2015 Montana Water Supply Initiative

Yellowstone River Basin

Introduction to Climate Science:

The Debate

and what other States are doing

November 14, 2013

Chuck Dalby
Hydrologist
DNRC Water Resources Division
Helena Montana

OVERVIEW

What is Climate ?

Historic climate, natural variation, and climate change

Global warming--humans and climate (current status of the "debate")

How are other western states' water plans handling climate change

What do we plan for ?

WHAT IS CLIMATE ?

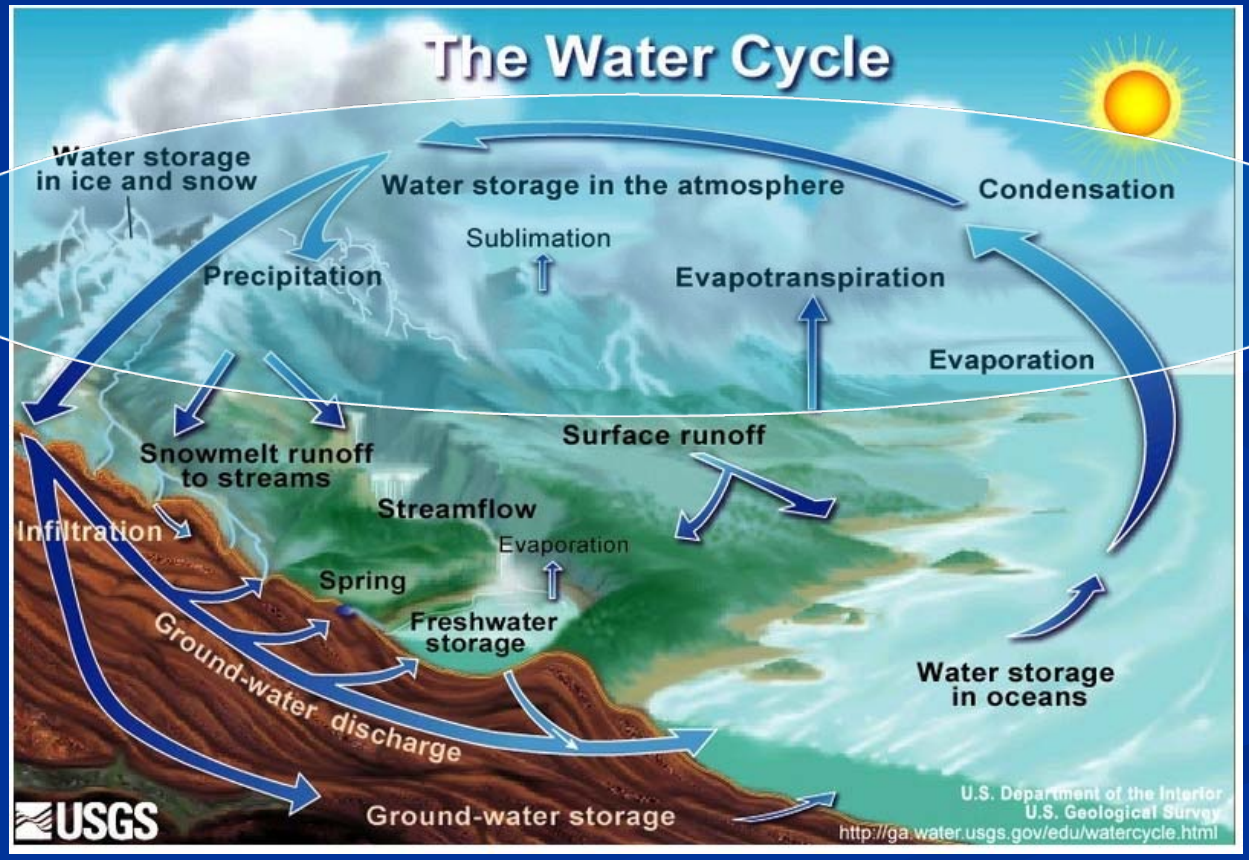
Climate is the pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation and other meteorological variables in a given region over long periods (~10-30 years).

Weather is the variation in these parameters over the short-term (hours, days, weeks, months, a few years)

Climate is weather "averaged" over a longer time interval

Climate "drives" the Hydrologic Cycle

that's why understanding and anticipating climate change is an important part of water planning



What controls Earth's climate ?

- Astronomy (long-term cycles)

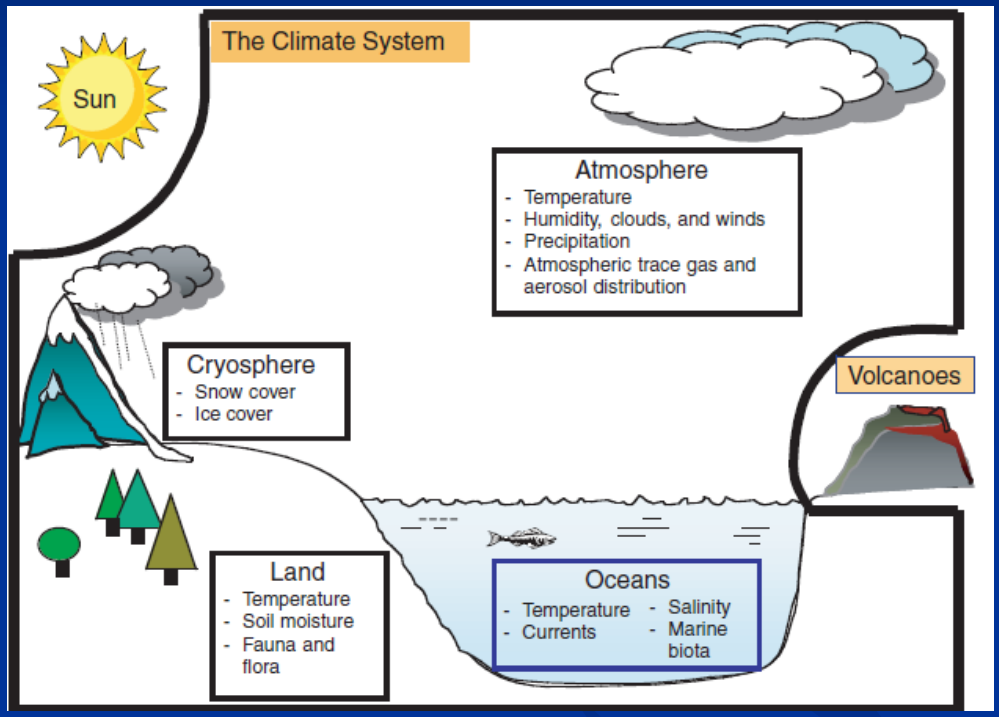
- **Oceans and circulation**
  (store, release, and re-distribute heat and chemicals--CO_2)

- **Atmosphere and processes**
  (same, but quicker interactions)

-**Volcanoes** (Krakatoa; Iceland; etc)

-**Cryosphere** (snow, ice, glaciers)

-**Land** (heat, moisture, life)



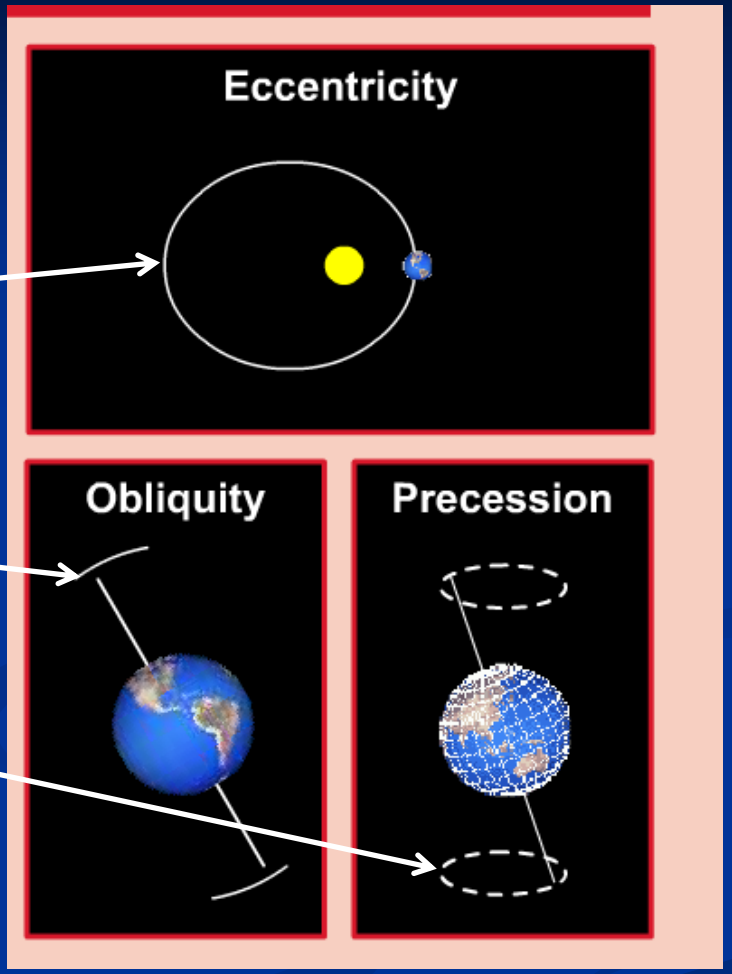
(What is Climate ?)

Astronomy

-Earth's elliptical orbit
(eccentricity)
-Angle of Earth's axis
(obliquity)
-Earth wobbles on axis
(precession)

Cause variation in solar energy reaching Earth's surface:

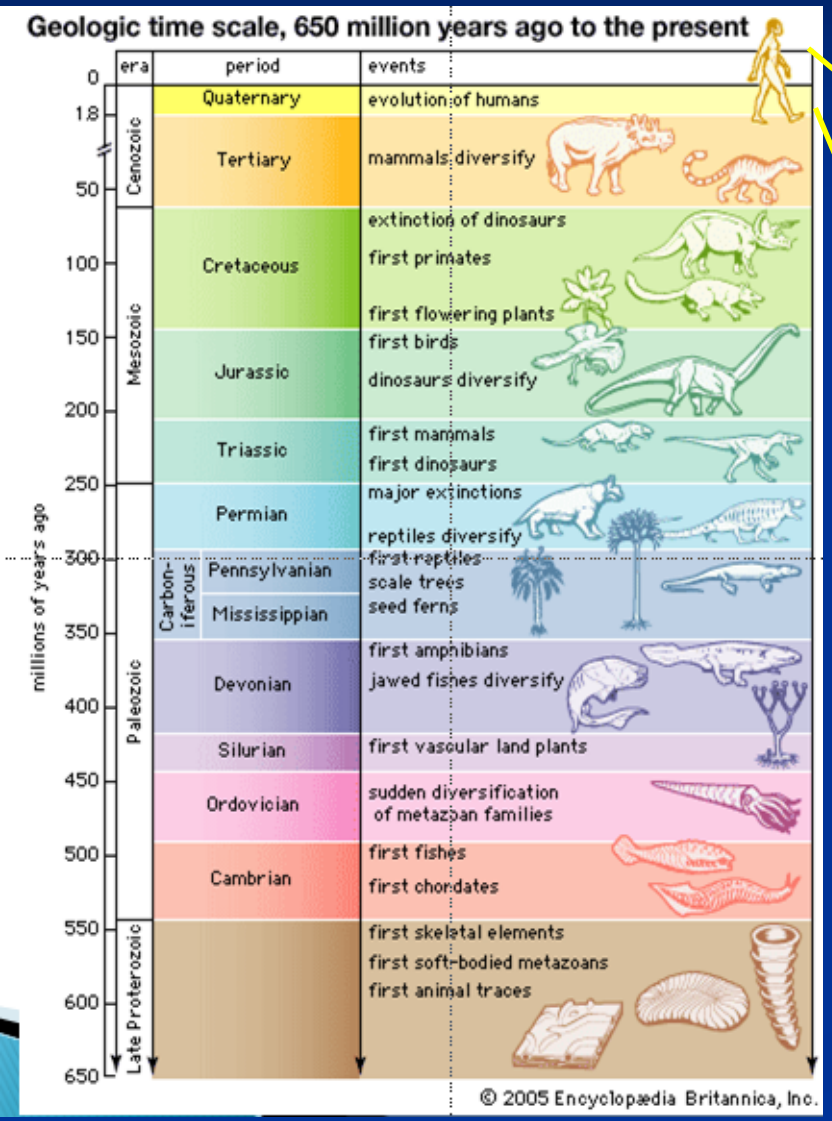
-Short-term (seasons)
-Long-term (Pleistocene glaciation)



