files

Science Presentations **http://www.mpcer.nau.edu/megadrought/drought_summit_report/science.htm**

Agency Summaries **http://www.mpcer.nau.edu/megadrought/drought_summit_report/agency.htm**

APPENDIX II

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Appendix II
Participant Responses

Participant Questionnaire

1. How did you hear about the presentation?
Email Newsletter Daily Newspaper Radio Colleague Other_____

2. How easy was registration?

Easy				Moderately Hard					Difficult
1	2	3	4	5	6	7	8	9	10

3. Was the material presented at the conference completely new, or a review of information you have had?

New				Moderately New					Complete Review
1	2	3	4	5	6	7	8	9	10

4. Was the material presented in a clear, understandable manner?

Clear				Moderately Clear					Difficult to Understand
1	2	3	4	5	6	7	8	9	10

5. How would you evaluate the visual material (power point, charts, tables)?

Clear				Moderately Clear					Difficult to Understand
1	2	3	4	5	6	7	8	9	10

6. Were the goals of the conference clear?

Clear				Moderately Clear					Difficult to Understand
1	2	3	4	5	6	7	8	9	10

7. Do you think we achieved our goals?

Achieved goals				Moderate Achievement				Lacked achievement	
1	2	3	4	5	6	7	8	9	10

8. Did you achieve <u>your</u> goals?

Achieved goals				Moderate Achievement				Lacked achievement	
1	2	3	4	5	6	7	8	9	10

9. Should there be another Drought Summit in:

3 months	6 months	1 year	2 years	Never

The tables below display the responses of the previous Participant Questionnaire. Of the ten questions, one, nine and ten are non-ranking in nature, whereas the other results displayed demonstrate a ranking from good to bad, with one being good, and ten being bad.

		QUESTIONS								
		1	2	3	4	5	6	7	8	9
Good	**1**	24 (email)	33		7	9	10	10	9	3 (3 months)
	2	4 (Newsletter)	3	5	7	10	6	3	12	12 (6 months)
	3	0 (Newspaper)	5	7	13	13	8	12	10	27 (1 year)
	4	2 (Radio)		6	6	8	4	4	4	4 (2 years)
Average	**5**	16 (Colleague)	2	7	7	1	7	6	3	
	6	2 (other)		5	2	2	5	4	5	
	7			10	3		1	1		
	8			4	1	1	3	3		
	9						1			
Bad	**10**									

Total		Good (1-3)	41	12	27	32	24	25	31	
Total		Average (4-6)	2	18	15	11	16	14	12	
Total		Bad (7-10)	0	14	4	1	5	4	0	

	10. Where should the next sumit be held?
Flagstaff	16
Tucson	10
Phoenix	7
Albuquerque	5
Arizona	5
Prescott	2
New Mexico	2
Utah	2
Colorado	2
Santa Fe	1
Durango	1
Chinle	1
Las Cruces	1
Kayenta	1

WORKING GROUP SUMMARIES

CLIMATE WORKING GROUP

Compiled by Gregg Garfin, Climate Assessment for the Southwest, University of Arizona

The Climate Working Group (CWG) examined issues with regard to key research, monitoring, prediction, and communication needs for the Southwest with a special focus on Arizona. Among the issues considered most important for further research and attention, was the need to investigate the mechanisms that initiate and end drought – especially persistent severe drought. The CWG recommends special attention be given to decade-scale climate variations, usually the result of long-term ocean circulation patterns. Such variations are key to understanding the timescales associated with water supply replenishment, recovery from drought, and our ability to predict sustained drought.

The CWG recommends attention and resources be devoted to monitoring drought on many spatial and temporal scales, with a special emphasis on hydrological monitoring and improving the network of high-elevation monitoring sites. In addition, the CWG recommends support of global monitoring systems, in order to improve our ability to track the persistent ocean circulation patterns that control long-term drought in the Southwest, according to the most up-to-date research available.

The CWG found that our ability to predict drought is, at present, poor. Prediction is, in part, constrained by seasonal climate variations that limit forecast accuracy in spring, for example. However, the CWG is sanguine that drought forecasts will improve as deep ocean monitoring networks are expanded, and as information about decade-scale climate variations is incorporated into forecasts. In the absence of substantial forecast skill, and in addition to the present array of available forecast tools, the CWG recommends the development of scenario tests, based on analogues from historical and paleo-climate records.

Finally, the CWG suggests increased and improved communication, a single state drought spokesperson/coordinator, for example, the State Climatologist, and improved public education on drought in order to enhance our ability to mitigate the effects of, and respond to, persistent drought in the Southwest.

Key Issues

1) What starts and ends droughts?
   - Drought inducing ocean patterns
   - Persistence in climate system

- Long-term decade-scale climate variations

2) What could trigger a wet period?

- Some combination of the following, which affect the position of the Jet Stream and delivery of moisture to the Southwest:
  - Positive phase of the Pacific Decadal Oscillation (PDO), Negative phase of the Atlantic Multidecadal Oscillation (AMO: an example would be cooling in the North Atlantic Ocean), El Niño
- A consistent combination of positive PDO and negative AMO for ~3 years
- Individual events such as El Niño are merely interruptions

3) What drought indices are appropriate for AZ?

- Palmer Drought Indices (PDSI< PHDI), Standard Precipitation Index (SPI), Surface Water Supply Index (SWSI), Remote Sensing-derived indices
- For effective drought monitoring and assessment, there is a need to calculate drought indices at finer spatial scales
  - For example, is a county or watershed scale more appropriate?

4) What are the ***sub-regional*** spatial patterns of precipitation?

5) There is a need for research on droughtas well as drought monitoring to continue during wet periods.

Predictions

- No predictions were offered by the working group due the limitations of forecasting, however there are some recommendations for ascertaining possible predictions in the future:
  - A more accurate 9-month forecast of ENSO-related sea surface temperatures is possible following the spring months. During the spring the ocean-atmosphere system is unstable, resulting in poor forecast skill. Forecasts can be provided by NOAA's Climate Prediction Center (CPC), and from independent Global Circulation Models (GCM's)
  - With improved ocean monitoring more accurate forecasts are possible
  - One long-term consensus forecast is possible

Scenario Testing vs. Prediction

- A distinction important to decision makers in the Southwest is that long-term drought is

subject to irregular *regimes*, rather than regular *cycles*.

- Droughts recorded in the historical and paleo-climate records can be used to develop a variety of scenarios for planning.
- Decadal-scale climate information, such as that derived from records of the PDO, El Niño-Southern Oscillation (ENSO), and AMO, should be incorporated into scenario development and testing.
- It is important that researchers provide explicit confidence statements with regard to scenarios and scenario testing.

Possible Scenarios

- Re-evaluate management decisions from recent drought years.
  - Ø For example, if we had 100% foresight about 1999-2002 drought, could certain management decisions have mitigated the effects of drought?
- Mega-drought Scenarios – what would happen if the Great Drought (1200-1300's) occurred today?
- What are the implications of Arizona-only droughts versus more regionally extensive droughts?