2015 Montana Water Supply Initiative

Yellowstone River Basin

HISTORIC CLIMATE and CLIMATE CHANGE



Holocene

Pleistocene

13 glacial stages and over past 2.6 million years

Separated by warmer inter-glacial periods

Last glacial advance ended about 11,000 to 14,000 years ago

Cyclic occurrence partially explained by astronomic variation

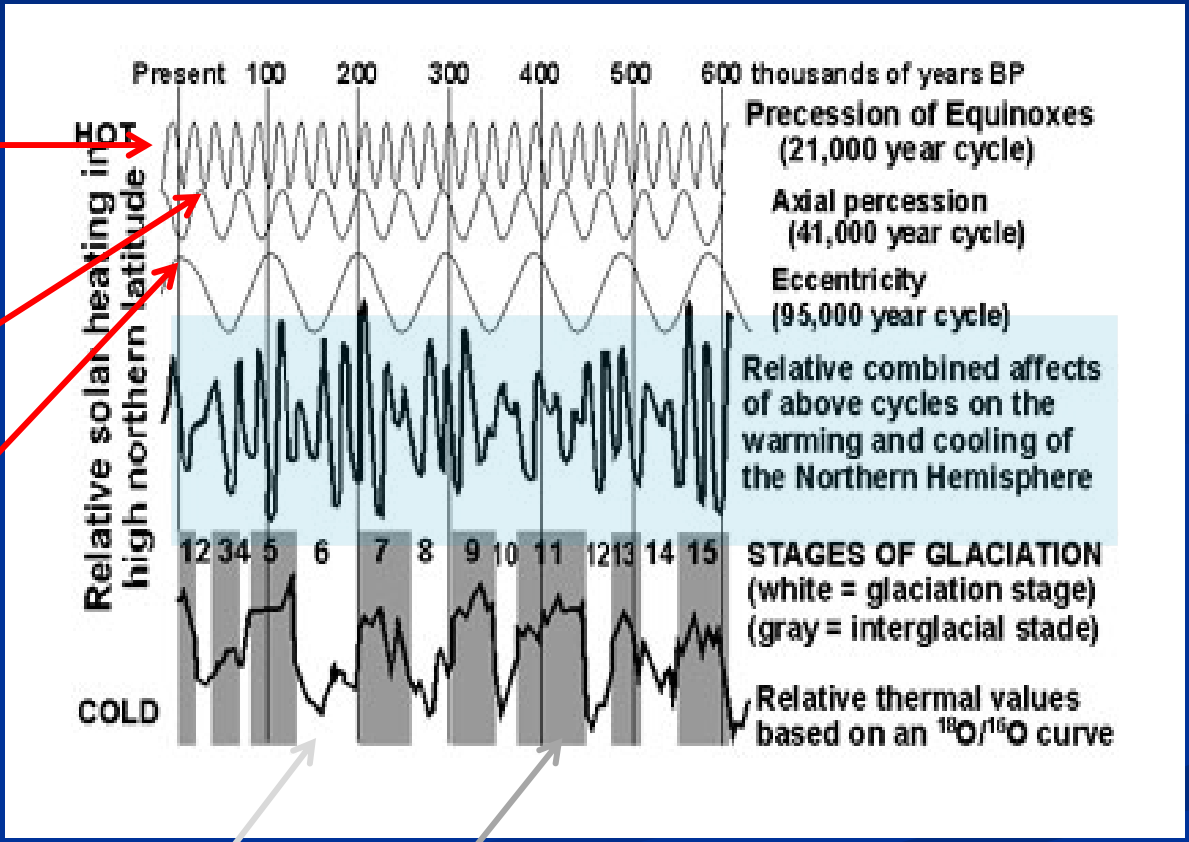
Historic Climate and Climate Change

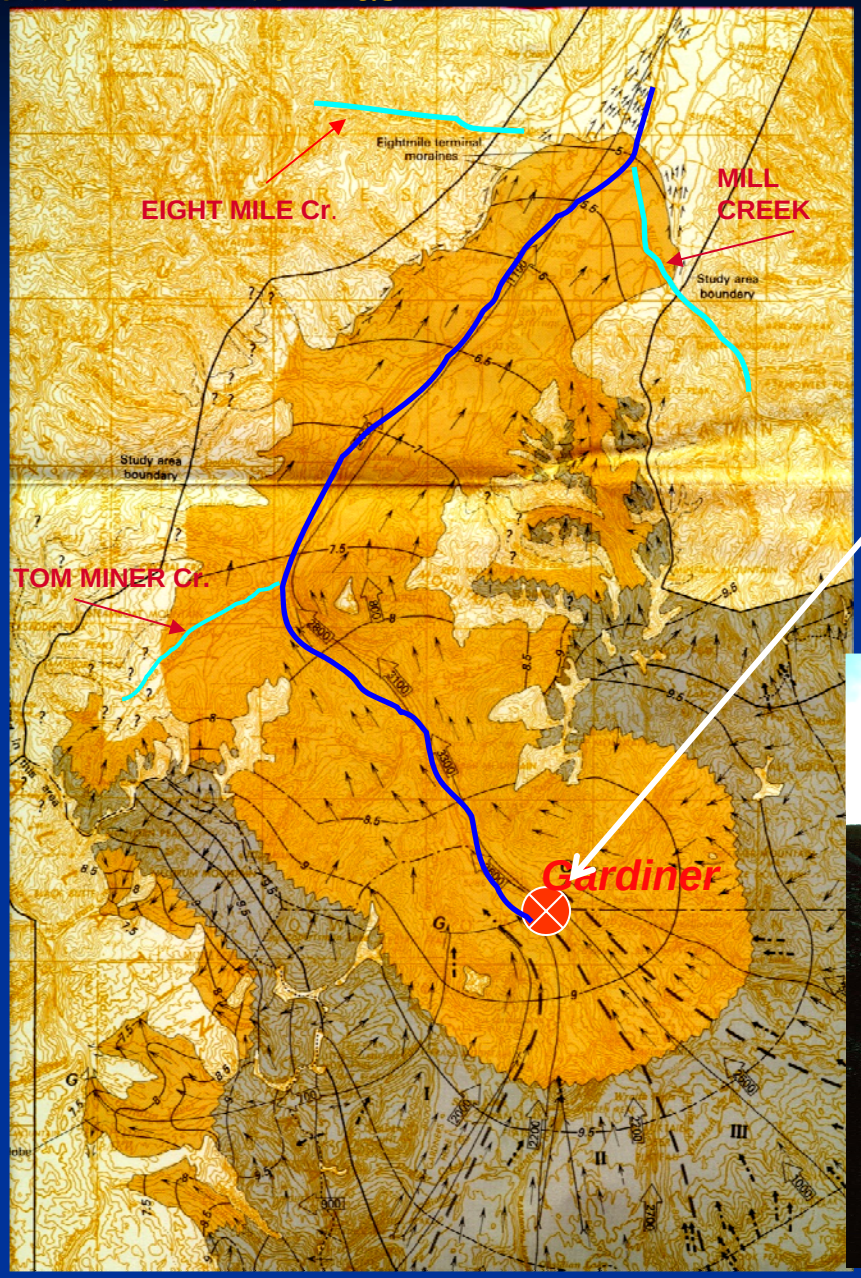
Milankovitch Curves

Earth's wobble toward and away from sun (19,000 to 23,000 year cycle)

Earth's angle of tilt on axis varies 22 to 24 degrees (41,000 year cycle)

Earth's orbit varies from circle to ellipse (100,000 year cycle)

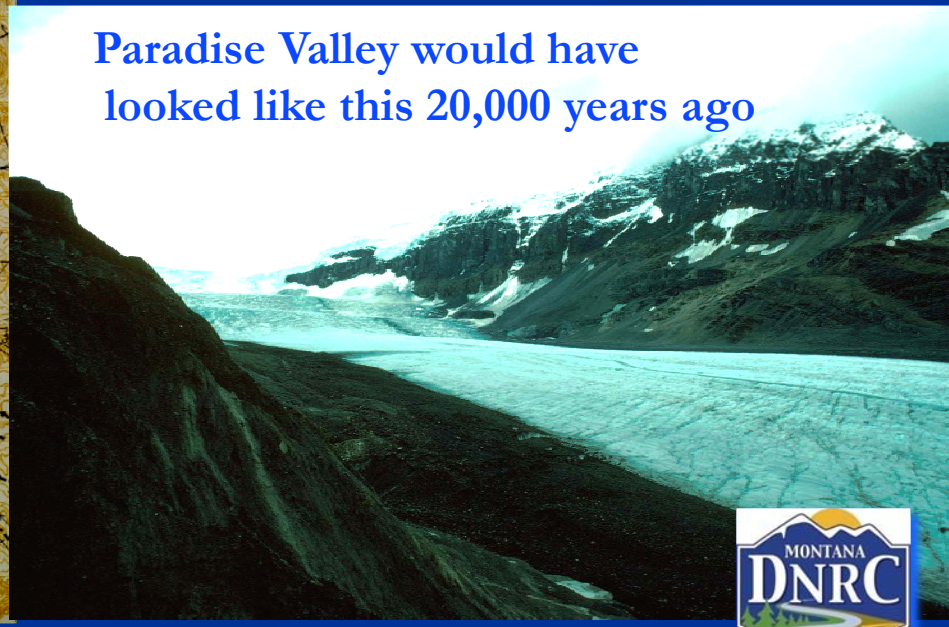




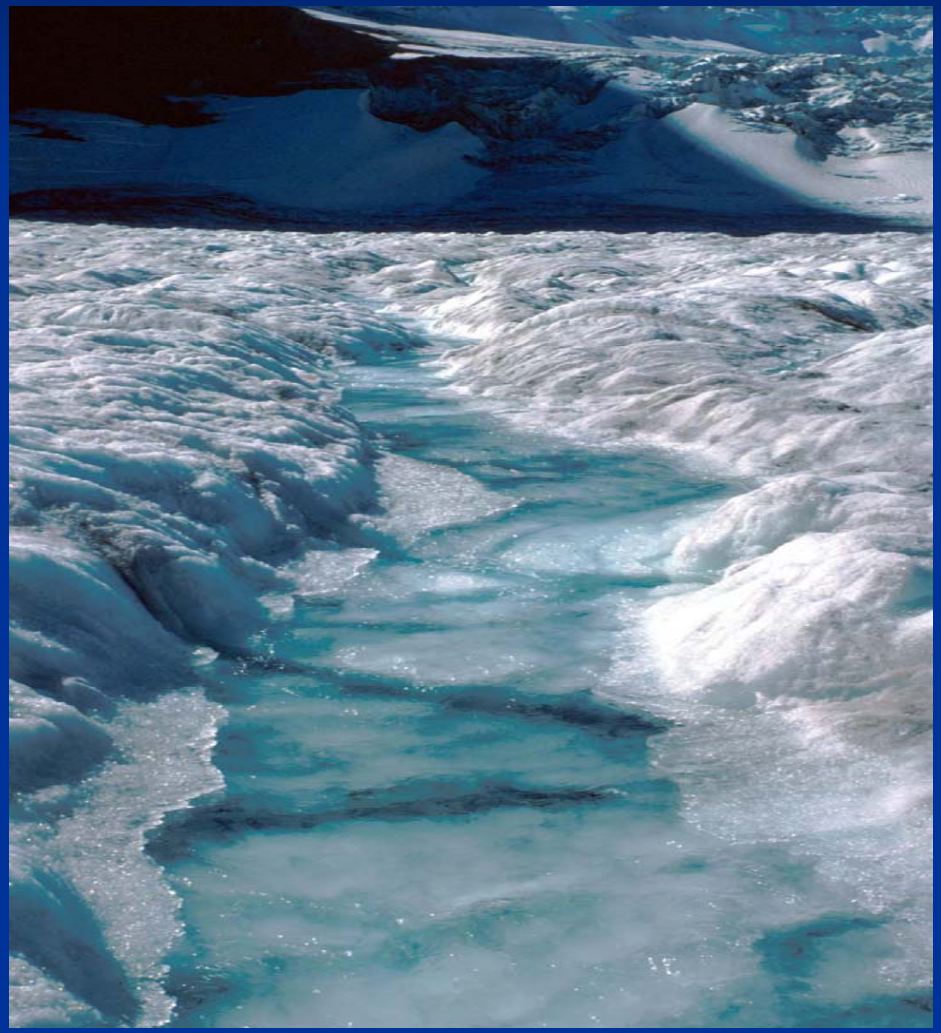
PARADISE VALLEY GLACIAL HISTORY

Large Ice-Cap Centered on Gardiner

Paradise Valley would have looked like this 20,000 years ago



Historic Climate and Climate Change



Glaciers melt and recede about 14,000 years ago -- every wherein Northern Hemisphere

For past 11,000 years we have been in a warm inter-glacial period.

How do scientists know this earth history ?

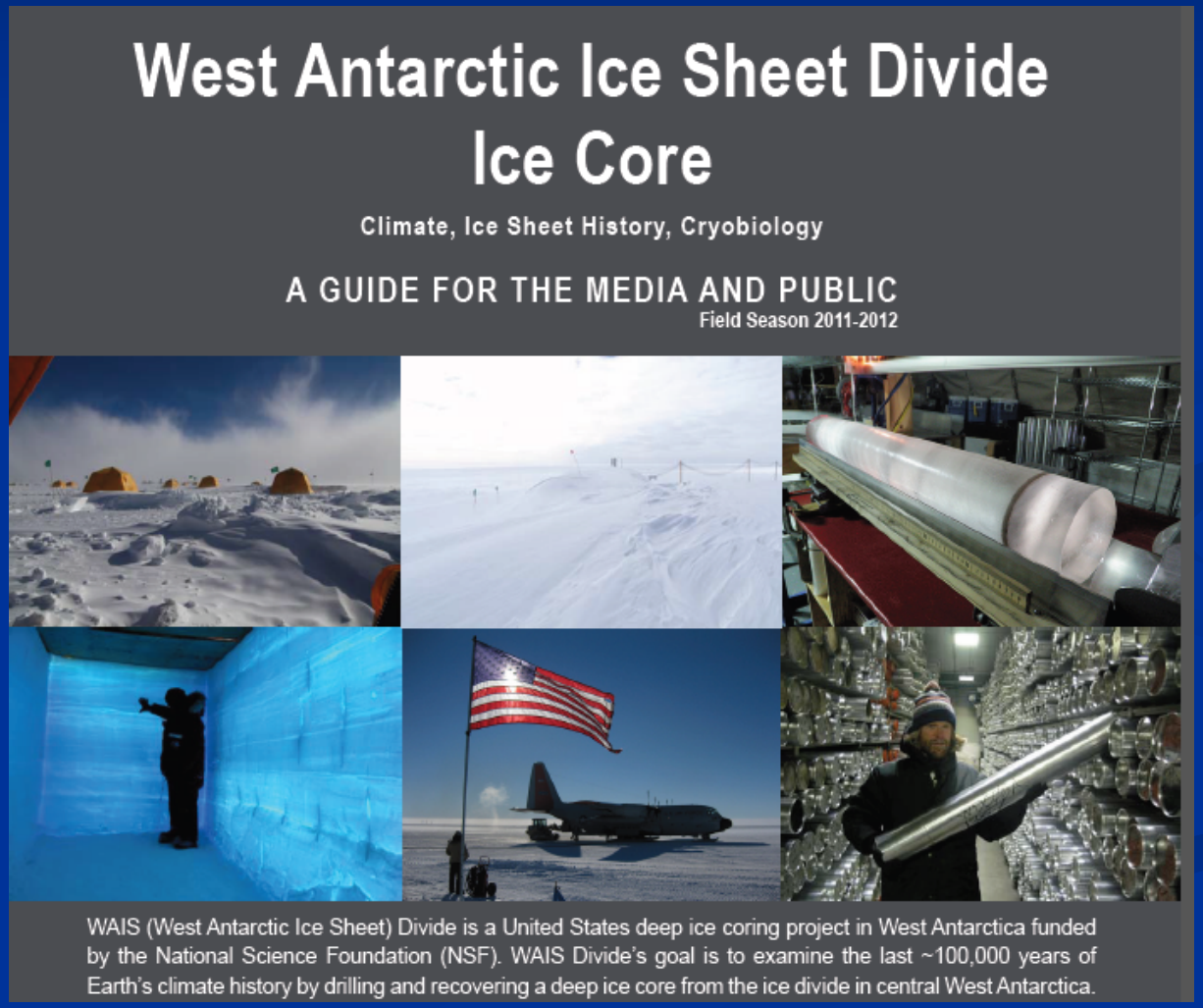
Geologists, glaciologists, ecologists use a variety of tools to examine the past climate:

Proxy records:

- **--sediment cores (oceans and lakes)**
- **--ice cores (glaciers and ice sheets)**
- **--tree rings (paleohydrology)**

Hendrix, Minnesota doctoral student Mark Shapley and UM geology Professor Johnnie Moore prepare to lower their coring device into the lake.

A key source of information on historic greenhouse gas concentrations and temperature: ice cores



Global warming--humans and climate (current status of the "debate")

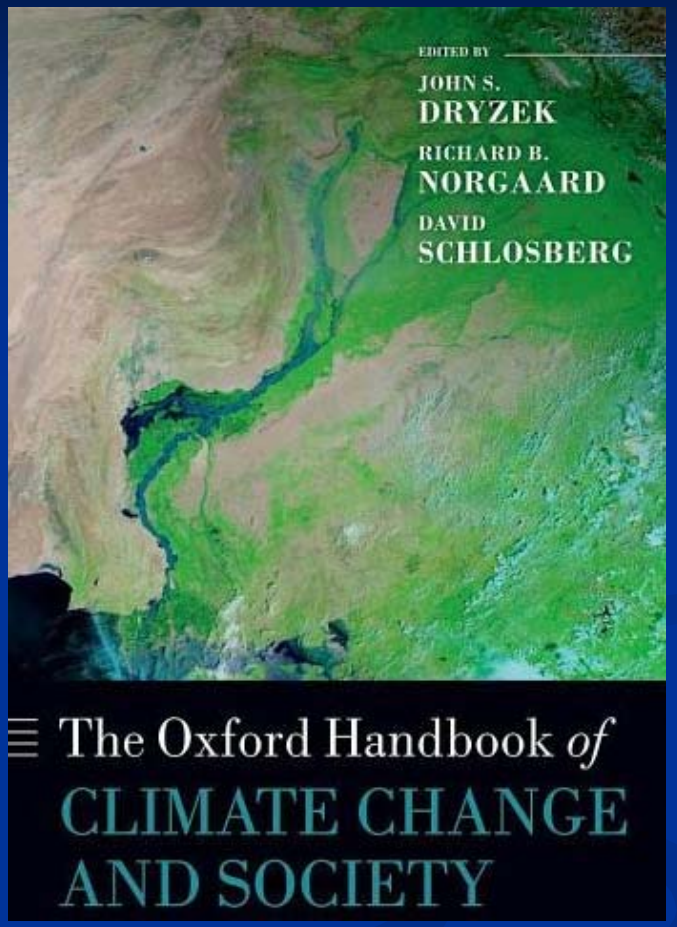
--is there a "legitimate debate" ?
climate science v. climate deniers

Global Warming-- The Debate ?