Research Needs

- Assess and Implement Solutions to State/Regional Monitoring Gaps
  - Ø Arizona requires soil moisture monitoring network of at least 25-30 stations
  - Ø Maintain funding for stream gauges, groundwater monitoring, and climate stations; high elevation precipitation/snow monitoring stations
  - Ø Update key tree-ring records
    - § Need 2002 to establish a more effective baseline for State/Regional
    - § Monitoring gaps
  - Ø Incorporate remotely sensed data in order to fill in spatial gaps, especially with regard to summer PPT
- Global Monitoring is necessary to help assess the status of climate patterns that affect the Southwest.
  - Ø Non-tropical ***deep ocean*** monitoring
  - Ø Support NOAA (CLIVAR) - have plans to increase instrumentation

- Be ware that better monitoring and forecast tools may be available in the near future
- Our understanding of climate is improving

Outreach & Communication Needs

- Improve public understanding through outreach programs.
  - Make published research available to managers and decision makers; encourage & improve such efforts
- Have a state drought spokesperson.
  - For example, a state climatologist
- Get the attention of federal forecast/climate agencies to focus on SW issues.
  - For example, decadal-scale drought
- Increase communication among and between disciplines .
  - For example, climatologists and economists

WATER WORKING GROUP

Compiled by Margot Truini[1], Abe Springer[2], David Ostergren[3]

[1]USGS, Flagstaff Field Office, [2]Northern Arizona University, Department of Geology, [3] Northern Arizona University, Center for Environmental Science and Education

Although the focus on droughts is usually on a lack of precipitation, this decrease in precipitation has consequences for hydrologic systems on and below the surface of the Earth. Drought leads to a decrease in recharge to aquifers through reductions in: (1) aerially distributed recharge, (2) focused recharge, (3) waste water return flows, (4) irrigation return flow, and from (5) increased evaporation and transpiration. The typical response of humans to a hydrologic drought is to: (1) pump more groundwater at existing wells to make up for loss of surface water, (2) drill more boreholes to augment supply, (3) remove riparian vegetation to decrease transpiration, (4) implement conservation practices, and/or (5) develop alternative water supplies.

Hydrologic drought impacts soil water and groundwater in many ways. It leads to a loss of groundwater and soil-water storage. This causes water levels in wells to be lowered and an increased depth to water in riparian areas with less water available for the plants to transpire. It also leads to a decrease in aquifer discharge. This will cause a decrease in base-flow in streams and lakes, decreased spring discharges, and decreased aquatic habitat in streams and lakes. Other

impacts are increases in the risks from land subsidence and saltwater intrusion.

The U.S. Geological Survey began a system of monitoring stream discharge in the late 1800's on many streams in the U.S. There are now continuous gages on over 7,000 streams, but a lack of stations with records of more than 30 years and a growing loss of gages on the smallest, unregulated streams, make it difficult to observe the impacts of drought on base-flow. In response to the drought of the 1930s, the USGS began monitoring water levels in a network of wells. Generally, this program has a more complete and extensive record in the Eastern U.S. than in the Western U.S. Some states use these wells as part of their drought management strategy.

Because of the lack of direct hydrological measurements of the impacts of recent droughts, it is useful to look at the hydrological impacts of land-use management to understand potential impacts on hydrological systems. There are good examples of changing agricultural practices and changing forest management practices to use as surrogates to understand the changes we might anticipate from drought. Also there may be animal taxa, such as spring snails, that may be very useful habitat indicators of long-term vegetation patterns, to understand drought on longer time scales.

The water in the Colorado River is fully subscribed, which will only exacerbate future drought conditions. There are a variety of demand tensions, including unprecedented population growth in the Southwest that need to be understood in order to develop viable plans for the region. International and Native American water rights claims/settlements need to be resolved and/or considered in drought plans that explicitly involve water use. There are supply tensions among political entities in the region that will have a major impact on dealing with basin wide drought. Sensitivity of snowpacks to climate forcings will be an important consideration in predicting future water availability. On-going water resource planning remains crucial for our future. Drought can exacerbate the potential for reactionary and politically motivated water planning. Systematic, basin wide natural resource planning that incorporates technical, policy and social knowledge is crucial for successful panning. For example, the Chesapeake Bay Program is a multi-state, multi-campus, multi-disciplinary program that exemplifies successful natural resource planning and management. This is one potential model that the Southwest should consider, in order to ensure that we are successful in developing future water supplies without compromising natural resources and quality of life for some communities in order to supply other communities.

Key Issues

1) There is a public perception that the resource is unlimited.

   - The notion that one might have to pay higher water fees, but there is plenty of water to go around right now without a lot of thought towards the future

2) There is a need for adequate land use planning.

- Real estate planners, golf courses

3) Conversion of agricultural land to residential land.

- Apparently, residential land use uses more water then the previous agricultural uses of the land

4) A desire to preserve “the rural way of life” despite its current conflict with maintaining or creating sustainable conditions.

5) Impacts on hydrologic processes (recharge/storage)

- Increased runoff where trees and plants have been removed from the land cover, allowing water to keep moving over the land instead of going into the ground
- Increased Fire and
- bark beetle infestations

6) There exist short-term institutional barriers to water movement.

- Conservation practices

7) There is a need for better communication/outreach/interaction on water shortage/supply.

- Devise approaches to educating people on how to conserve water, where the water comes from, who is sharing the water with them, and why they should conserve

8) Urban/rural polarization must be reduced.

- Devise better communication between the urban and rural communities with regards to water use, water needs (i.e. livestock needs versus filling your swimming pool). The larger voting body is typically urban and thus rural needs and issues may be overlooked.

9) Regular stakeholder involvement in is needed more in the planning process.

- Allow greater public participation

10) Greater communication of hydrological issues to land managers is needed along with promoting greater public participation.

11)

12) The problems that arise with water availability in relation to a growing population must be taken into account.

- The growing population means more wells pulling out more water. How many wells can we put in the ground and on what evidence is this water use based? Can a community establish a population number, based on the water availability, beyond which there can be no more growth?

13) Need to evaluate the impact of drought on watershed scale, point monitoring (e.g., single wells) is not adequate.

- An example of this is wells drying up in Parks, Arizona

14) Further study of groundwater/surface-water interaction is necessary.

- Is ground water being withdrawn from wells near a flowing river impacting the river stage?
- For example, Chino Valley and the Verde River, or the Little Colorado River Basin

15) How will the dynamics of drought and decreased snow pack impact water availability?

- For example, increased temperatures
- Less snow means less recharge to ground water or run off to Lake Powell. How does this affect water use in communities?

16) It is necessary for many different constituents to understanding the water budget.

- Regional understanding of where the water from the tap is coming from. Learn how to communicate this to water managers and communities to help conserve water and/or limit growth

17) There needs to be centralized management and planning authority.

- Make sure all parties involved are making informed decisions based on sound information

18) A greater understanding of supply and demand is necessary.

- How much water is available and who needs it?

19) How does location affect water availability in certain communities?

- upstream vs. downstream
- water rights issues, water quality issues

20) More accurate information/indices are needed.

- Make sure the parameters and conditions under which the data were collected are well understood
- For example, long-term versus short-term surface water gauging data; or tree ring data; or paleo-climatic data)

21) Time scales for the information being collected and used in planning must be taken into consideration.

- Same concerns and suggestions as for #19

22) The integrity of spring, seep, and riparian ecosystems must be protect and preserved.

- Make sure riparian ecosystems are not adversely impacted by human needs

23) Protection of endangered species is necessary.

- Protection of the ecosystem(s) in which the species lives

Predictions

- Droughts are normal and will continue.
  - Understanding that drought is part of the climatic cycle whether caused by anthropogenic or natural causes
- Less snow pack will decrease recharge to aquifers and reduce surface water availability.
  - Fits into understanding the water budget and how drought affects the water used by a community and/or decisions made by City water managers
- Increased evapotranspiration (i.e., water transpired by plants) will occur with increases in temperature.
  - Evapotranspiration removes a lot of water from a system. More plants lead to an increase in water loss
- Aquifers will continue to be drained regardless of drought conditions.
  - Communities ignore drought conditions and continue with the same level of water usage as in non-drought conditions
- Policy links must be made between groundwater and surface water.
  - Communities have to be pro-active and learn about the hydrologic connection between groundwater and surface water and make sound water use decisions based on this understanding
- The increase in population will result in an increase of ground water pumping.
- There will be an increase in sedimentation in existing reservoirs due to the impacts of fire in watersheds.
  - Surface water runoff in areas where foliage has been removed by fire or other means will increase the salinity within the reservoirs from increases in the sediment being carried in with the water and diminish the water quality

  - Decrease storage
  - Decrease in water quality
- Changes in channel morphology will occur.
  - Down cutting and/or aggradations
  - Apparently, either process can occur in times of drought
- Groundwater usage and pumping will increase as it is no longer possible to create new surface-water reservoirs.