VIEW WEBSITES for CURRENT SUMMARY of "DEBATE"

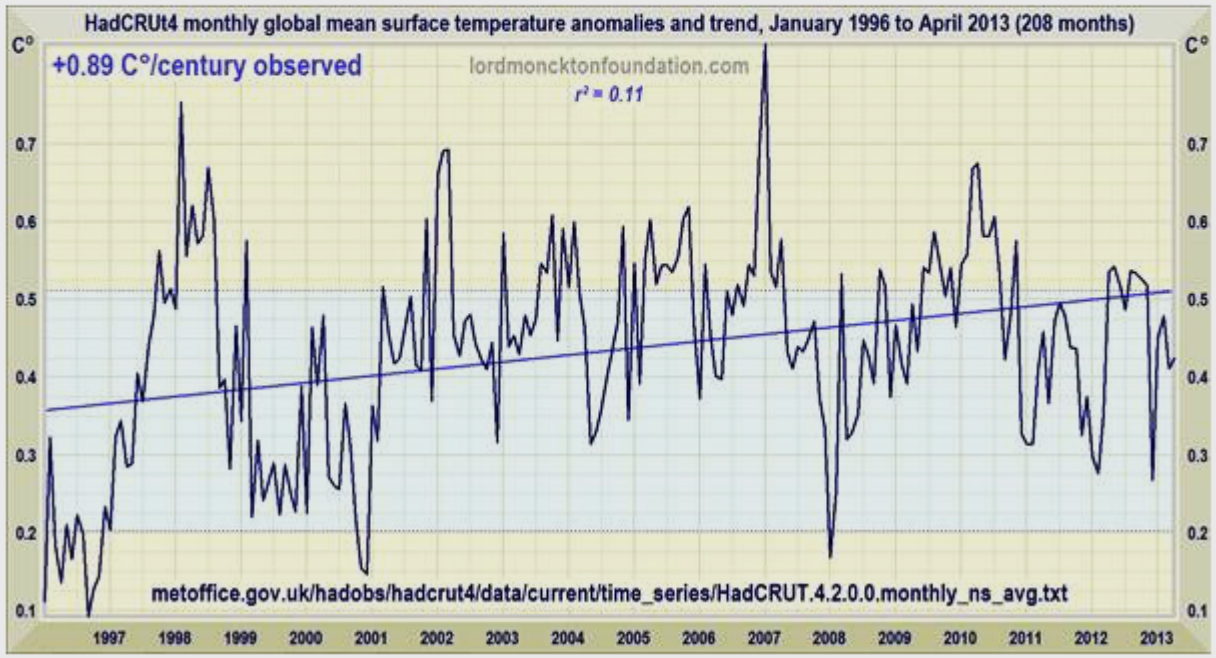
http://www.pbs.org/wgbh/pages/frontline/climate-of-doubt/

http://illinoisreview.typepad.com/illinoisreview/2012/10/heartland-institutes-critique-of-pbs-frontlines-climate-of-doubt.html

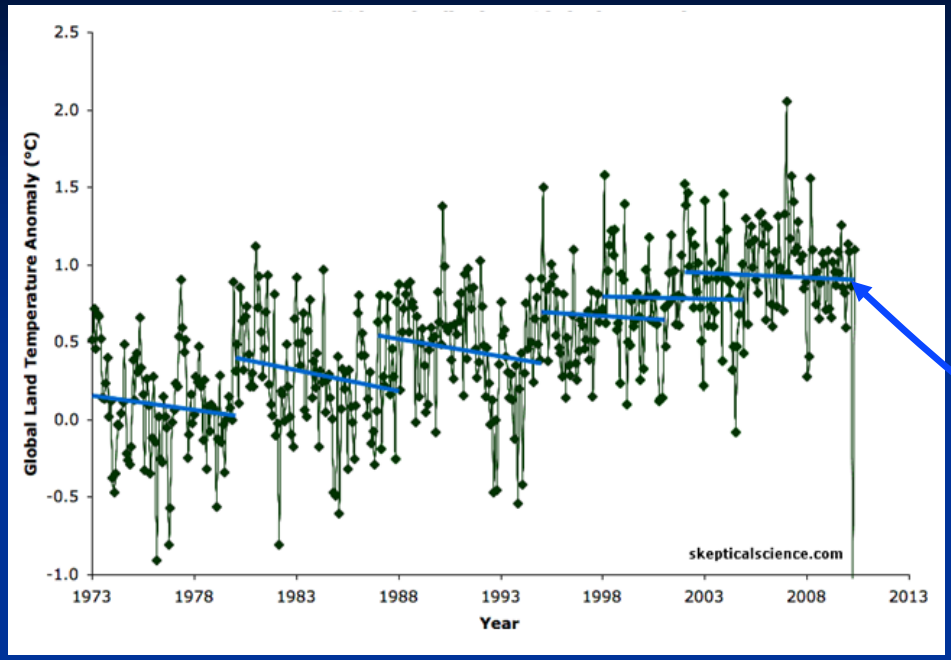


Temperature example: Is the Earth cooling or warming ?

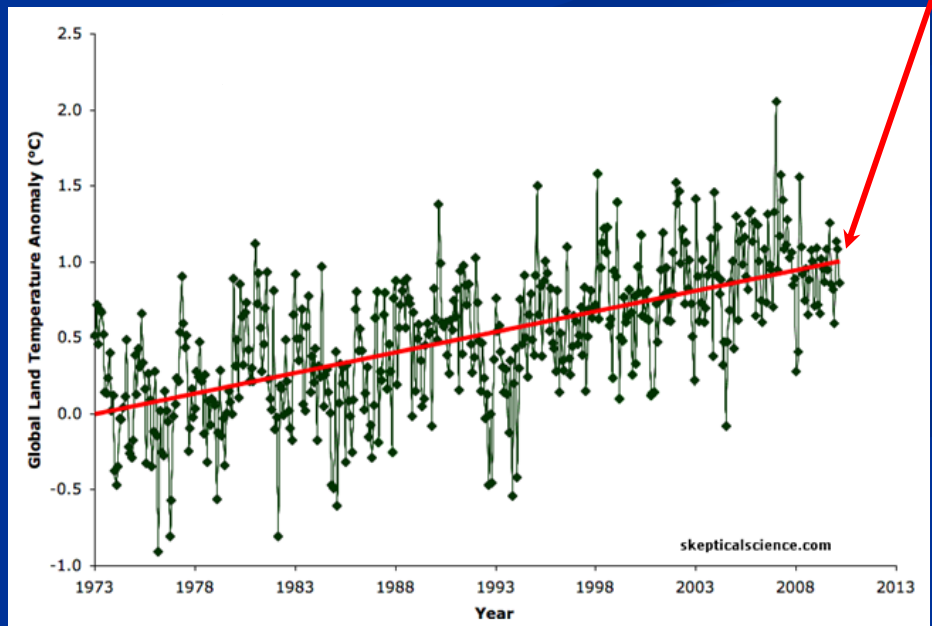
Superimposing the temperature curve and its least-squares linear-regression trend on the statistical insignificance region bounded by the means of the trends on these published uncertainties since January 1996 demonstrates that there has been no statistically-significant warming in 17 years 4 months:



Global Warming-- The Debate ?



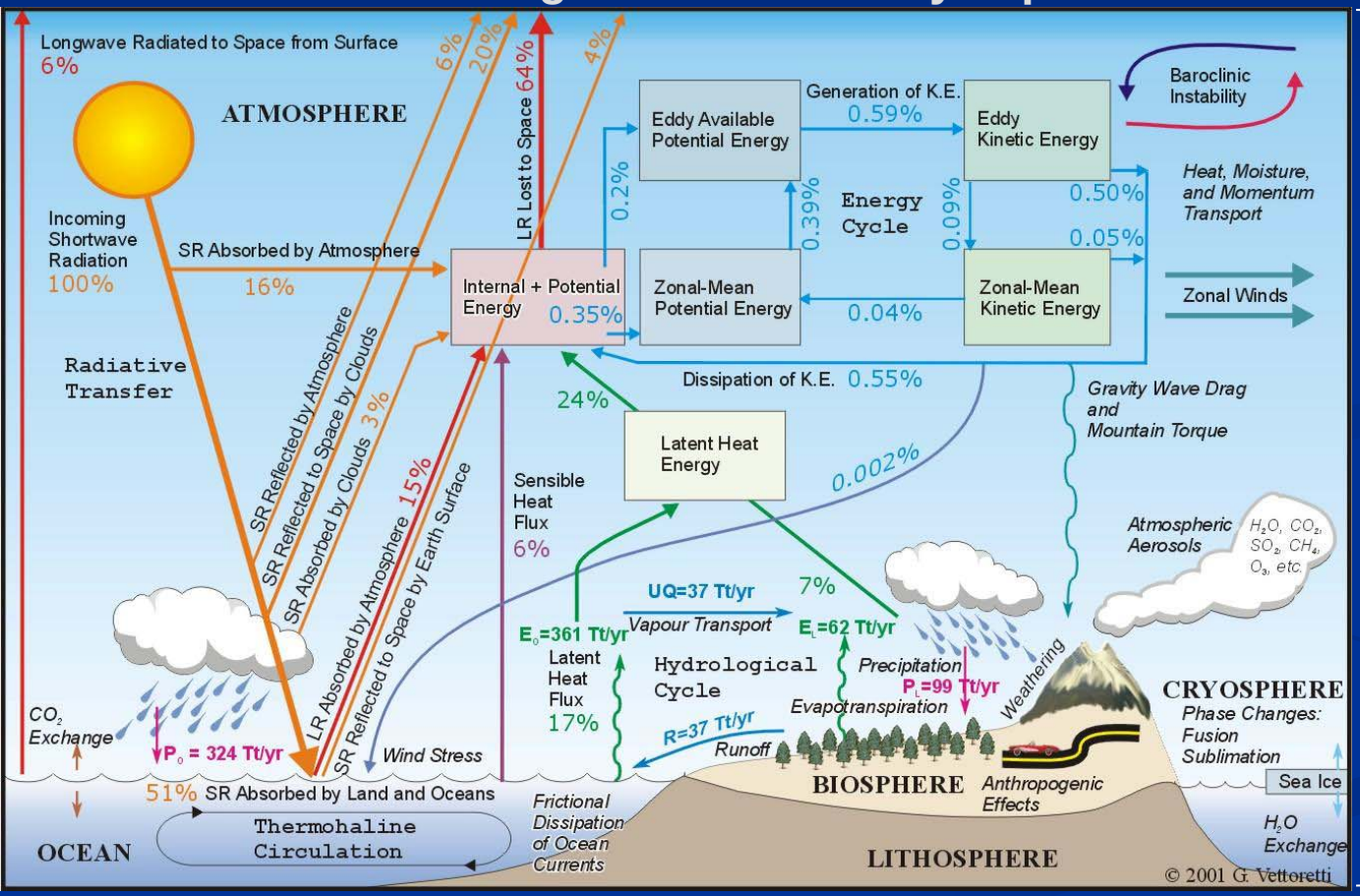
Temperature example:
Is Earth cooling or warming?



Global Warming-- The Debate ?

Are there "legitimate" climate SKEPTICS-- YES!

--peer review process (ego and competition in the academic sector);
--scientific disagreement over key aspects of model predictions



Plenty for scientists to dig into and disagree about--

and plenty for obfuscators and deniers to snark about

Common misunderstandings in the Debate

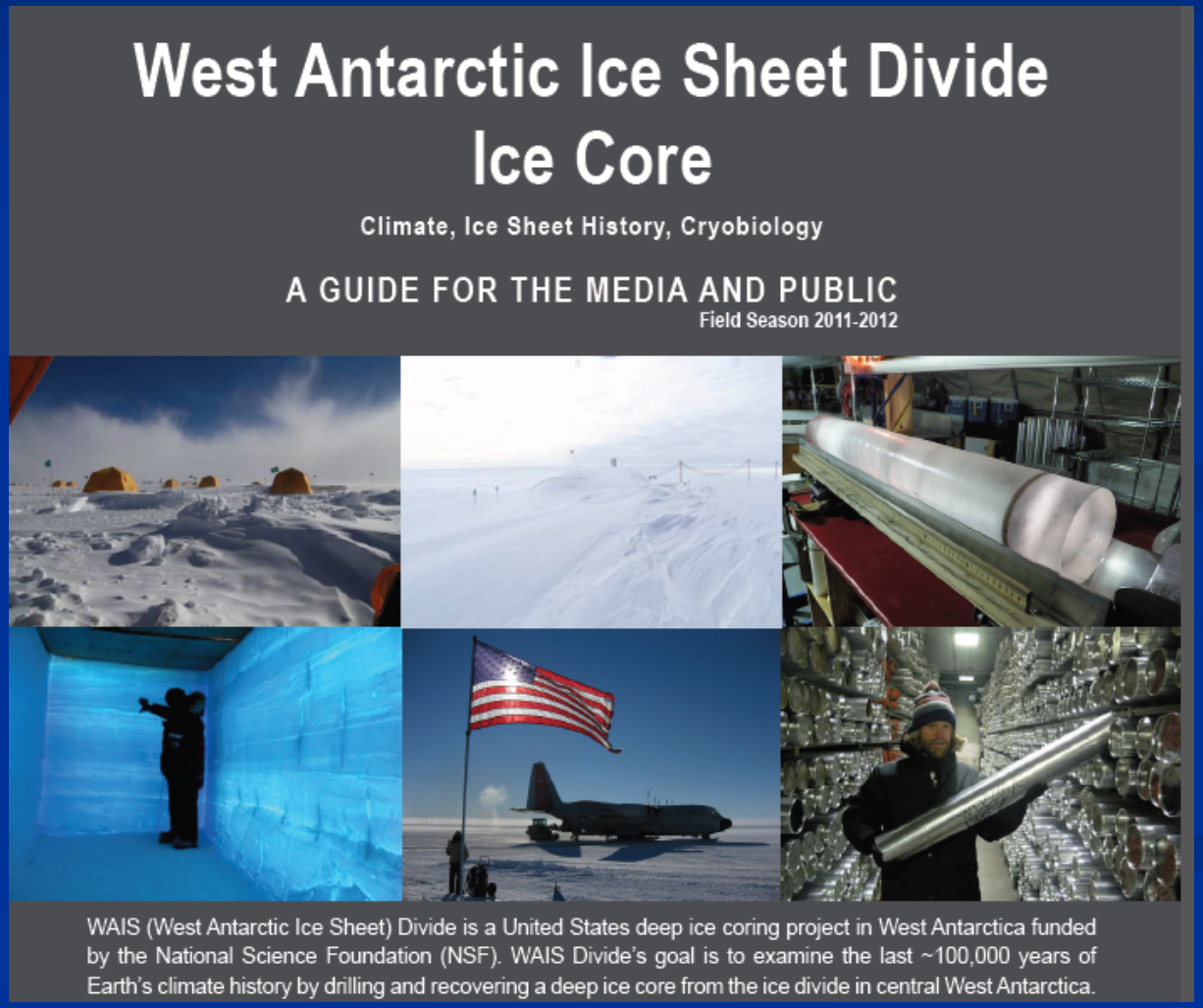
"Settled Science" : The process of SCIENCE is never settled ! Science only tells the best and most defensible story with available knowledge at a point in time.

Can't prove global warming: Science cannot "prove" anything -- proof is exclusive turf of math and logic.
Science can only reduce uncertainty about our knowledge of the physical, chemical and biological world.

Science is a process and not a courtroom trial where someone wins and someone loses.

Global Warming-- Ice Core Paleo Climate

A key source of information on climate change (especially Temperature and CO_2) is provided by ice cores from Antarctica



Global Warming-- Ice Core Paleo Climate

Numerous ice-cores taken from multiple locations (to depths of 10,000 feet) that record past 400,000 to 800,000 years of earth's climate changes

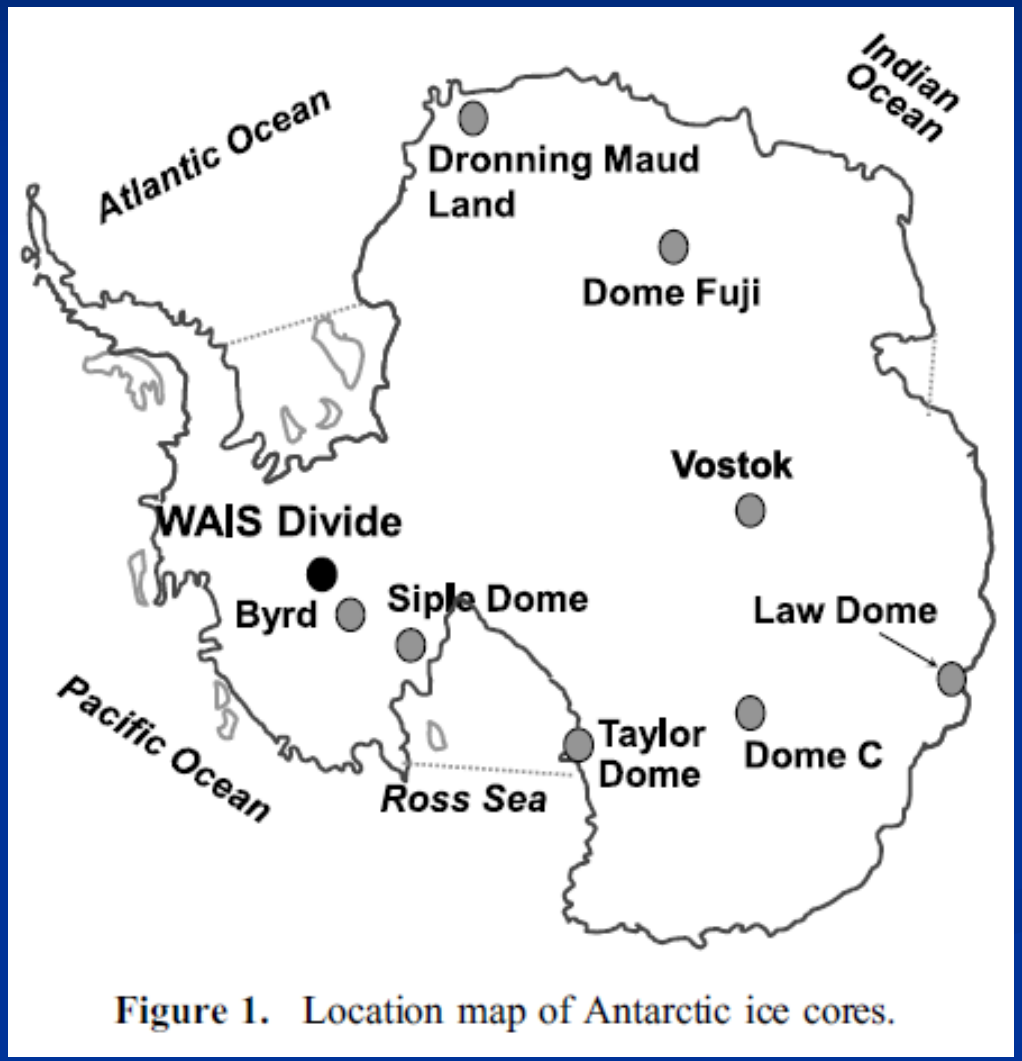
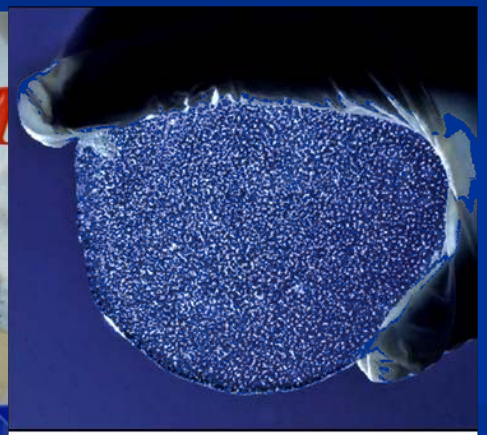


Figure 1. Location map of Antarctic ice cores.

Chemical analysis of ancient air trapped in ice provides detailed record of earth's paleoclimate



A slice of ice core containing tiny bubbles of ancient air

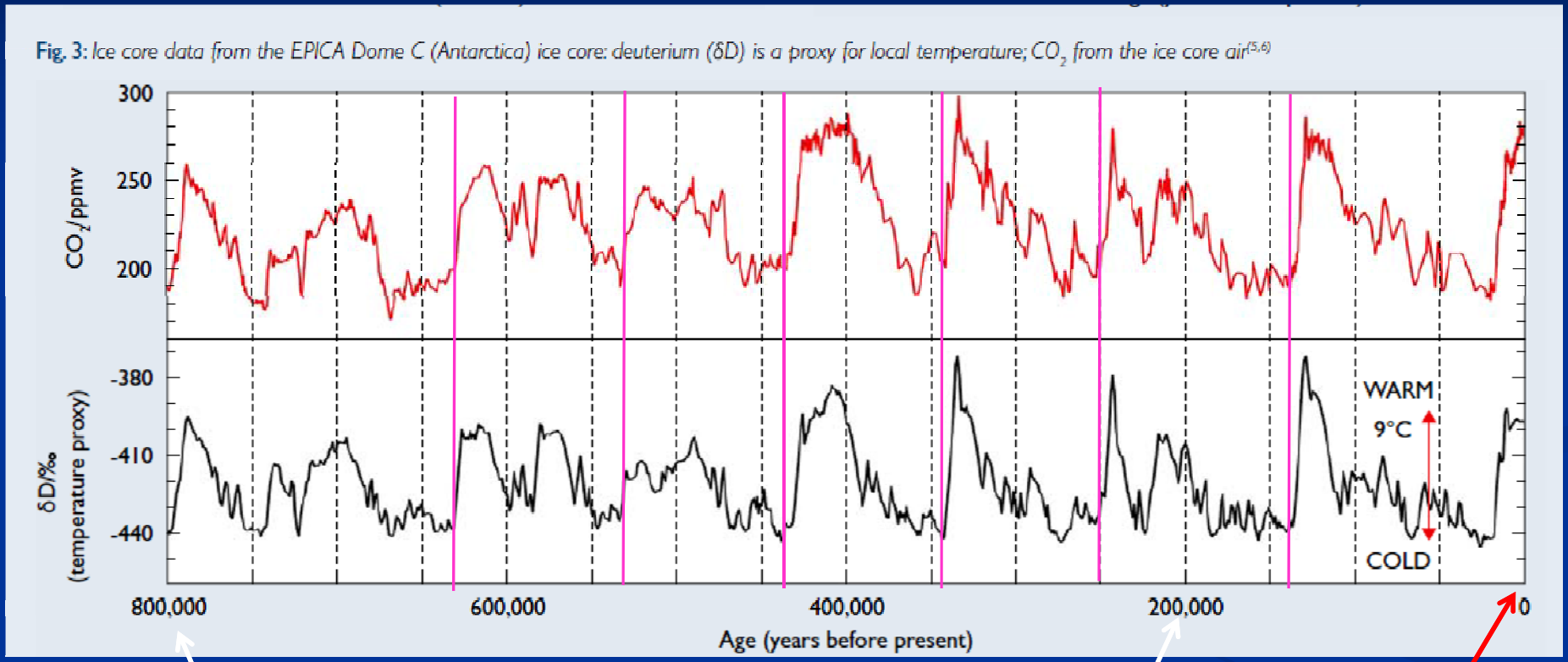
FIGURE 3.1 A one-meter long section of ice core from the West Antarctic Ice Sheet Divide Ice Core; section contains a dark ash layer. SOURCE: Photo by Heidi Roop.

2015 Montana Water Supply Initiative

Yellowstone River Basin

Global Warming-- Ice Core Paleo Climate

High resolution temporal history of CO^2 and Temperature for last 800,00 years



800,063 years ago

200,063 years ago

1950

Global Warming-- Ice Core Paleo Climate

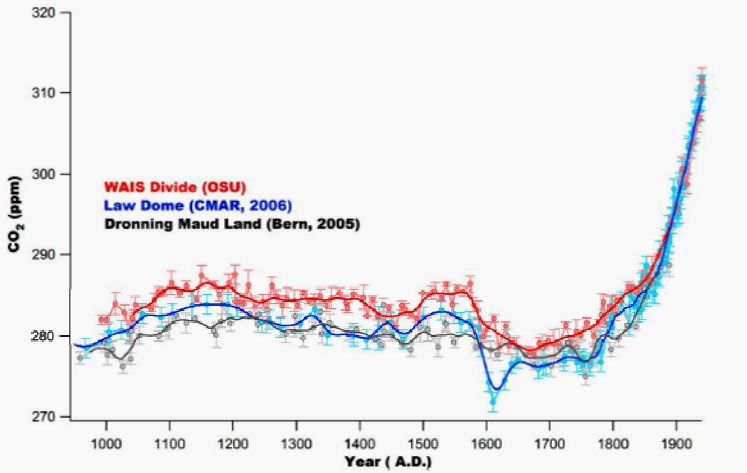


Figure 2. Atmospheric CO_2 for the last 1000 years. WAIS Divide data (red, this study) are compared with those from the Law Dome (blue) [*Etheridge et al.*, 1996; *MacFarling Meure et al.*, 2006] and EPICA Dronning Maud Land (black) [*Siegenthaler et al.*, 2005]. To facilitate comparison of CO_2 records, a Gaussian filter (1σ = 10 years) was applied to interpolated annual data sets (darker lines). O
for Oregon State University and CMAR, CSIRO Marine and Atmospheric Research.

Which came first ?

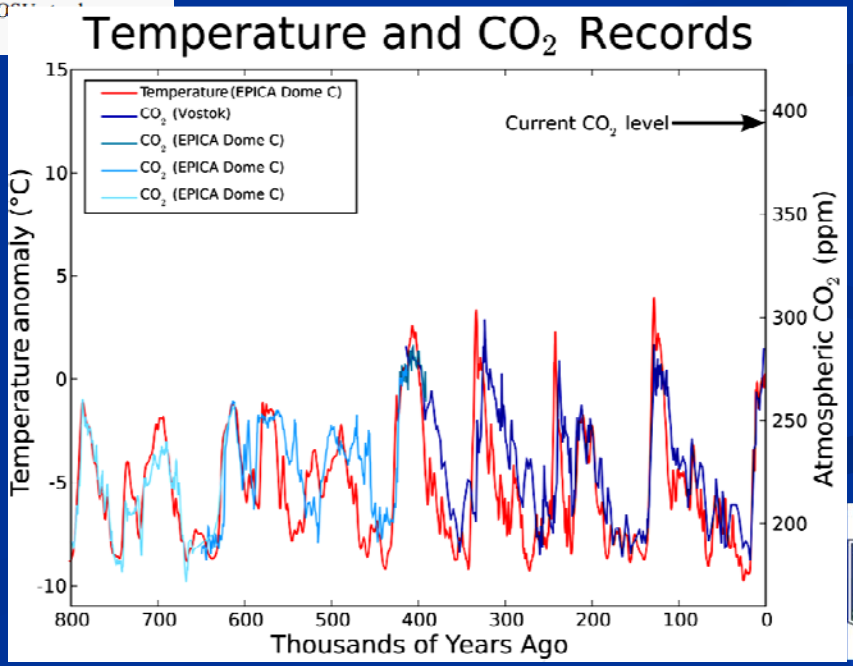
Temperature increase ?

or

Increase in CO_2 ?

DOES IT MATTER ?

(not really)



Global Warming-- Ice Core Paleo Climate

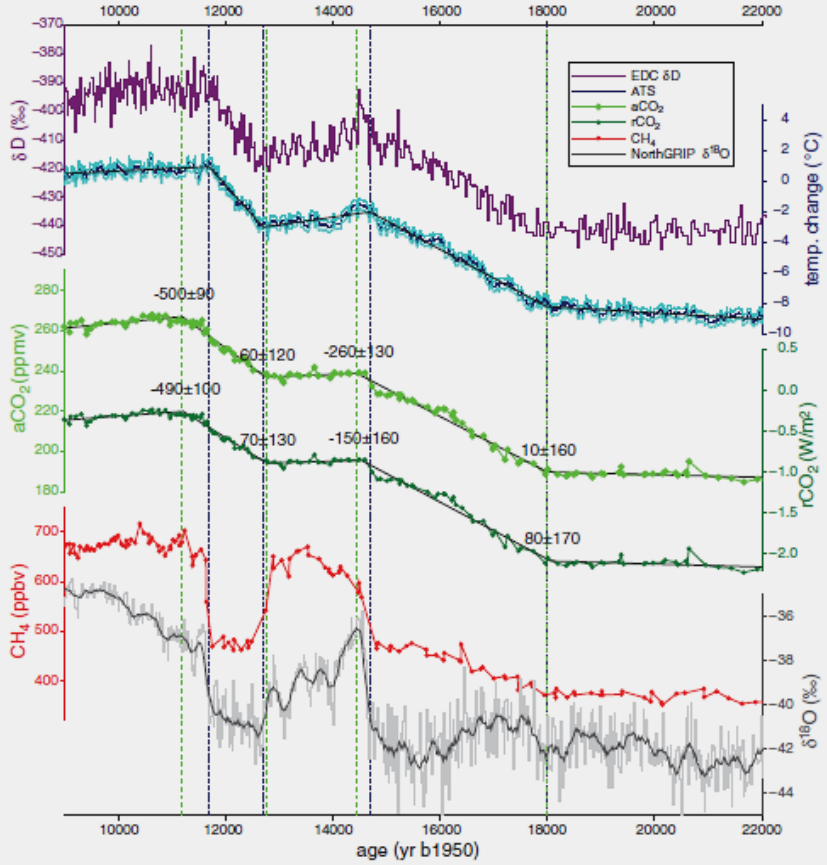


Fig. 4. Various climate time series during TI. Shown are δD from EDC (*28*) (purple), ATS (dark blue, this study) and confidence interval (light blue), aCO_2 from EDC (*1*, *2*) (light green), rCO_2 (dark green), atmospheric CH_4 from EDC (*29*) (red), and Greenland $\delta^{18}O$ from NorthGRIP (gray) onto the GICC05 age scale (*27*) with a 220-year running average (dark gray). The solid lines represent the best six-point linear fit of ATS, aCO_2, and rCO_2 (supplementary materials). The vertical dashed lines mark the four break points in ATS (blue) and in aCO_2 (green), where we evaluated the aCO_2-AT and the rCO_2-AT phase lags (black numbers). The new EDC age scale is described in the supplementary materials.