- Rivers, streams and washes will be negatively impacted by the continued loss of discharge from the groundwater systems due to a increased water use and a lack of recharge. This condition will be aggravated by the impacts if pumping in rivers and streams, and base-flow will be especially problematic near pumping centers.

- A greater use of alternative water supplies will need to occur.
  - Recycled water, reclaimed effluent, and captured water, for example, storm water
  - Gray water
- Water quality will continue to decline as wastewater is a soup of unregulated compounds.
  - Know what is in your reclaimed/recycled water and which uses are reasonable
- We will work together---the population will respond.
- We will protect rivers, plants, animals.
- A change in the economic paradigm must occur so that growth is not the only valid indication of the future health of our country.

Manager Needs

- Define the triggers and thresholds of drought for clarification and identification purposes.
  - Through dependable scientific means identify ways to measure aspects of the hydrologic system that clearly declare drought conditions
- Make data readily accessible as well as understandable, and easy to interpret.
- Researchers must produce information and materials in a timely manner.
- Create a comprehensive, integrated spring monitoring program.

  - Identify vulnerable springs
  - Establish monitoring program
- Assess hydrologic needs and concerns at the geographic scale of watersheds.
- Know and understand redundant water supplies, especially in rural areas.
- Understand transient nature of water budgets and associated processes.
  - Recharge
- Generate better GIS information for hydrologic planning/models for floodplains and watersheds.
-
- Define appropriate baseline conditions/trends, triggers, and thresholds of drought.
- Create a comprehensive, integrated, monitoring program in real time in designated monitoring wells.
    - Determine well sites that are unused, to collect water level data, which can be used to determine the health of the ground water system
    - Identify vulnerable aquifers
    - Establish monitoring program
- Increase resources for proper management.
- Incorporate cultural information into hydrologic system management.
- Estimate returns on previous investment in research.
  - Make sure the manager understands what will happen if they do not invest in gaining knowledge about the hydrologic system they depend on for water

- Need to support long-term monitoring.
  - Managers often provide funding for short time period, but scientists understand and need long term monitoring to provide information for at least some solutions
- Participation in Drought Task Force and subgroups is required.
- Create an organizational framework that would facilitate communication among researchers, managers, and other stakeholders.

Researcher Needs

- Increase in allocation of resources, including funding that are adequate and sufficient, towards drought research.
- Make data from land and water managers accessible to help guide research efforts
  - Ø Knowing past & present land uses (e.g., grazing, timber sales) would be helpful for directing research, or placing it in appropriate context
- issues.
- Management planning documents and policy papers need to incorporate more results from studies. Researchers need to know how the results of their research will be disseminated. Despite researchers voluntarily compiling their results for managers, they are not always incorporated into management plans.
- Government and agency support for long-term studies. Land management plans and funding agencies need to invest at least some resources in long-term monitoring and research in order for early detection of drought impacts and initiation of drought mitigation plans.
- Scientists must have a forum for collaboration with stakeholders, managers, and others.
- Scientists must build relationships with managers and take time to interact with them.
- Prioritize research.
- Responsibilities must be delineated.
- Scientists must participate in the AZ Drought Task Force and in each subgroup.

BIODIVERSITY WORKING GROUP

Compiled by Peter Price, Neil Cobb and Kitty Gehring

Northern Arizona University, Department of Biology, and Merriam-Powell Center for Environmental Research.

The Biodiversity Working Group examined several areas of interrelated interest that were highly relevant to drought issues. Concerns about loss in biodiversity is relevant because of the direct impact of drought on plants and animals and the added pressure of human activities exacerbating the problem of drought for plant and animal species.

The areas of focus by the working group were native plant and animal populations, species, and communities, with a complementary but separate focus on key wildlife species. The other areas of focus were the role of drought in promoting insect outbreaks, invasive plant species, and

diseases affecting humans and wildlife. Here we summarize the predictions and issues regarding biodiversity and provide some recommendations for mitigation biodiversity losses, including population reductions of key wildlife and plant species at risk.

Key Issues

1) Species at risk – threatened and endangered species

   Ø We need to know the species that are impacted by drought, those that are at the southern end of their range, those that exploit temporary water holes and small springs, and those that utilize other species susceptible to drought, such as herbivores

2) Habitat types at risk (fragmentation and conversion) along with keystone/dominant species

   Ø There will be increasers and decreasers in response to drought. The proportion in each of these categories will likely depend on the length and severity of drought

   Ø Predictions are needed on the response of many species. Keystone species are defined as those species that greatly impact the ecosystems in which they live (i.e. productivity, biodiversity) well beyond their biomass, e.g. ants

3) The problems of invasive species and several diseases are likely to increase

   Ø Detection protocols are needed to reduce movement and colonization of invasive species in new areas. Monitoring programs need to provide early warning of the existing of emerging diseases.

4) The scale of studies and interactions affect perceptions on the importance of drought

   Ø Highly mobile animals may be less impacted than immobile plants and poor dispersers such as snails and fish. Conversely, large animals might be more impacted than small animals. Wildlife species, insects and plants will respond to drought in different ways, which we need to understand

5) Long-term and short-term effects are important to understand

   Ø This will require long- term studies and the establishment of a data bank with any relevant long-term data generally available. Shortage of long-term studies, experiments and monitoring of permanent plots is a disadvantage for understanding the consequences of drought. Existing data sets should be exploited

   Ø There are few sources of funding designated to support the long-term integrated aspects of drought

6) Education at all levels, from bio-political to management and cultural

- Paradigm shifts will be necessary for any activity that could have major impacts on biodiversity during droughts. Such activities and policies include grazing and grazing rights, home water use, irrigation, grey water, storage of run-off, promotion of efficiency and general water conservation

7) Priorities need to be set, scenarios developed and general planning established to interface society, research, management and policies

8) Socioeconomic priorities need to be debated and resolved, including outdoor recreation, promotion of planning for urban development or its restriction, farming, sports, natural areas and wilderness. Protection of property and sensitive habitats against fire will be essential

9) The role of temperature as a factor explaining insect outbreaks and invasive species needs to be considered. Although we focus on precipitation during droughts, increased temperatures can play an important role in promoting pest outbreaks.

Predictions

- We predict several changes will occur in the biodiversity of plants and animals. One of the biggest concerns is that sensitive species will go locally extinct. These will include species that are the most directly dependent on water resources such as springs. Populations of most species will be more likely to move north in latitude or up elevational gradients to areas that fulfill needs for sufficient water and reduced temperatures. Contraction of geographic range may be common as large areas become too stressful for reproduction and survival. Drought-adapted species will increase in abundance and/or expand their range. Thus, there will be different responses to drought, both in the short term and long term. Some species will increase in abundance and distribution while other species will decrease. Examples of species include:
  - Short-Term Response
    - increasers – bark beetles, invasive plants, generalist species, bark foragers
    - decreasers – threatened and endangered species, specialists, many wildlife species
  - Long-Term Response
    - increasers - invasive species, some wildlife (depends on habitat shifts)
    - decreasers – bark beetles and bark foragers, specialists
- Resetting of succession. Death of dominant plants and fire will set plant community succession back to earlier stages, for example from forest to weedy annuals. Drought may result in terrestrial plant succession succeeding aquatic habitats

- Existing refugia may decline or be lost. Sky island habitat will shrink, and aquatic and moist habitats will decline, perhaps resulting in unsustainable populations of residents
- Foci of interactions concentrate around limited water resources, leading to greater competition and potential for spread of diseases
- Bottlenecks develop in space and time. As size of populations decrease to critical levels, genetic bottlenecks result and establishment of new and viable populations is greatly limited