At this point ice-core research indicates that when Temp and CO_2 change, initial increases occur nearly at the same time. Orbital changes may initiate the cooling (glaciation) or warming trend (de-glaciation). Once trend is initiated, greenhouse gases strongly influence rate and amount of increase in temperature.

Synchronous Change of Atmospheric CO_2 and Antarctic Temperature During the Last Deglacial Warming

F. Parrenin,[1]* V. Masson-Delmotte,[2] P. Köhler,[3] D. Raynaud,[1] D. Paillard,[2] J. Schwander,[4] C. Barbante,[5,6] A. Landais,[2] A. Wegner,[3]† J. Jouzel[2]

Understanding the role of atmospheric CO_2 during past climate changes requires clear knowledge of how it varies in time relative to temperature. Antarctic ice cores preserve highly resolved records of atmospheric CO_2 and Antarctic temperature for the past 800,000 years. Here we propose a revised relative age scale for the concentration of atmospheric CO_2 and Antarctic temperature for the last deglacial warming, using data from five Antarctic ice cores. We infer the phasing between CO_2 concentration and Antarctic temperature at four times when their trends change abruptly. We find no significant asynchrony between them, indicating that Antarctic temperature did not begin to rise hundreds of years before the concentration of atmospheric CO_2, as has been suggested by earlier studies.

Analyses of polar ice cores have shown that the concentration of atmospheric CO_2 (aCO_2) and surface air temperature are closely related and that they have risen and fallen in tandem over most of the past 800,000 years. However, whether changes of temperature

1 MARCH 2013 VOL 339 SCIENCE www.sciencemag.org

Global Warming-- The Debate ?

Science is not based on consensus, but……

AGU
American Geophysical Union

Human-induced climate change requires urgent action.

Humanity is the major influence on the global climate change observed over the past 50 years. Rapid societal responses can significantly lessen negative outcomes.

"Human activities are changing Earth's climate. At the global level, atmospheric concentrations of carbon dioxide and other heat-trapping greenhouse gases have increased sharply since the Industrial Revolution. Fossil fuel burning dominates this increase. Human-caused increases in greenhouse gases are responsible for most of the observed global average surface warming of roughly 0.8°C (1.5°F) over the past 140 years. Because natural processes cannot quickly remove some of these gases (notably carbon dioxide) from the atmosphere, our past, present, and future emissions will influence the climate system for millennia.

Scientific organizations endorsing the consensus

The following scientific organizations endorse the consensus position that "most of the global warming in recent decades can be attributed to human activities":

- American Association for the Advancement of Science
- American Astronomical Society
- American Chemical Society
- American Geophysical Union
- American Institute of Physics
- American Meteorological Society
- American Physical Society
- Australian Meteorological and Oceanographic Society
- Australian Bureau of Meteorology and the CSIRO
- British Antarctic Survey
- Canadian Foundation for Climate and Atmospheric Sciences
- Canadian Meteorological and Oceanographic Society
- Environmental Protection Agency
- European Federation of Geologists
- European Geosciences Union
- European Physical Society
- Federation of American Scientists
- Federation of Australian Scientific and Technological Societies
- Geological Society of America
- Geological Society of Australia
- Geological Society of London
- International Union for Quaternary Research (INQUA)
- International Union of Geodesy and Geophysics
- National Center for Atmospheric Research
- National Oceanic and Atmospheric Administration
- Royal Meteorological Society
- Royal Society of the UK

MONTANA DNRC

2015 Montana Water Supply Initiative
Yellowstone River Basin

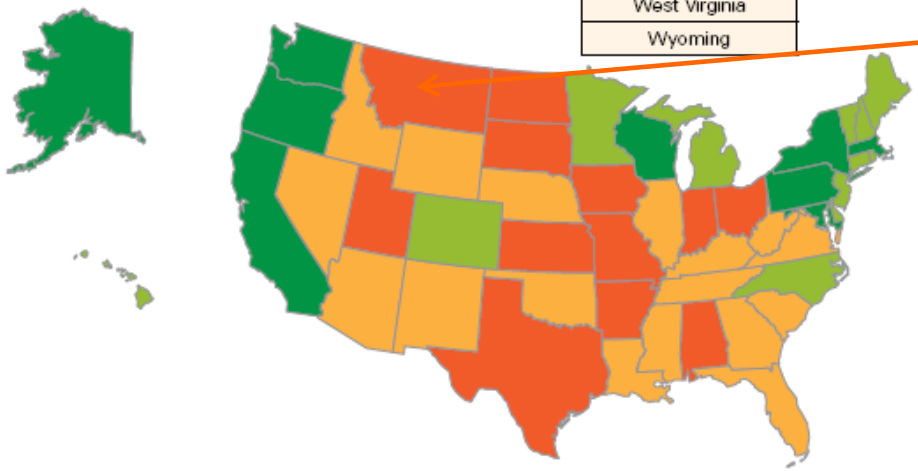
HOW ARE WESTERN STATES PLANNING for WATER RESOURCE EFFECTS of CLIMATE CHANGE ?

Wyoming
North and South Dakota
Idaho
Colorado
Washington
Oregon

Western State's Water Planning For Climate Change

Figure ES-2: Ranking of states according to climate preparedness planning

Category 1	Category 2	Category 3	Category 4
Alaska*	Colorado	Arizona	Alabama
California	Connecticut	Georgia	Arkansas
Maryland	Delaware	Florida	Indiana**
Massachusetts	Hawaii	Idaho	Iowa
New York	Maine	Illinois	Kansas**
Oregon*	Michigan	Kentucky	Missouri
Pennsylvania*	Minnesota	Louisiana	Montana
Washington	New Hampshire	Mississippi	North Dakota
Wisconsin*	New Jersey	Nebraska	Ohio
	North Carolina	Nevada	South Dakota
	Rhode Island	New Mexico	Texas**
	Vermont	Oklahoma	Utah**
		South Carolina	
		Tennessee	
		Virginia	
		West Virginia	
		Wyoming	



*Denotes a state where climate preparedness activities at the state government level, although once more robust, appear to have slowed or stalled in some planning areas.
**Denotes a state that has some existing water programs and policies (e.g., water conservation) that, if recognized as climate change adaptation tools, could prove beneficia for climate preparedness.

PAGE 3 | Ready or Not: An Evaluation of State Climate and Water Preparedness Planning

Water Plan Incorporates Climate Change ?

1: Comprehensive/ Implementation

2: Fragmented/unguided

3: Limited

4: Yet to incorporate into water planning

Western State's Water Planning For Climate Change

WYOMING

Citizen Government Business Visitor

Wyoming State Water Plan
Wyoming Water Development Office
6920 Yellowtail Rd
Cheyenne, WY 82002
Phone: 307-777-7626

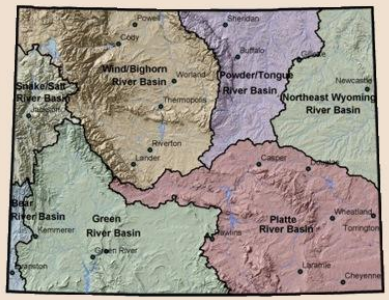
News and Information
- Newsletter
- Water Planning Process

History
- Historical Planning

Documents
- Wyoming Water Facts

River Basin Plans
- Statewide Framework Plan
- Bear River Basin
- Green River Basin
- NE River Basin
- Platte River Basin
- Powder/Tongue River Basin
- Snake/Salt River Basin
- Wind/Bighorn River Basin

Basin Advisory Groups
- Mission and Purpose
- Calendar
- Agendas
- Meeting Records
- Reference Material



Summary of the State Water Planning Process

In 1997 the Legislature directed the WWDC to conduct a water planning feasibility study with the assistance of the University of Wyoming (UW). In conjunction with the State Engineer and the University, the WWDC completed an intensive public outreach effort, a

IDAHO

State Adaptation Planning

Water planning in Idaho at the state level consists of three components: the Idaho State Water Plan, comprehensive basin planning, and comprehensive aquifer planning. The current State Water Plan was released in 1996 and does not include consideration of climate change impacts. The state has been working on an update to this plan since 2007; the update will include a discussion of climate variability and the need for increased flexibility in water management to adapt to climate-induced hydrologic changes.[40,41] Other updates to the plan involve water rights transferability, water supply banking, conjunctive management of surface water and groundwater, aquifer recharge and storage, weather modification, and water use efficiency. In addition, comprehensive basin plans, which focus on assessing regional water resources and existing water supply and quality issues, have been completed for 10 basins statewide and are included in the State Water Plan.[42]

MONTANA DNRC

Western State's Water Planning For Climate Change

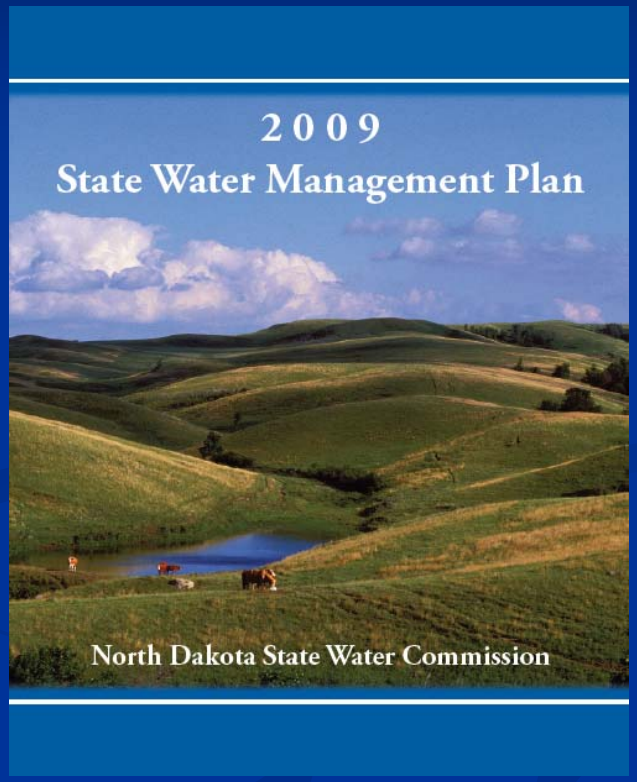
SOUTH DAKOTA

The State Water Plan consists of two components - the State Water Facilities Plan and the State Water Resources Management System. Projects that will require state funding assistance or state assistance to acquire federal funding assistance or authorization must be on the State Water Plan.

State Water Facilities Plan

The State Water Facilities Plan is a listing of potential water projects. The facilities plan includes projects such as rural, municipal, and industrial water supply; wastewater facilities; storm sewers; water conservation; watershed management and restoration; solid waste management; ground water contamination; pollution prevention or remediation; and dam safety. View the projects currently on the list.

NORTH DAKOTA

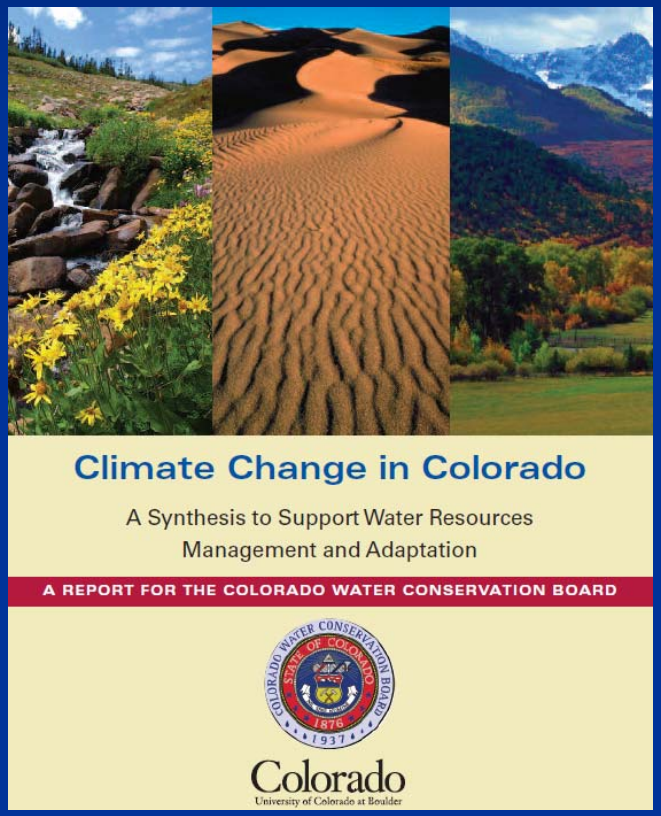


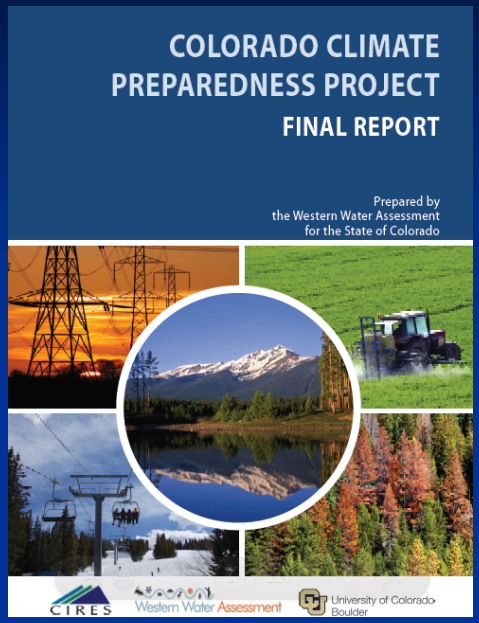
2015 Montana Water Supply Initiative

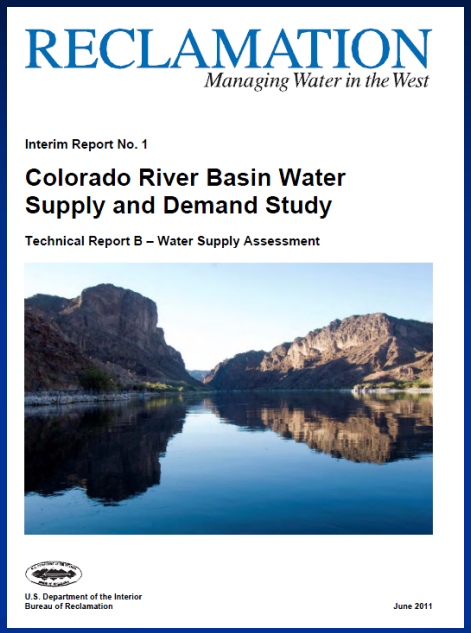
Yellowstone River Basin

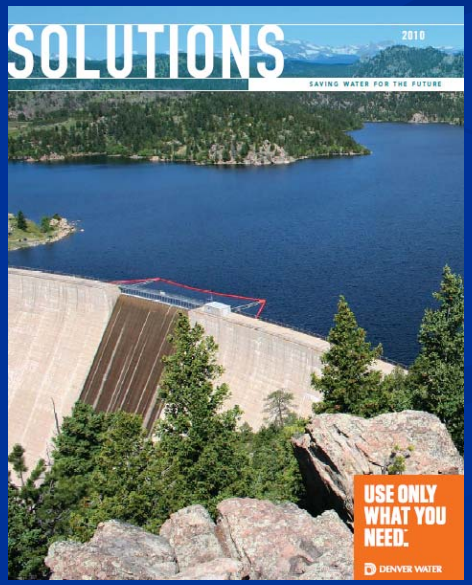
Western State's Water Planning For Climate Change