Common Needs for Managers and Researchers

- Priority lists for planning, including identifying species of concern, habitats of concern, and how their viability depends on water conservation, and land use practices
- Setting socioeconomic priorities such as outdoor recreation, private property use and hunting.
- Long-term data sets from experiments to monitoring of species distributions and abundances, plant and animal community structure, and response of key species to drought
- Network of long-term protected plots representing all southwest habitat types, including control plots, for extended observation of communities, interactions and responses to drought
- Monitoring criteria and protocols for standardized data collection and directly comparable results
- Acceleration of permitting processes to conduct critical studies for understanding how drought impacts populations, and plant and animal communities
- Improved information exchange between researchers and managers
    - Meetings, conferences and online research forums necessary for researchers and managers to effectively respond to one another's needs
- Review and synthesis of scientific information needs to be conducted on an annual basis through interdisciplinary research/management teams
- Historical photographs, remote sensing, databases should be incorporated into current drought-specific data so that we can better ascertain how habitats have changed over time (historic photos) and across the Southwest (remote sensing), as well as how they might impact different land management practices (existing databases)
- Development of predictive models and scenario modeling to better understand how sensitive species, dominant species, and biodiversity will be impacted across spatial and temporal scales

- Identification of sensitive habitats and environments and the reduction of impacts by increased active management during drought
- Management for movement and range extension of exotics, invasives, disease and vectors of disease. Disease transmission dynamics will change with drought conditions, which need to be anticipated
    - e.g., How is an emerging disease like West Nile virus impacted by drought?
- Management at multiple scales. Management needs to be concerned with genetic, population, community, ecosystem, landscape, bioregion and global scales
- Management as if every year is a drought year, at least for species and communities at risk so that they are buffered during droughts, which are unpredictable
- Conflict recognition and resolution. Predictions and management plans are necessary to resolve inevitable conflicts of interest when shortages occur

ECOSYSTEMS WORKING GROUP

Compiled by Matthew Loeser
Northern Arizona University, Center for Environmental Science and Education University

The Ecosystems Working Group (EWG) identified the effects of drought on rural ecosystems, including reduced food security, lost economic vitality, and diminished environmental sustainability. The drought of 2002 in combination with consecutive years of dry conditions has had extensive negative effects on the rural lands and people of Arizona. The EWG predicted that the 2002 drought will have long-term effects on rural communities and that state resources should be invested in mitigating the effects of future droughts. In particular, the EWG recommends a statewide research program that would identify priority areas for monitoring and subsequently serve as a warning system for imminent threats.

The EWG predicts future droughts will produce many of the same negative effects of the 2002 drought on rangelands and agriculture because regional mitigation plans do not exist. Rural economic security would be bolstered by further economic diversification as well as emphasis on managing our natural resources for drought-readiness. Successful preparedness will depend on an educated public, particularly on the issues of natural resources and food production. We recommend the creation of a drought-focused educational outreach program for rural and urban communities.

In summary, the EWG supports a pro-active approach to drought and its effects on rangelands, agriculture, and desertification. It was our estimation that cost-savings, in both economic and environmental terms, would greatly exceed the costs of initiating a drought-readiness program.

Key Issues

1) Plans for managing land must consider and address a range of drought conditions even before drought occurs.

- Agencies need established criteria upon which to judge the severity of a drought and then apply appropriate mitigation efforts

2) There is a need for planning across boundaries so that efforts will be effective and appropriate for political, urban, and rural constituents.

- Drought commonly crosses political boundaries, but agencies struggle to work across those same boundaries

3) Identify common goals between environmental and agricultural sustainability.

- Resource managers would benefit from an enumeration of the shared goals of constituents

4) Raise awareness about the connection between plants and animals and rocks, water, soils.

- The public should be better educated on the interrelationships of hydrology, geology, and biology

5) The deferral of ecological debts on public land has been institutionalized.

- Pay now or pay later
- The public should be informed as to the trade-offs that exist in management actions
- Failing to act now or without some level of conservation of water may be limiting options in the future

6) There is a need for rapid measurement tools to allow for de-stocking & restocking of livestock.

- In some parts of Arizona, livestock die-offs occurred due to a lack of understanding of the severity of the drought. Managers need tools to inform their decisions

7) The measurement of ecological changes must be ongoing to put drought in context.

- Resource managers rarely have information on ecological dynamics that occur at multi-century time scales, let alone multi-decadal scales. We need scientific information to put ecological change in context

8) There must be monitoring at the landscape and/or watershed scale.

- Effective monitoring requires an assessment of the appropriate scale. We recommend a

large-scale approach

9) Monitoring protocols need to be standardized. Standardization of monitoring protocols

- Different agencies apply different monitoring protocols which makes inter-agency collaboration difficult

10) There is a need to identify thresholds/triggers of major ecological change.

- There is a growing awareness that ecological change often occurs once a threshold has been crossed. Can we identify drought thresholds for the ecological communities of Arizona?

11) The impacts of drought on agriculture needs to be assessed, including any subsequent changes in the industry's feedback to the economy.

- There needs to be an assessment of the costs of drought based on its effects to Arizona's agriculture

12) The impacts of ranchland being converted to subdivisions due to economic pressure needs to be explored and addressed.

- Drought conditions can push ranching families into selling land for development that may have negative consequences for ecosystems

13) Strategies for dealing with an increased water demand as the result of the urbanization of farmland need to be developed.

- As farmland becomes developed, more water is consumed. Communities may wish to apply growth boundaries

14) The economic viability of rural communities during drought needs to be explored and addressed.

- Diversification: Drought conditions highlight the need for a diversified income, but rural people may need support to diversify
- Forest health

15) There is a need for public outreach to educate citizens about drought and what an appropriate response to it should be.

- More informed citizens would lead to more effective decisions

16) Seek a common understanding of land management goals among all stakeholders

- Resource managers would benefit from an enumeration of the shared goals of constituents

17) Education and outreach is needed to reconnect society with the land and food production.

- Over the last 100 years the American people have become further and further separated from their source of food. This separation limits the ability of the people to make informed decisions regarding the security of their food

18) There is evidence of frequent, low-intensity fires in Southwestern ponderosa pine forests prior to Euro-American settlement. The disruption of this fire regime in the late 1800's, and large increases in tree density since then, are irrefutable.

- Increasing fuel loads and drought in Southwest ponderosa pine forests cause large, synchronous crown fires

Predictions

- An export of soil will cause state changes in plant communities.
  - Drought tends to lead to increases in soil loss through erosion which may lead to the following ecological responses
    - Higher proportions of woody vegetation
    - Increased desertification
- Changes in land use practices are contingent on changing behavior.
  - Human behavior may be more limiting to changing land use practices than scientific knowledge
- Frequency of large synchronous crown fires will likely increase in the future because present fuel loads and future increases in fuels overwhelm current capacity for fuels reduction treatments.
  - Effects of these large synchronous crown fires include: increased opportunities for invasion by exotic, noxious weeds; massive soil erosion; flooding; damage to down slope riparian areas; deforestation for decades to centuries; degradation of aesthetics; degradation of recreation opportunities; and many others
  - Heavy crown damage to ponderosa pine reduces tree resistance to bark beetle attack, and may promote landscape scale beetle outbreaks
- Heavy ponderosa pine mortality from bark beetles, an effect of the 2002 drought, will likely affect fire incidence and behavior, but data is scarce. A hypothesis is: As long as dead needles remain on the dead trees the hazard for an intense crown fire is high. When the needles fall to the ground the probability of an intense crown fire decreases, but increases for a low-intensity ground fire until they deteriorate. When the dead trees fall, the probability of crown fire is nil, and the residence time of ground fires should increase because of more slow-burning fuels.

- Severe drought decreases herbaceous productivity and diversity, with the following possible effects: increased soil erosion, increased opportunities for exotic plant invasion, reduced energy transfers through food webs, lower NPP and carbon sequestration, altered food webs , and less animal forage.
- Thinning causes small, ephemeral increases in down slope water runoff and drainage; effects diminish as vegetation recovers.
- Landscape scale thinning in the future will be limited by the high costs of treatment, low wood value, and lack of regional markets; inadequate resources for quick NEPA has been suggested as a constraint. Solutions include: 1) coordinated/consistent wood supply, 2) incentives to stimulate local markets/biomass energy, 3) “super NEPA” teams, 4) large state/ federal subsides/public works programs.