COLORADO









COLORADO

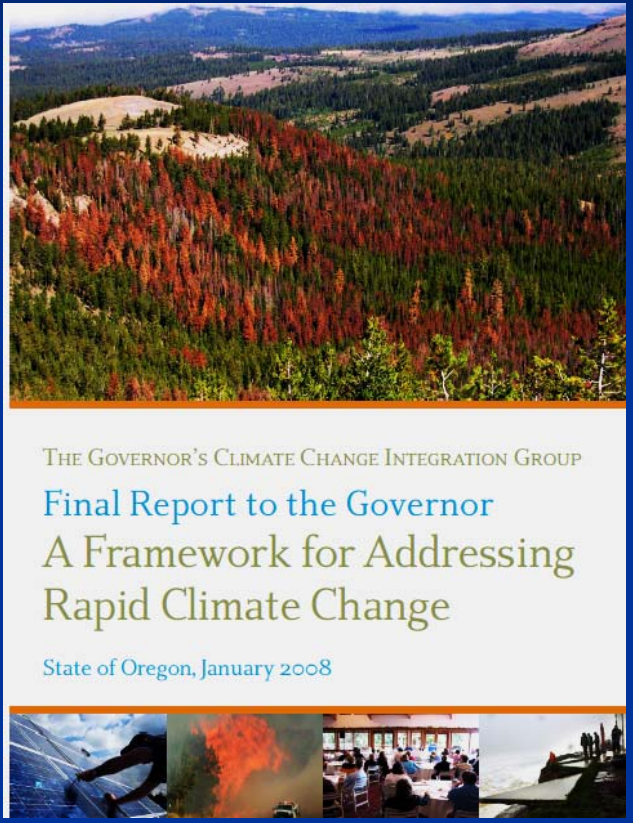
TABLE 6-1. Challenges Faced by Water Managers, and Projected Changes

Issues	*Observed and/or Projected Change*
Water demands for agriculture and outdoor watering	Increasing temperatures raise evapotranspiration by plants, lower soil moisture, alter growing seasons, and thus increase water demand.
Water supply infrastructure	Changes in snowpack, streamflow timing, and hydrograph evolution may affect reservoir operations including flood control and storage. Changes in the timing and magnitude of runoff may affect functioning of diversion, storage, and conveyance structures.
Legal water systems	Earlier runoff may complicate prior appropriation systems and interstate water compacts, affecting which rights holders receive water and operations plans for reservoirs.
Water quality	Although other factors have a large impact, "water quality is sensitive both to increased water temperatures and changes in patterns of precipitation" (CCSP SAP 4.3, p. 149). For example, changes in the timing and hydrograph may affect sediment load and pollution, impacting human health.
Energy demand and operating costs	Warmer air temperatures may place higher demands on hydropower reservoirs for peaking power. Warmer lake and stream temperatures may affect water use by cooling power plants and in other industries.
Mountain habitats	Increasing temperature and soil moisture changes may shift mountain habitats toward higher elevation.
Interplay among forests, hydrology, wildfires, and pests	Changes in air, water, and soil temperatures may affect the relationships between forests, surface and ground water, wildfire, and insect pests. Water-stressed trees, for example, may be more vulnerable to pests.
Riparian habitats and fisheries	Stream temperatures are expected to increase as the climate warms, which could have direct and indirect effects on aquatic ecosystems (CCSP SAP 4.3), including the spread of in-stream non-native species and diseases to higher elevations, and the potential for non-native plant species to invade riparian areas. Changes in streamflow intensity and timing may also affect riparian ecosystems.
Water- and snow-based recreation	Changes in reservoir storage affect lake and river recreation activities; changes in streamflow intensity and timing will continue to affect rafting directly and trout fishing indirectly. Changes in the character and timing of snowpack and the ratio of snowfall to rainfall will continue to influence winter recreational activities and tourism.
Groundwater resources	Changes in long-term precipitation and soil moisture can affect groundwater recharge rates; coupled with demand issues, this may mean greater pressures on groundwater resources.

Climate Change in Colorado 41

Western State's Water Planning For Climate Change

OREGON



The Oregon Climate Change Adaptation Framework

December 2010

Drought Response Tools Available in Oregon

When the Governor makes a drought declaration, WRD may exercise emergency water rights authority, generally for the duration of the declaration or one year, whichever comes first (unless the declaration is renewed). In those cases, the Water Resources Department may:

1. Issue temporary emergency permits under an expedited process. The drought permits a e limited to replacement of water not available under a permanent water right.

2. Issue temporary transfers, authorizing changes in type of use, place of use, or point of diversion of an existing water right, including "split season" transfers.

3. Issue temporary instream leases to convert all or part of a water right to augment instream flow.

4. Approve special option agreements during drought emergencies. Water used under the terms of an approved option or agreement may be used at locations, points of diversion version, and for beneficial uses other than those described in the water right.

5. Authorize temporary substitution of a supplemental groundwater right for a primary surface water right.

6. Authorize temporary exchange of the source of water allowed under a water right, such as moving from a direct flow right to a stored water source; and

7. Grant preference of use to water rights for human or livestock consumption.

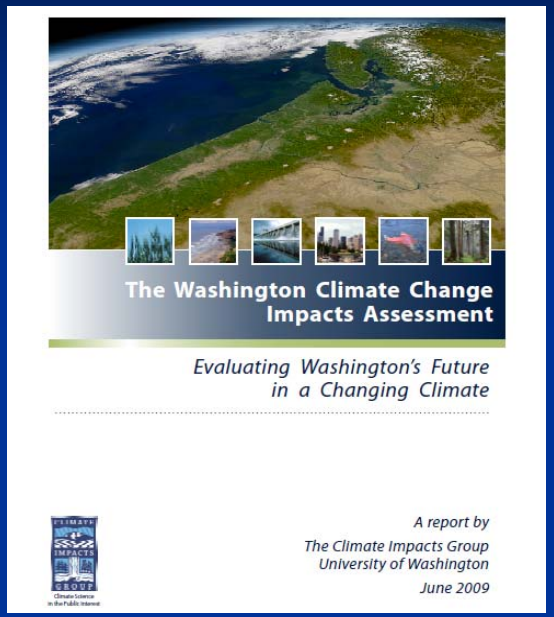
Note: Emergency actions involve a review process that includes an abbreviated public interest determination and a test for injury to existing water rights. There is a specific set of reduced fees for many of these transactions under Oregon Administrative Rules.

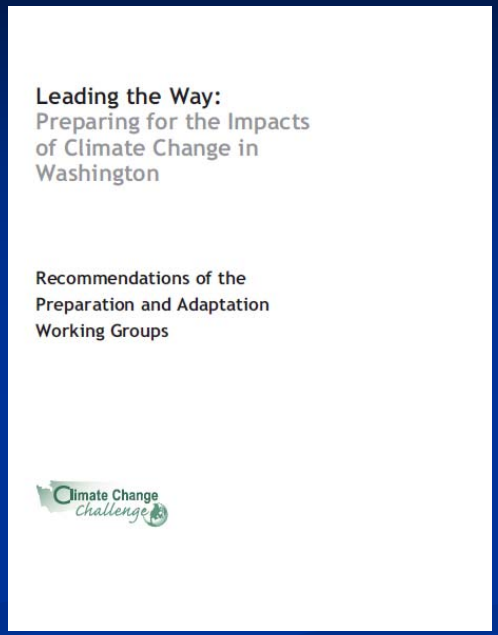
2015 Montana Water Supply Initiative

Yellowstone River Basin

Western State's Water Planning For Climate Change

WASHINGTON





MONTANA DNRC

Western State's Water Planning For Climate Change

WASHINGTON

Implement operational changes	• Rebalance flood control rule curves and reservoir refill schedules • Allocate increased storage for instream flow • Improve hydrologic forecasting and use of forecasts • Increase use of optimization in reservoir management to rebalance systems • Shift hydropower generation schedules to emphasize summer energy production • Revise maintenance schedules to conserve water (e.g. seasonal pipe and reservoir flushing schedules) • Use existing flood irrigation systems to recharge soil moisture and groundwater during winter
Increase ability to transfer water between uses and users	• Use water banks, water pools, and water markets to facilitate the reallocation of water resources in times of shortage • Remove obstacles to flexible water reallocation in existing water law and water policy • Factor in climate change impacts in renegotiations of transboundary water agreements where applicable
Increase drought preparedness	• Improve drought forecasting capability • Update drought management plans to recognize changing conditions • Increase emergency aid assistance for droughts • Improve coordination between stakeholders during drought

WASHINGTON

Table 2. Options for adapting to the impacts identified in the Washington Climate Change Impacts Assessment enhancing or supplementing Washington's Preparation/Adaptation Working Group recommendations, released February 2008

Sector	Adaptation Strategy	Examples of Adaptation Actions and Activities that Build Adaptive Capacity
Hydrology and Water Mngmt.	Expand and diversify existing water supplies	• Connect regional water systems to utilize overall water supply more efficiently • Enhance existing groundwater supplies through aquifer storage and recovery • Purchase existing water rights to meet changing supply needs • Add capacity to existing reservoirs by raising dam height
	Develop new or alternate water supplies	• Develop new sustainable groundwater sources • Construct new surface water reservoirs • Develop advanced wastewater treatment capacity for water reuse ("gray water" or "purple pipe") • Implement new technologies such as reverse osmosis for desalination (coastal areas only) • Encourage rainwater harvesting to provide water supply for residential and commercial buildings
Reduce demand/ improve efficiency		• Increase water conservation measures • Price water to encourage conservation in summer • Reduce outdoor landscape water demands (e.g., promote drought tolerant landscaping) • Update building codes to require highest efficiency plumbing fixtures (e.g. dual flush toilets) • Provide financial incentives (e.g., tax breaks, rebates) for switching to more efficient manufacturing processes, irrigation practices, and appliances • Reduce system losses (repair pipes, line irrigation canals)

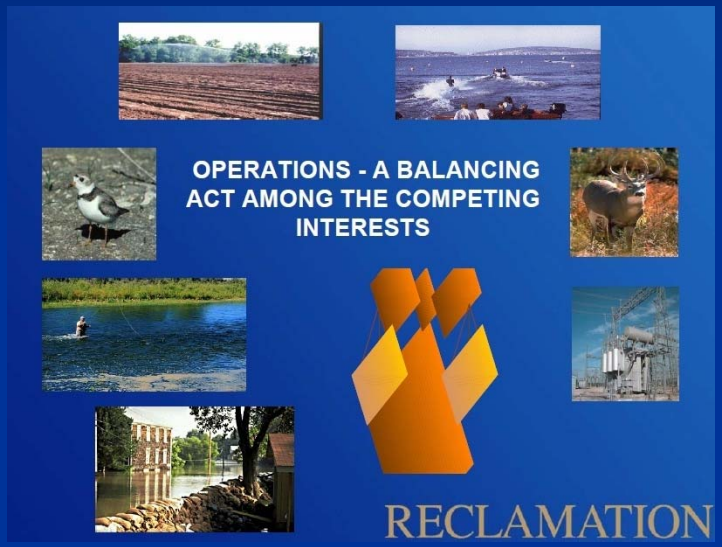
Western State's Water Planning For Climate Change

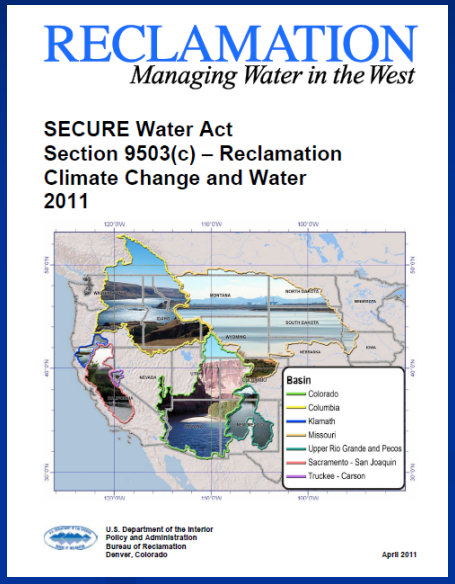
WASHINGTON

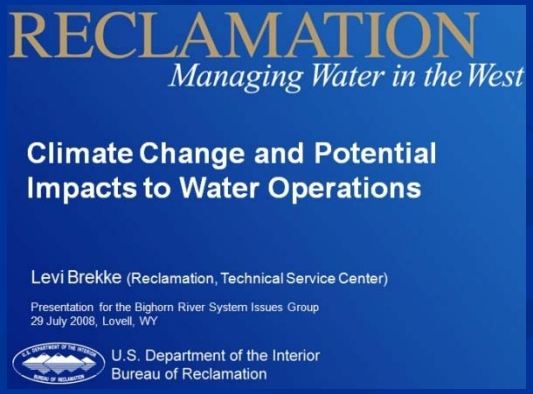
Agriculture	Adjust production to reflect changing conditions	• Change planting dates • Change planting varieties to include crops that are better suited to projected climate conditions • Improve approaches to insect and weed management
	Improve agricultural water supply and use	• Promote new irrigation technologies to improve water use efficiency • Promote water conservation • Use market forces to distribute water • Diversify and expand water supplies and infrastructure
	Improve information and technology used in managing agriculture	• Maintain well-funded monitoring network and information center for data collection on impacts to agriculture • Support research on biotechnology-based breeding to increase the number of crop varieties that are suitable for projected climate conditions • Increase research on automation, sensors, and overall improvement of agricultural management practices to reduce costs and compensate for yield losses