Manager Needs

- An increase in rapid and statistically reliable monitoring techniques that are also inexpensive is needed.
- Resource managers need to know what and how to monitor drought conditions.
- Research must begin to emphasize the value of practical applications.
- Academic research should be encouraged to achieve both basic and applied results.
- Grazing management/planning systems should be based on research and account for climate.
- Resource management needs to create management plans that do not assume a consistent climate.
- An adequate response to drought will require the effort of more people and funding.
  - Better monitoring of rangeland, determining forage production
  - Established protocol for decision making due to drought
- Planning should take into account the beneficial effects of thinning on ponderosa pine water uptake and growth are most pronounced in drought years; thinning ameliorates effects of drought on tree stress.
- Thinning is recommended to reduce ponderosa pine tree density in order to increase tree resistance against bark beetles and reduce crown fire occurrence
- Need to resolve potential conflicts among different users (i.e. recreation versus wildlife) in order to better plan and manage land across administrative boundaries.

- An example of this is the Hopi – Navajo boundary

- Policymakers need to be informed on the consequences of developing rural land.
  - Preventing desertification of woodlands and savannahs as a practical matter over large areas
  - A region-wide plan should be developed for limiting desertification and its negative effects
  - Getting criteria for drought management into land use plans for federal agencies
- Drought management plans should exist at every level of government, from cities to the federal level.
  - Rethinking grazing practices/management and partnerships
    - For example, individual vs. common allotments
- Rapid response to drought will be more effective than a post-mortem approach.
  - Giving people options for what to do with their livestock
- Political decisions should recognize ecological constraints.
  - Ongoing ecological changes putting drought in context:
    - Grassland to woodland
    - Effects on water
    - Effects on resource availability (forage)
    - Effects on economic viability
  - Good ways of identifying onset and relief of drought

Researcher Needs

- Researchers need to know the questions to which the resource managers are seeking answers.
- More funding and involved people are necessary.
- Rapid measurement tools to allow for de-stocking and restocking of livestock are needed.
- The ongoing measurement of ecological changes is needed to put drought in context.
- Monitoring at landscape and/or watershed scale is necessary.

- Monitoring protocols must be standardized.
- Thresholds and triggers of major ecological change need to be identified.
- Much less is known about effects of thinning and fuels treatments on pinyon-juniper woodlands than ponderosa pine forests. Current thinning experiments in P-J offer research opportunities.
- Resource managers need early warning tools.
  - Ø Primary goal of managing grazing
  - Ø Identify thresholds/triggers of removing grazing or resuming grazing
    see previous comments
  - Ø Analysis needs to recognize effects on the watershed scale
    see previous comments
  - Ø Need to provide information from the 2003 drought summit and other sources to people to ensure an educated public

Outreach and Communication Needs

Creative solutions are needed to balance ecological and economic sustainability must be generated.

- Ø Arizona should invest in an active research program in this arena

The state needs to share a responsibility in the resolutions of cross-political boundary conflicts.
urban-rural interface issues , for example, development impacts on water resources

Grazing practices should incorporate drought planning.

Changing emphasis from drought mitigation to management early on in drought

Livestock owners, especially those on tribal lands, need more options in drought conditions.

- Ø Restoration strategy

A restoration strategy should be developed for ecological communities when drought periods end.

- Ø Incorporating/recognizing other uses than domestic livestock as impacts to range:
  - § OHV’s
  - § Oil and gas
  - § Wildlife demands on forage
- Ø Information in needed on drought recovery in order to allow use that was curtailed due

to drought, particularly grazing.

- Ø Political pressures versus ecological reality must be addressed.

- Drought education should be ongoing, even in drought-free times.

The Current Drought (1999-2003) in Historical Perspective

Julio L. Betancourt, Desert Laboratory, U.S. Geological Survey & University of Arizona, jlbetanc@usgs.gov

In the southwestern U.S., the past century has seen several large swings in climate. These swings are defined by dry spells during 1898-1904, 1946-1972, and wet periods during 1905-1924 and 1976-1998. Since 1999, the southwestern U.S., the southern and central Rockies and the western Great Plains have been gripped by persistent drought, particularly in 2002. The water year (October-September) of 2002 was the driest of the last century (45% of the normal from 1895-2002) in Arizona and second driest for the Southwest (AZ, NM, CO, UT). Still, the four-year average from 1999-2002 (77.8% of normal) did not exceed that for 1953-1956 (76.6%) or 1901-1904 (71.9%). Regardless of ranking, the ongoing drought has produced remarkable phenomena on the southwestern landscape, from a half-a-million-acre fire on the Mogollon Rim to more than a million acres of pinyon and ponderosa tree dieoffs in Arizona and New Mexico alone. Warmer and increasingly longer growing seasons cast troubling uncertainty about plant succession and movement in the wake of large-scale disturbances, synchronized by drought from New Mexico to Montana. How unusual is the current drought, what caused it, and how long can it continue?

Instrumental records of climate, spanning only the last 100 years, are inadequate for assessing the potential severity, persistence and frequency of drought, and for examining the sources of low-frequency climatic variability underlying short-term precipitation trends. As a proxy for instrumental records, ring widths from climatically sensitive trees provide a robust method for evaluating the long-term context for drought during the last millennium. Tree rings yield continuous, annually-resolved climatic reconstructions that are usually highly replicable. With proper sampling and analysis, tree rings can capture both high- and low-frequency signals of climate variability at local to subcontinental scales. In the long-term context provided by the rapidly-growing network of tree-ring chronologies, there are a few, perhaps relevant observations.

1. Drought frequency and magnitude varies considerably over time and space. During the 20th century, New Mexico experienced more frequent and severe droughts than Arizona. The reason may be that Arizona receives precipitation from a greater mix of storm types than New Mexico, and Arizona climate is therefore less susceptible to multiseasonal drought. Another explanation is that the Arizona-New Mexico contrast is peculiar to the 20th century, and Arizona perhaps has been drier than New Mexico at other times in the past. Tree rings suggest that the 20th century may or may not be representative of extreme climatic variability, depending on the region. For example, in southern New Mexico, 1950-1956 was the third driest period, while 1976-1998 represents the third wettest spell, in the last millennium. In the upper Colorado River Basin, none of the dry spells in the 20th century approach the severity or duration of extreme droughts in the tree-ring record, and the last 100 years stand out as the wettest century of the millennium. Hence, in New Mexico the 1950s drought is an appropriate, worst-case scenario for water and resource managers; in the upper Colorado River Basin, it is not.

2. There is conspicuous decadal (20-30 yrs) to multidecadal-scale (30-70 yrs) variability in the tree-ring record indicating large-scale persistence of climatic anomalies. Over a few centuries in a few tree-ring records (primarily in New Mexico), this variability appears cyclical. There is some optimism in the climate community that, once understood, cyclic behavior in the climate of western North America (and ocean temperatures as the likely source) could help extend severe drought prediction beyond seasonal forecasts. A more complete assessment of the regional network for tree-ring reconstructed precipitation, however, indicates that these low-frequency oscillations are not cyclic; instead they are unstable in time and space. This apparent nonstationarity (change in means and moments of the distribution through time) in the tree-ring record means that extended droughts (and extended wet periods) are generally unpredictable. Regional phasing of the most extreme droughts across large areas of North America, however, strongly implicate abrupt shifts and persistent anomalies in ocean climate.

3. A barrage of recent studies on decadal-scale climate variability linked to slow ocean processes holds some promise that the forecasting window for drought can be widened from a few months to a few years. This is what all the commotion has been about the so-called Pacific Decadal Oscillation or PDO, the fact that Pacific sea surface temperatures (SST) and associated climate tend to vary on a 20-30 year 'cycle' with abrupt regime shifts. For example, in 1946 the tropical Pacific went cold and the Southwestern U.S. went dry, producing the 1950s drought. And in 1976, the tropical Pacific got warm and the Southwest experienced a prolonged series of wet winters. More recent studies indicate that the relationship between ENSO, PDO and warm season (May-September) rainfall across North America is modulated by low-frequency variability in North Atlantic SST's (Atlantic Multidecadal Index or AMO). The North Atlantic was anomalously warm between 1930 and 1960, encompassing summer drought in both the 1930s and 1950s. Could we have predicted the 1950's drought, involving dry winters and summers, or the moist period after 1976, defined by wet winters and summers, and all of their consequences for the Southwest? In other words were 1946 and 1976 diagnostic of years to follow? Are there precursor states in oceanic climate, similar in fact to the way we now use Tropical Atmosphere Ocean (TAO) moorings in the tropical Pacific to predict and monitor El Niño or La Niña, which might allow us to anticipate catastrophic drought?

4. Beginning in 1995, the North Atlantic turned warm and in 1998, the tropical Pacific became cold, prompting many climatologists across the country to unofficially speculate that catastrophic and perhaps multi-year to multidecadal drought was right around the bend. To many, the dryness in 1999-2002 was no surprise. We can't say how severe or how many years this drought will last, but based on the slow turning of the ocean, the odds are that it will. It is always prudent to be conservative about water and other resources vulnerable to drought; it is particularly prudent now. Finally, there are some added complications. Societal demands on surface water are on the increase. Leaf area and tree densities are higher than ever, while the growing season has increased by as much as two weeks in the spring, raising both heat load and evapotranspiration. Clearly, the context for long-term drought is different now than it has been in the past.

Hydroclimatology of Southwestern Droughts

Michael Dettinger, U.S. Geological Survey, Scripps Institution of Oceanography, La Jolla, CA (mddettin@usgs.gov) and Greg McCabe, U.S. Geological Survey, Lakewood, CO

Drought in the southwestern U.S. arises from the confluence of a variety of regional to global climatic influences. The large-scale climatic underpinnings of Southwestern droughts, along with their global-to-regional scale influences on Southwestern precipitation, streamflow, baseflows, and ground-water levels, provide a basis for understanding and tracking the current drought. In particular, extended periods of Southwestern drought are associated with ocean-atmosphere interactions in the Tropical and North Pacific Ocean basin, and in the North Atlantic. Pacific climate influences tend to steer storms and precipitation either into, or away from, the Southwest, and thus are particularly important controls on drought in this region. The net effect of the Pacific influences on year-to-year and decade-to-decade time scales is to spatially reorganize precipitation within western North America as a whole, but not to change the overall amount of precipitation delivered. Depending on the state of Pacific climate, the Southwest can be the beneficiary of this reorganization, or the loser. In contrast, North Atlantic influences, on decade-to-decade time scales, are associated with almost Northern Hemisphere-wide changes in midlatitude westerly winds and thus with the overall amount of precipitation delivered to western North America, yielding simultaneous droughts or wet periods over much of the western U.S. These influences of Pacific and North Atlantic variations on Southwestern drought, in turn, are just regional aspects of the global reorganizations of precipitation associated with changes in the two ocean basins. Finally, recent analyses suggest that a third component of drought occurrence in the Southwest may parallel the 20th Century Northern Hemispheric warming trends, in a sense that is increasing the frequency of droughts in the Southwest and in the Northern Rockies.
On decadal time scales, the influences on Southwestern drought of these Pacific, North Atlantic, and Northern Hemispheric climatic variations can be separated from each other, in historical observations, because the variations are largely uncorrelated on that time scale. As the Pacific and North Atlantic influences vary—more or less independently—through the decades, their combination sometimes enhances and sometimes reduces the frequency of droughts in various parts of western North America. In particular, though, during epochs when both the Pacific and North Atlantic are positioned to contribute to drought in the Southwest, the results can be extremely deep, extensive, and prolonged droughts (i.e., in the 1950s). The present (1999-2003) Southwestern drought began during just such a confluence of drought influences (with onset in 1999 of a La Nina-like Pacific climate state and in 1995 of a a warm North Atlantic state), and thus the possibility of a severe prolonged drought currently exists. Such speculation, however, hinges on long-term continuation of that configuration of ocean climates and this winter has seen a partial reversal of both the Pacific and North Atlantic ocean climates, which may still provide relief. Furthermore, the prospect that drought frequencies may be changing along with recent hemispheric warming trends needs to be incorporated into discussion of the future of Southwestern drought.

Drought impacts on functions of hydrologic systems

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Although the focus on droughts is usually on a lack of precipitation, this decrease in precipitation has consequences for hydrologic systems on and below the surface of the Earth. Drought leads to a decrease in recharge to aquifers through (1) areally distributed recharge, (2) focused recharge, (3) septic return flow, (4) irrigation return flow, and from (5) increased evaporation and transpiration. The typical response of humans to a hydrologic drought is to (1) pump more groundwater at existing wells to make up for loss of surface water, (2) drill more boreholes to augment supply, (3) remove riparian vegetation to decrease transpiration, (4) implement conservation practices, (5) develop alternative water supplies.

Hydrologic drought impacts soil water and ground water in many ways. It leads to a loss of groundwater and soil-water storage. This causes water levels in wells to be lowered and an increased depth to water in riparian areas with less water available for the plants to transpire. It also leads to a decrease in aquifer discharge. This will cause a decrease in baseflow in streams and lakes, decreased spring discharges, and decreased wetted area (aquatic habitat) in streams and lakes. Other impacts are increases in the risks from land subsidence and saltwater intrusion.

The U.S. Geological Survey began a system of monitoring stream discharge in the late 1800s on many streams in the U.S. There are now continuous gages on over 7,000 streams, but a lack of stations with records of more than 30 years and a growing loss of gages on the smallest, unregulated streams, making it difficult to observe the impacts of drought on baseflow. In response to the drought of the 1930s, the USGS began monitoring water levels in a network of wells. Generally, this program has a more complete and extensive record in the Eastern U.S. than in the Western U.S. Some states use these wells as part of their drought management strategy.

Because of the lack of direct hydrological measurements of the impacts of recent droughts, it is useful to look at the hydrological impacts of land-use management to understand potential impacts on hydrological systems. There are good examples of changing agricultural practices and changing forest management practices to use as surrogates to understand the changes we might anticipate from drought. Also, vegetative indicators, such as springsnails, may be very useful to understand drought on longer time scales.

Case studies will be provided from the Verde Valley of Arizona to show what is known about baseflow of springs and streams with existing monitoring, and how we can use this to interpret the impacts of the current and future droughts.

Bark beetles, drought and forest conditions in the Southwest

Outline

John Anhold and Joel McMillin, USFS-FHP, Flagstaff Arizona

- History and status of pine bark beetles in the Southwest
- Major issues related to bark beetle outbreaks
- Predicted extent and intensity of outbreaks

Pine Bark Beetles in Arizona

- Pine engraver beetles (*Ips*)

–11 species in Arizona

- Western pine beetle
- Roundheaded pine beetle
- Mountain pine beetle
- Southern and Mexican pine beetle (Chiricahua Mts.)
- Larger Mexican pine beetle
- Red turpentine beetle

Historical status of pine bark beetle outbreaks in SW

- Several localized outbreaks of various bark beetles in the Southwest since the 1800's
- Typically insufficient records of historical outbreaks to compare with present events
- 1950's drought and beetle-caused pine mortality
    - 490,000 ac beetle activity in Arizona in 1957 (Yasinski & Pierce 1958)
    - Million ac of pine mortality in the SW
    - 95% of all age classes of pine at Bandelier
    - Largest impacts on low elevation, dry sites (info from Allen and Breshears)
- History of mountain pine beetle outbreaks on the North Kaibab
    - 7 outbreaks back to 1837. Largest killed 12% of ponderosa pine growing stock (1917 – 1926).
- Roundheaded pine beetle
    - 6 outbreaks back to 1937 in the Sacramento Mtns. Largest killed 11 to 54% of ponderosa pine.
- Western pine beetle
    - Periodic outbreaks with Ips throughout SW, i.e. Jemez Mtns, often associated with drought (Allen, 1989)

Current status of pine mortality in the Southwest

- More than 2 million ponderosa pine died in 2002 in AZ & NM (600,000+ac)
- Millions of piñon pine died across SW (undetermined acreage)
- Most initial attacks are by *Ips* species
- Other bark beetle species are common in lower portion of large ponderosa pine

What are the major issues?