Western State's Water Planning For Climate Change

Federal Government



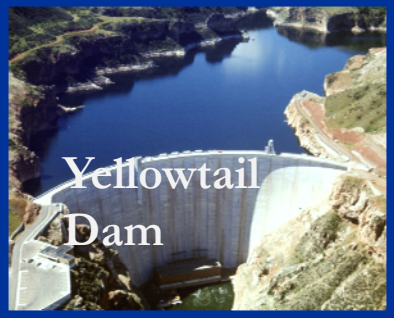


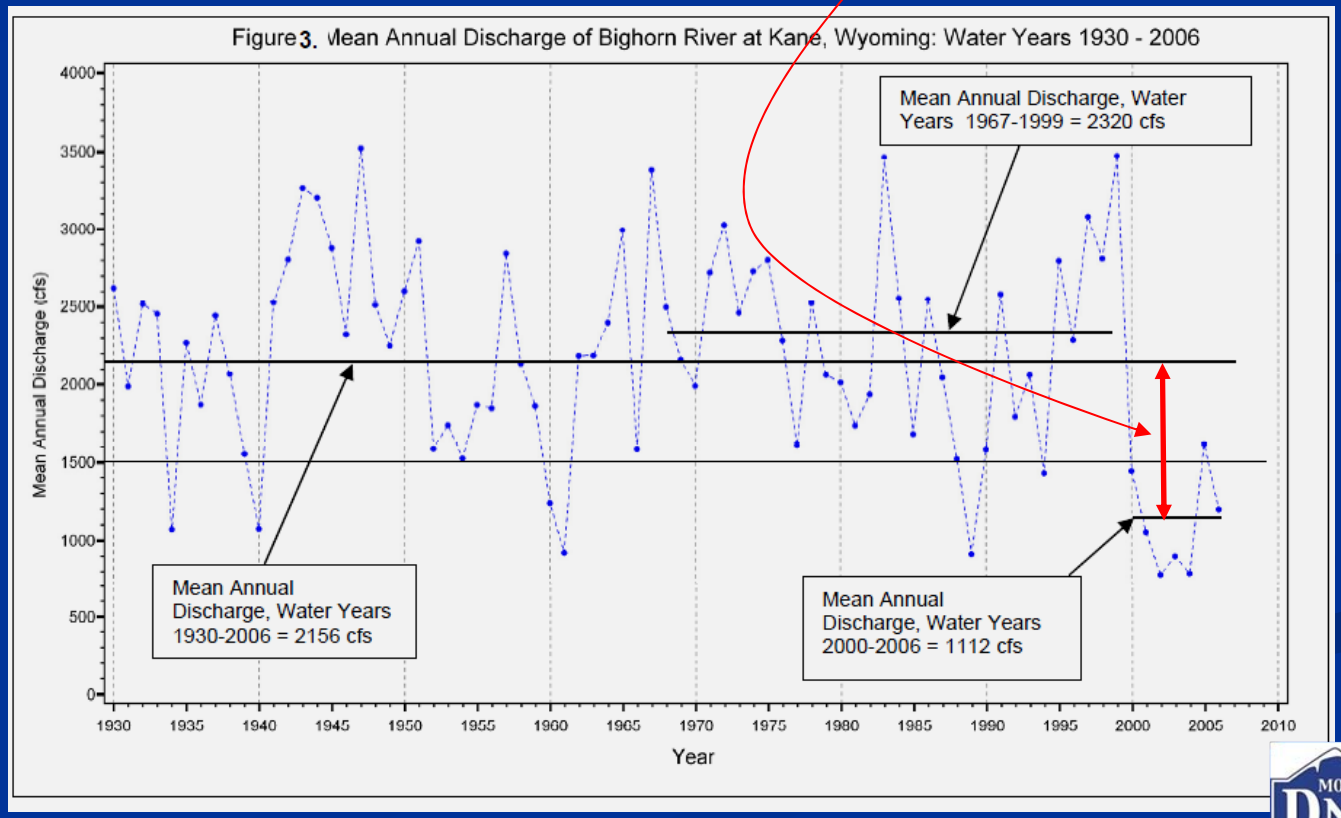


Western State's Water Planning For Climate Change

Droughts of the present (2000's) and past (1930's) provide insight into future water availability and water supply problems as climate warms:

Inflow to Bighorn Reservoir (Kane, WY) 2001 to 2004 and 2006 one- half of long-term mean: USBR develops public process on modified reservoir operations to accommodate competing uses: fish, hydropower, boating and irrigation -- ongoing process.

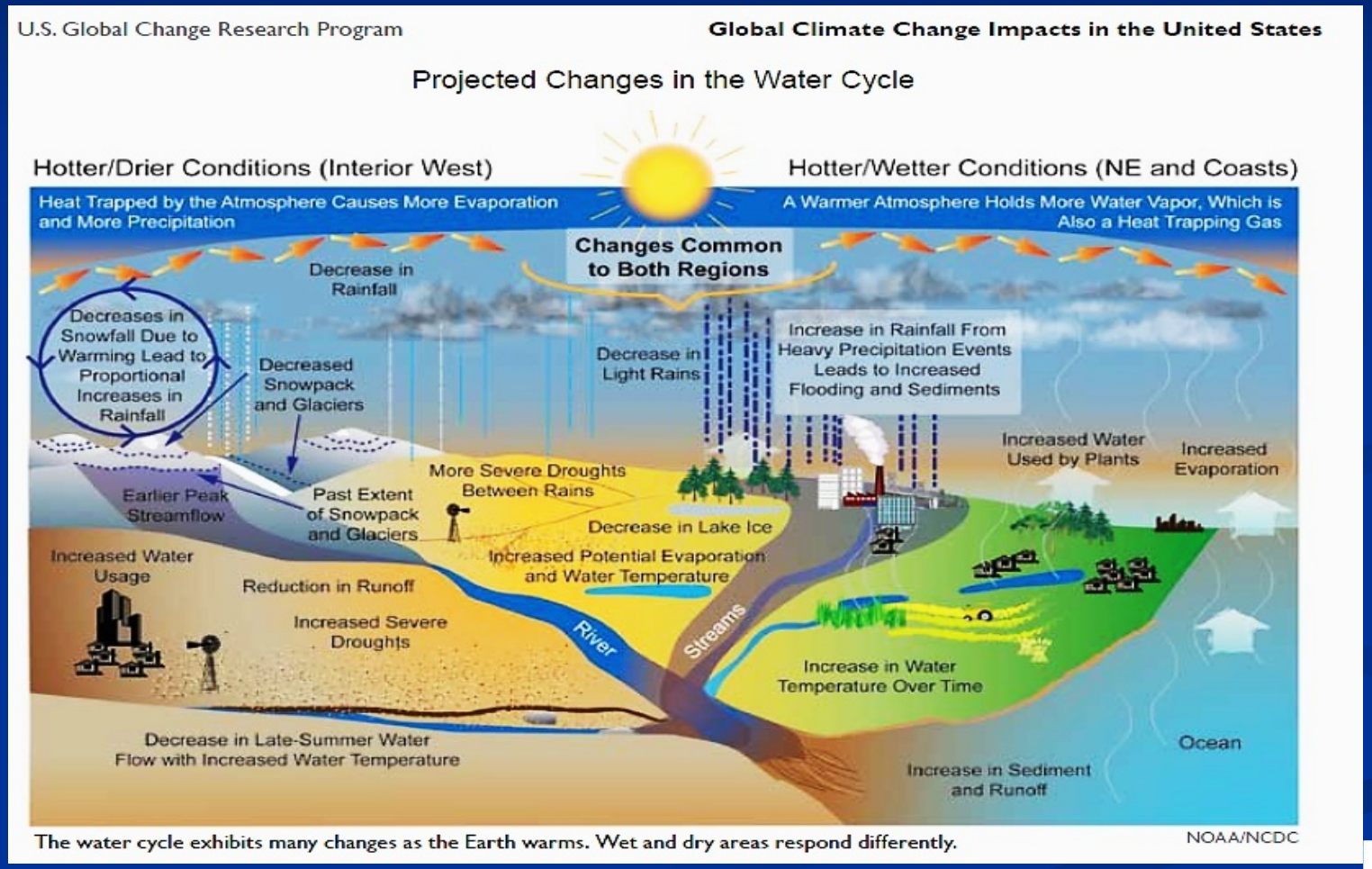




Western State's Water Planning For Climate Change

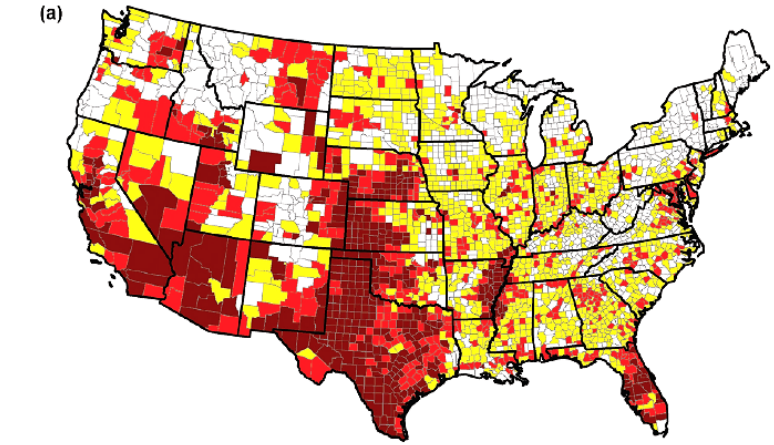
Observed Water-Related Changes During the Last Century[142]		
Observed Change	**Direction of Change**	**Region Affected**
One to four week earlier peak streamflow due to earlier warming-driven snowmelt	Earlier	West and Northeast
Proportion of precipitation falling as snow	Decreasing	West and Northeast
Duration and extent of snow cover	Decreasing	Most of the United States
Mountain snow water equivalent	Decreasing	West
Annual precipitation	Increasing	Most of the United States
Annual precipitation	Decreasing	Southwest
Frequency of heavy precipitation events	Increasing	Most of the United States
Runoff and streamflow	Decreasing	Colorado and Columbia River Basins
Streamflow	Increasing	Most of East
Amount of ice in mountain glaciers	Decreasing	U.S. western mountains, Alaska
Water temperature of lakes and streams	Increasing	Most of the United States
Ice cover on lakes and rivers	Decreasing	Great Lakes and Northeast
Periods of drought	Increasing	Parts of West and East
Salinization of surface waters	Increasing	Florida, Louisiana
Widespread thawing of permafrost	Increasing	Alaska

ANTICIPATED EFFECTS of CLIMATE CHANGE



Western State's Water Planning For Climate Change

Environmental Science & Technology
Policy Analysis



ENVIRONMENTAL Science & Technology
Policy Analysis
pubs.acs.org/est

Projecting Water Withdrawal and Supply for Future Decades in the U.S. under Climate Change Scenarios

Sujoy B. Roy,[†,*] Limin Chen,[†] Evan H. Girvetz,[‡] Edwin P. Maurer,[§] William B. Mills,[†] and Thomas M. Grieb[†]

[†]Tetra Tech, Inc., Lafayette, California, United States
[‡]University of Washington and the The Nature Conservancy Global Climate Change Program, Seattle, Washington, United States
[§]Santa Clara University, Santa Clara, California, United States

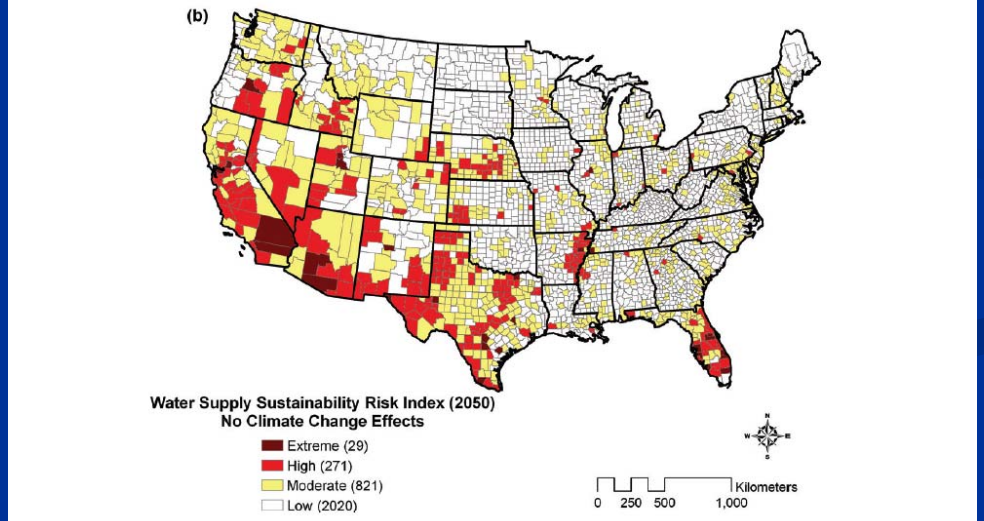


Figure 7. Water Supply Sustainability Risk Index in 2050 (a) with available precipitation computed using projected climate change and (b) with available precipitation corresponding to 20th century conditions, i.e., 1934–2005.

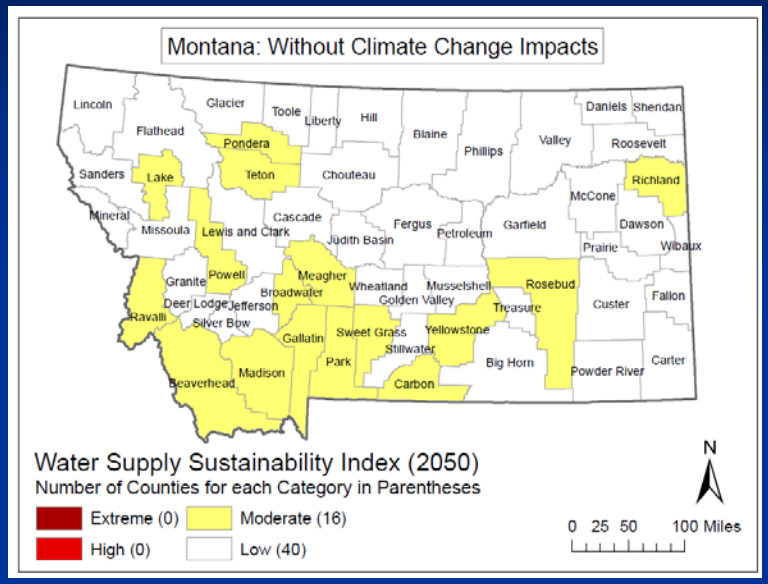
MONTANA DNRC

2015 Montana Water Supply Initiative

Yellowstone River Basin

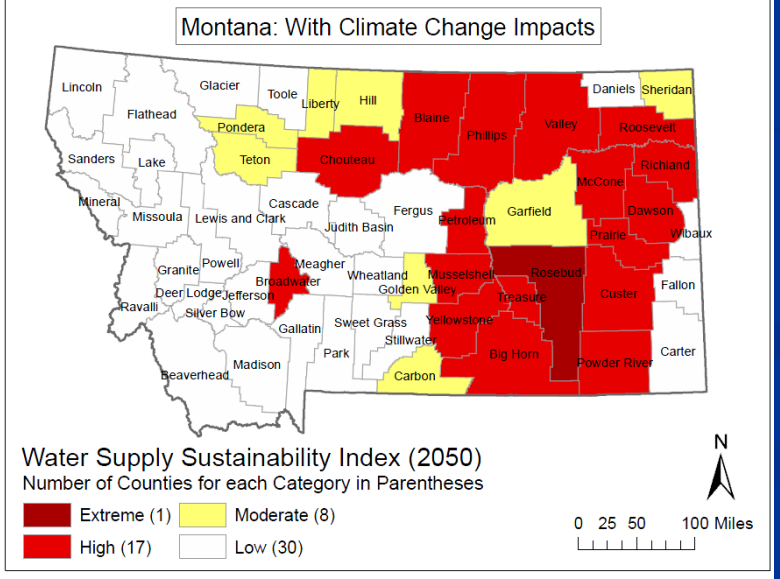
Western State's Water Planning For Climate Change

Estimate of Water Supply Sustainability
with and without Global Warming



Climate Change, Water, and Risk: Current Water Demands Are Not Sustainable

Climate change will have a significant impact on the sustainability of water supplies in the coming decades. A new analysis, performed by consulting firm Tetra Tech for the Natural Resources Defense Council (NRDC), examined the effects of global warming on water supply and demand in the contiguous United States. The study found that more than 1,100 counties—one-third of all counties in the lower 48—will face higher risks of water shortages by mid-century as the result of global warming. More than 400 of these counties will face extremely high risks of water shortages.