- Is the drought or the bark beetles causing the tree mortality?
- How does drought affect pine resistance to bark beetles? How do we measure resistance?
- How important is tree density or stand density?
- What sites are experiencing the highest mortality and are there predictive models?
- What other factors regulate beetle populations?
- When will the beetle populations collapse?

Stand density & bark beetles

- Density of trees has increased more than 35 times in the last 100 – 150 years
- High stand density leads to inter-tree competition for resources & weakened defense mechanisms
- Density also affects micro-site conditions and pheromone interactions that may be more favorable to beetles
- Close association between stand conditions and *Dendroctonus* bark beetles, less clear for most *Ips*

Other factors affecting bark beetles

- Stress
    - Fire
    - Defoliation
    - Disease – i.e., root disease, mistletoe
- Food
    - Storm damage
    - Logging residue

What is the beetle forecast?

- Uncertain, but high levels of additional tree mortality probable
    - Ø 8-fold increase in area affected each of last 2 years for Arizona
    - Ø more than 150-fold increase last year on some forests in Arizona
- Weather – unpredictable

- Precipitation – the big unknown
- Cold temperature – hasn’t happened yet

Altered Fire Regimes and Forest Thinning in Major Biomes

Tom Kolb and Pete Fule
NAU School of Forestry

The main points of our presentation are:

- Evidence of frequent, low-intensity fires in Southwestern ponderosa pine forests prior to Euro-American settlement, disruption of this fire regime in the late 1800s, and large increases in tree density, are irrefutable.
- Increasing fuel loads and drought in these forest cause large, synchronous crown fires
- The frequency of these large synchronous crown fires will likely increase in the future because present fuel loads and future increases in fuels overwhelm current capacity for fuels reduction treatments
- Effects of these large synchronous crown fires include: increased opportunities for invasion by exotic, noxious weeds; massive soil erosion; flooding; damage to downslope riparian areas; deforestation for decades to centuries; degradation of aesthetics; degradation of recreation opportunities; and many others
- Heavy crown damage to ponderosa pine reduces tree resistance to bark beetle attack, and may promote landscape scale beetle outbreaks
- Thinning that reduces ponderosa pine tree density can increase tree resistance against bark beetles and reduce crown fire occurrence
- Heavy ponderosa pine mortality from bark beetles, an effect of the 2002 drought, will likely affect fire incidence and behavior, but data is scarce. A hypothesis is: As long as dead needles remain on the dead trees the hazard for an intense crown fire is high. When the needles fall to the ground the probability of an intense crown fire decreases, but increases for a low-intensity ground fire until they deteriorate. When the dead trees fall, the probability of crown fire is nil, and the residence time of ground fires should increase because of more slow-burning fuels.
- Beneficial effects of thinning on ponderosa pine water uptake and growth are most pronounced in drought years; thinning ameliorates effects of drought on tree stress
- Severe drought decreases herbaceous productivity and diversity, with the following possible effects: increased soil erosion, increased opportunities for exotic plant invasion, reduced energy transfers through food webs, lower NPP and carbon sequestration, altered food webs (simplification?), less animal forage
- Thinning causes small, ephemeral increases in downslope water runoff and drainage; effects diminish as vegetation recovers.
- Much less is known about effects of thinning and fuels treatments on pinyon-juniper woodlands than ponderosa pine forests. Current thinning experiments in P-J offer research opportunities
- Landscape scale thinning in the future will be limited by the high costs of treatment, low wood value, and lack of regional markets; inadequate resources for quick NEPA has been

suggested as a constraint. Solutions include: 1) coordinated/consistent wood supply, 2) incentives to stimulate local markets/biomass energy, 4) “super NEPA” teams, 3) large state/federal subsides/public works programs

THE NATURE OF DROUGHT

- ***Agricultural drought*** – primarily affects dryland farming and grazing
- ***Hydrological drought*** – affects water supplies and riverine ecosystems, agriculture dependent solely on surface-water irrigation
- ***Ecological drought*** – affects ecosystems dependent on meteoric water

AGRICULTURAL DROUGHT (Grazing)

- Before widespread use of stockponds and wells, water supply for grazing animals was the largest problem (1891-1904 drought)
- Now, forage availability is a large problem exasperated by previous grazing history
- Woody plant increases in 20th century also increase drought effects

AGRICULTURAL DROUGHT (Grazing)

HYDROLOGICAL DROUGHT

- Water availability is generally less (particularly winter runoff) but changes in flood frequency is less predictable
- Riparian vegetation is unlikely to reproduce but may not have profound short-term impacts

HYDROLOGICAL DROUGHT

Salt River near Roosevelt, Arizona

HYDROLOGICAL DROUGHT

HYDROLOGICAL DROUGHT

- Riparian vegetation is unlikely to be significantly affected along perennial streams
- Plants on distal floodplain margins or along ephemeral streams will be most affected
- Extended drought can kill riparian trees in sites with less dependable water (influent reaches)
- Additional groundwater pumpage or surface-water diversion could significantly compound drought effects

HYDROLOGICAL DROUGHT

- Extreme events aren’t necessarily linked to droughts
- In 1896, a major Utah drought year, large floods occurred during record rainfall in September
- In 1951, during the mid-century drought, record flooding occurred in central Arizona during August

ECOLOGICAL DROUGHT

- Desert plants are dependent on meteoric water
- “Deep soil water” is distinguished from “shallow soil water” but is actually moisture recharging to greater depths from past high rainfall years

•Root structure and physiological characteristics (C3/C4/CAM) may determine survivability of desert species to drought

DYNAMICS OF UNDISTURBED VEGETATION IN THE MOJAVE DESERT

•Before our study, most ecologists viewed Mojave Desert vegetation as static and unchanging

•Some ecologists retain the community view of ecosystem processes; others consider species response to be individualistic

NTS CLIMATE, 1960-2000
NATIVE VERSUS NON-NATIVE ANNUALS
POSITIVE RESPONSE OF INDIVIDUALS

LARGE, FLUCTUATING RESPONSE
HIGH DROUGHT-RELATED MORTALITY

CLIMATICALLY-INSENSITIVE SPECIES

LONG-TERM (1963-2003) CHANGE IN UNDISTURBED PERENNIAL VEGETATION
LONG-TERM STABILITY OF VEGETATION ASSOCIATIONS?
•In 1979, Beatley used her data to define 16 vegetation associations in the Mojave and Transition Deserts. Of those, 8 named spiny hopsage (*Grayia spinosa)* as a dominant.
•In 2000, Ostler *et al*. defined 10 vegetation associations for Mojave and Transition Deserts. One lists *Grayia* as dominant.
•In 1999-2002, *Grayia* doesn't dominate any of Beatley's plots, and only 3 of 28 plots had enough *Grayia* to justify calling them associations.
DROUGHTS ARE ESSENTIAL TO ECOSYSTEM FUNCTION

•Drought helps reset elements of Mojave Desert shrub assemblages

•Drought may drive successional processes, killing short-lived species and enabling long-lived species to establish dominance

•Drought ultimately may help control non-native annual species that are adapted to more predictable climates
THE PROBLEM OF DROUGHT SEVERITY AND FREQUENCY

•The severity of a drought depends upon its nature (whether agricultural, hydrological, or ecological)

•Magnitude and frequency are difficult to assess – some ecological catastrophes may be strongly

influenced by the history leading up to the drought (*e.g.*, high, unsustainable growth periods beforehand)

- Droughts do not affect all landscape elements equally

Tom Whitham, Peter Price, Kitty Gehring, Joe Shannon, Adrian Stone, Talbot Trotter, Alicyn Gitlin and Larry Stevens

EXAMPLES OF IMPACTS ON BIODIVERSITY

DROUGHT EFFECTS ON NON-FORESTED COLORADO PLATEAU ECOSYSTEMS

Casual observations on 2002 drought impacts on 5 common desert plant species in northern Arizona (Stevens, unpub. Data).

Grand Canyon Wildlands Council, Inc.

Long-term sawfly populations on willows closely track the Palmer Drought Severity Index (PDSI). 67 other herbivore species on willows are predicted to exhibit the same pattern. (Price & Hunter unpubl)

Ash and sediment runoff damage streams for many years.
In Kanab Creek, 24 miles downstream of the 1996 Bridger-Complex Fire, macroinvertebrate biomass was reduced 65-75% and biodiversity was reduced 90% for 7 years.

Tree Rings Predict Arthropod Species Richness & Abundance

Mycorrhizal mutualists increase with intermediate stress, but decline at high stress levels.

The southwest has the highest proportion of native fishes that are threatened or endangered. Droughts, increased demands on water use and fires are likely to make this worse.

PREDICTIONS

1. Extreme drought is a bottleneck event that results in increased extinction of rare species, especially those dependent upon rare habitat types impacted by drought (e.g., springs & riparian).

2. Human impacts on the environment (i.e., increased water use and fire hazards) make droughts far more severe such that a 100 year drought may effectively become a millenium-level drought.

3. Short and long-term effects of drought may switch such that species that initially benefit may subsequently decline. The same holds true for management decisions, especially ones focused on individual species, rather than the community or ecosystem.

4. Marginal or edge habitats that suffer chronic stress can be barometers of change and may be crucial to preserve as sources of extreme genotypes that may be best adapted to changing environments.

MAJOR GAPS IN OUR KNOWLEDGE

1. Lack of long-term studies emphasizing community responses to stress and drought.
2. Lack of protected long-term study sites where observational and experimental studies are emphasized.
3. A general lack of a community perspective as most efforts focus on individual species.

Management Implications

1. Need to plan for droughts that last decades or more.
2. Need to minimize human impacts that exacerbate the effects of drought.
3. Need special emphasis on rare habitat types that are especially sensitive to drought. For example, controlled fires during drought may place riparian habitats at unacceptable risks.
4. Especially important to manage for the community and ecosystem.

Rick Miller
Arizona Game & Fish

Effects of Drought On Wildlife

- Reduced Food and Cover
- Reduced Water
- Reduced Reproduction
- Reduced Effective Habitat
- All These Effects Probably Last At Least 3 Years Following a Serious Drought
- Moderate to Severe Drought Has Lasted as Long as 75 Months in the Last 100 Years

Things We do to Make It Worse

- We have lowered water table
- We have reduced vegetative diversity
- We have added to barriers and fragmentation
  - Highways and Freeways
  - Cities and Towns
  - Fences
  - Canals

Drought or other rare events may make existing problems worse. In One Day in 2002 near Tusayan, AZ Game & Fish hauled 135,000 gallons of water and still could not offset the drought

Management Possibilities Between Events

- We can improve plant diversity between major events – By using fire, restoring forests savannas and grasslands, controlling grazing, reducing recreation impacts.
- We can manage for drought as a norm – A suggestion has been made that we target wildlife and livestock populations at levels that do no harm through at least six months of drought.
- We can put physical structures such as water tanks, passable fences, and bentonite seals, in place.

Management Possibilities During an Event

- During an event we should carefully set priorities to emphasize practicality and

effectiveness.

- We should recognize how slowly the ecological system usually responds to positive change, in other words, the effects don't end when the event ends.
- During an event we should focus on rarest species which can benefit from what we can do.

INVASIVE SPECIES AND DROUGHT

Kathryn Thomas, USGS

An invasive species is an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health

How does drought change plant physiology?

Changes

- Slower growth
- Thickened cuticle
- Accumulation of nitrates, oxalates and other chemicals

Outcomes

- Foliar herbicides less effective
- Potentially increased toxicity to grazing and browsing animals

Which invasive non-native plants are drought hardy?

Decreasers

•Annual Grasses (Note: Cheat grass [Bromus tectorum] exploded throughout most parts of Arizona during the 2002-3 winter. It may be that late-winter-early Spring species such as cheat grass do not experience drought stress and they may increase during drought)

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Increasers

•Leafy spurge
•Squarrose knapweed
•Diffuse knapweed
•Scotch thistle
•Hoary cress
•Jointed goatgrass
•Yellow starthistle
•Kochia
•Russian thistle
•Tamarisk

Changes in the landscape associated with invasive plants

Plant characteristics

•High drought tolerance
•Contributors to fine fuel and flammable biomass

•Rapid colonizers
•Long deep roots particularly for phreatophytes

Possible outcomes: Competitive replacement of native plants
•Plant cover may decrease
•Increased landscape fire vulnerability
•Early succession may be dominated by invasives
•Floodplains/riparian areas are highly impacted

Other environmental influences and invasive plants

•Increased temperature (warmer winters may allow for new invasives to colonize; hotter summers may lead to increased mortality of native plants, opening up the habitat).
•Increased CO2 and NO2
•Grazing/browsing by wildlife and domestic livestock

Possible outcomes
•Elevation expansion of species, including frost sensitive species
•May enhance performance of some invasive plants
•Increased stress on native species, enhanced dispersal from roadsides & water sources

Conclusions

•Some invasive non-native plants, particularly perennials, will be very competitive and successful during drought; annual grasses will be less so
•New landscapes patches will open up for colonization
•New landscape habitats will open up for colonization
•Animal movements may accelerate some dispersal

DISEASES AND DROUGHT
Charles vanRiper USGS

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TRENDS

- Diseases and vectors will move up in elevations as temperatures increase
- Disease Vectors will generally become more concentrated around existing water sources
- Wildlife, humans and vectors will come into increasing overall contact because of concentrated

water sources

PREDICTIONS

Diseases that will Decrease

- **Plague:** Most likely, drought would decrease plague risk as drought may have a negative impact on reservoir rodent populations and consequently, on flea vectors. Higher temperatures seem to have a definite negative effect on plague activity as it adversely affects a fleas ability to form *Y. pestis* blocks. Wetter years can cause an increase in plague activity, but it is usually a delayed effect (1-2 years).
- **Rocky Mountain Spotted Fever**
- **Hanta Virus**: Drought can have a negative effect on hantavirus in wild areas because *Peromyscus* mouse populations may plummet. However, "articificial" water sources created by human habitation in rural areas can sustain ample mouse populations, especially rural homes, ranches, and farms. So this reduction in hanta risk may not be across the board, and we may still see some human cases of HPS in drier years.

Diseases that will Increase

- **Rabies**: Drought can help trigger rabies epizootics in enzootic areas w/ terrestrial animal reservoirs such as foxes and skunks as animals become more concentrated around limited water sources.

- **West Nile Virus**: The 1999 WNV outbreak in NYC occurred during drought conditions - perhaps creating highly concentration of organic water habitats which favor *Culex pipiens* breeding, and other key factors that concentrat birds and vectors in common areas.

New Disease that Might Occur

- Malaria
- Chagas Disease
- Dengue Fever
- Yellow Fever

Unpredictable Diseases

- **Aborovirus** (Mosquito-borne): There are too many variables (preponderance of vector vs.

nuisance sp., location, habitat, reservoirs, surveillance bias, etc.) to predict whether arboviruses will be affected by drought

- **Tularemia:** Predictions concerning Tularemia are very difficult. Drought can concentrate rabbit populations somewhat, and/or reduce populations (ie, pos. and negative impacts). Drought may also reduce breeding habitats for deerfly vectors.

DISEASE SUMMARY

Consequences of Drought

- Some diseases will remain the same
- Some diseases will increase
- Some diseases will decrease
- New diseases will enter the system