MONTANA DNRC

What range of climatic variation do we plan for ?

Paleoclimate (tree-ring) work by Dr. Greg Pederson (USGS) and associates

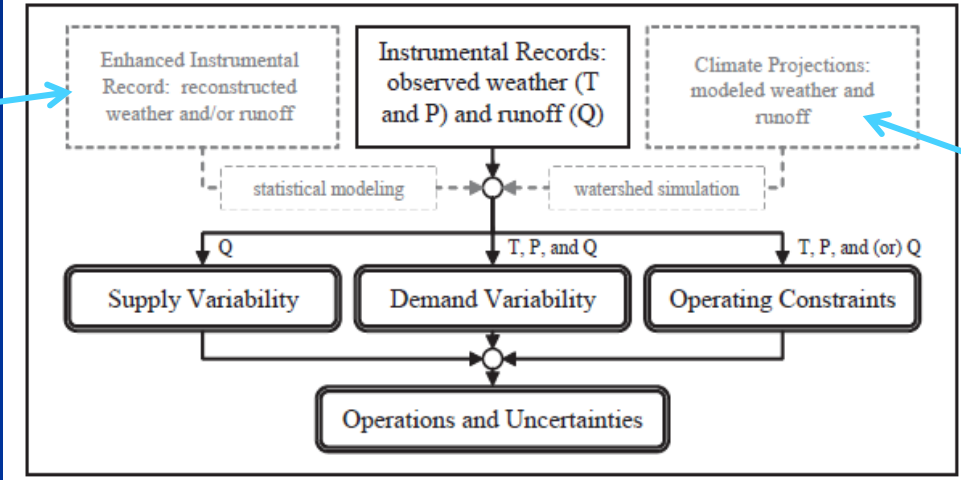
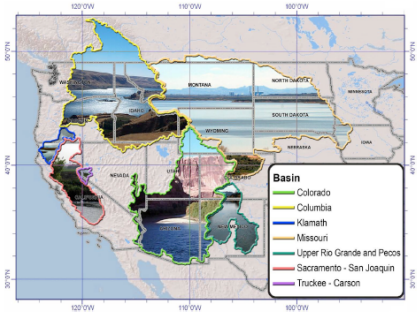


Figure 8. Analytical framework for relating climate to water supplies, demands, and constraints.

RECLAMATION
Managing Water in the West

SECURE Water Act
Section 9503(c) – Reclamation
Climate Change and Water
2011



U.S. Department of the Interior
Policy and Administration
Bureau of Reclamation
Denver, Colorado

April 2011

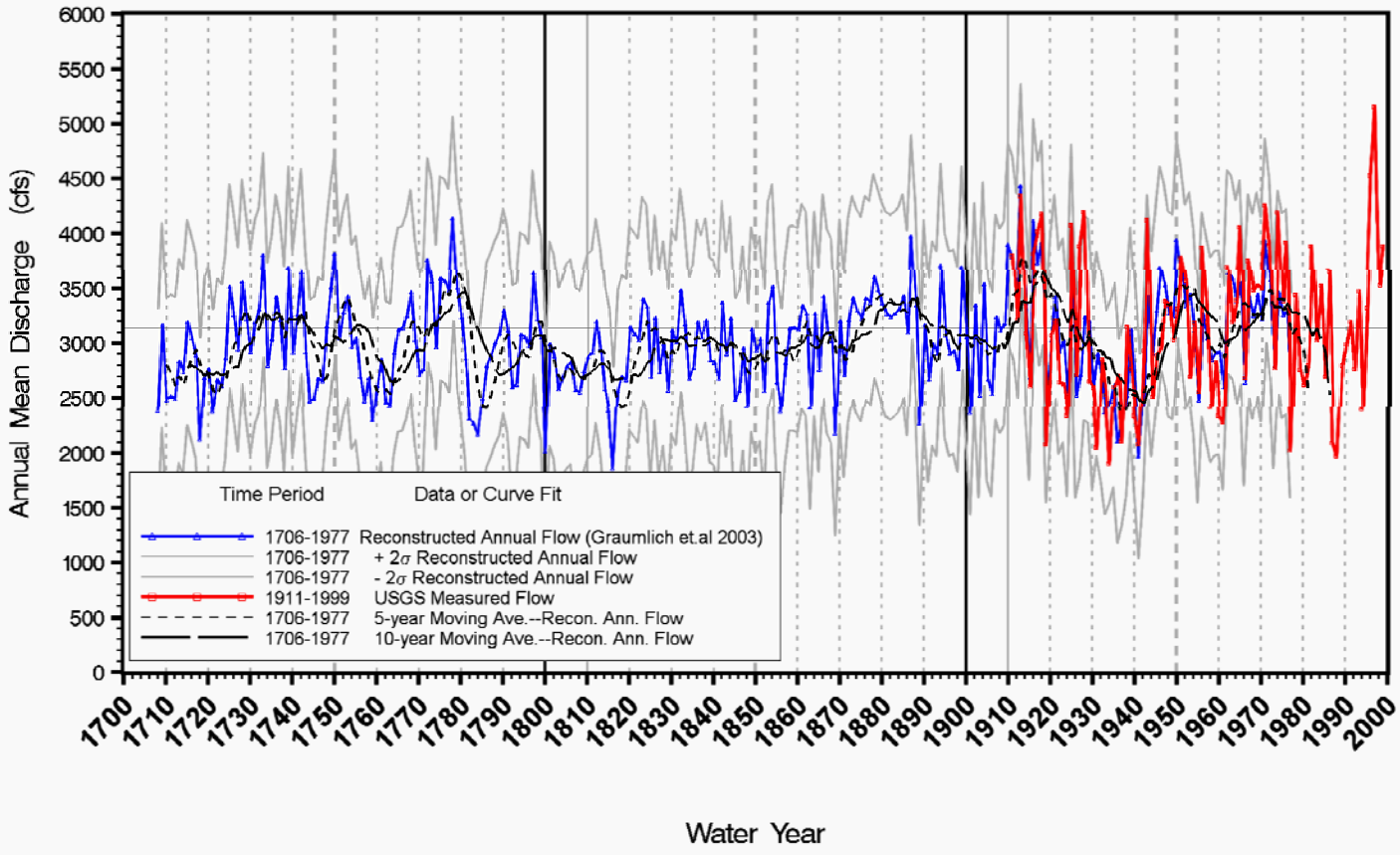
THE END

2015 Montana Water Supply Initiative

Yellowstone River Basin

Climate and Discharge Variability – Corwin Springs

Figure . Reconstructed (1706 to 1977) and Measured (1911-1999) Annual Runoff by Water Year:
Yellowstone River near Corwin Springs, Montana (U.S. Geological Survey Station 06191500)



Flow reconstruction by Graumlich et.al. 2003 (Upper Yellowstone River flow and teleconnections with Pacfic Basin climatevariability during the past three centuries. Climatic Change 59: 245-262).
Annual streamflow 1706-1977 reconstructed by Graumlich et.al. (2003) using upper Yellowstone tree-ring width chronologies and extra-regional climate parameters.
Data Source: Reconstructed Annual Flow, -2 and + 2 Standard Deviation of Flow, and USGS Measured Flow = Graumlich, L.J., et.al., Upper Yellowstone River Flow Reconstruction International Tree-Ring Data Bank. IGBP PAGES/World Data Center for Climatology, Data Contribution Series #2002-074. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.
Five and ten-year moving averages computed from retrieved data. (DNRC Water Resources Division, Helena, MT.)

MONTANA DNRC

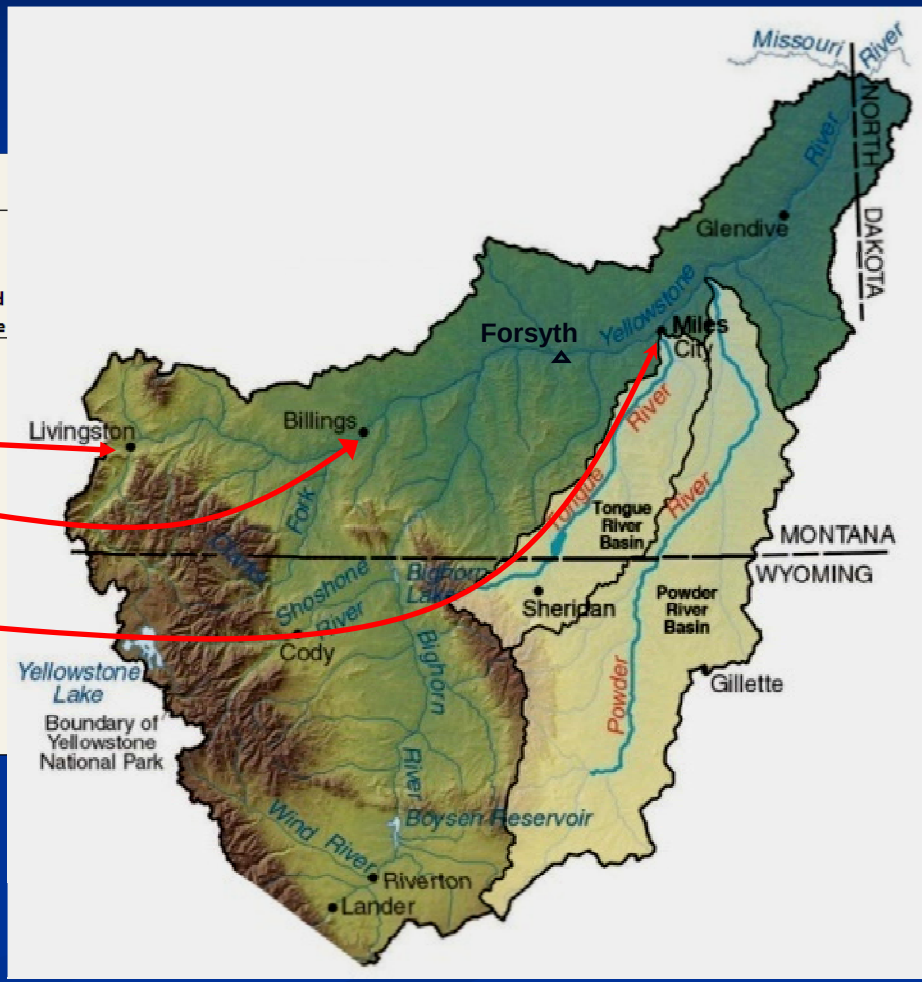
2015 Montana Water Supply Initiative

Yellowstone River Basin

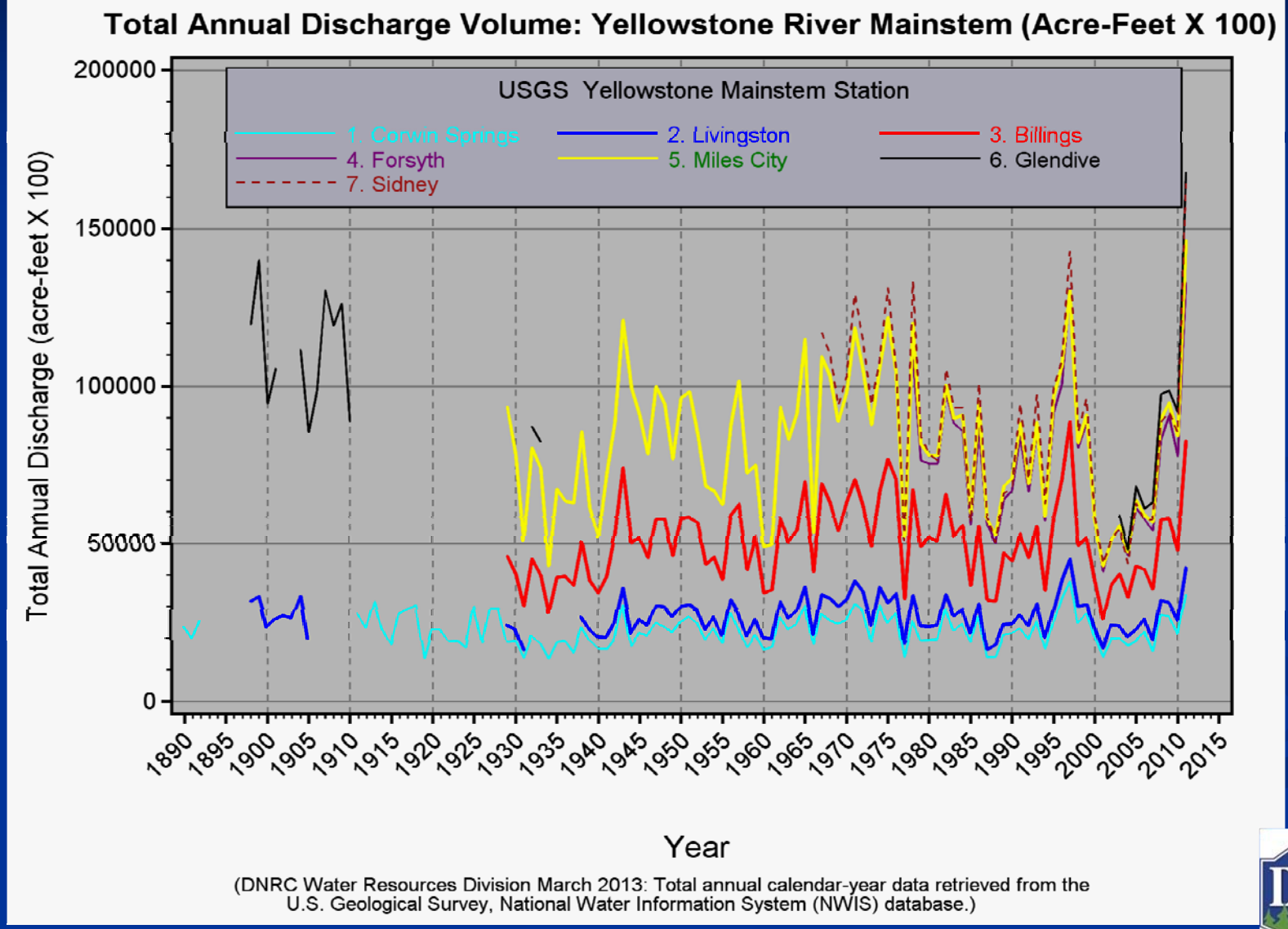
Geography and Basin Characteristics

Yellowstone River Basin Drainage Areas

LOCATION	USGS Station ID	Basin Area (mi^2)	Percent of Total	Period of record of Annual, Monthly, and Mean-Daily Discharge
Yellowstone River at Corwin Springs	6191500	2,619	4	1930-2011
Yellowstone River near Livingston	6192500	3,551	5	1930-2011
Yellowstone River at Billings	6214500	11,805	17	1930-2011
Yellowstone River at Forsyth	6295000	40,146	58	1977-2011
Yellowstone River at Miles City	6309000	48,253	70	1930-2011
Yellowstone River at Glendive	6327500	66,788	97	1930-2011
Yellowstone River near Sidney	6329500	69,083	100	1930-2011



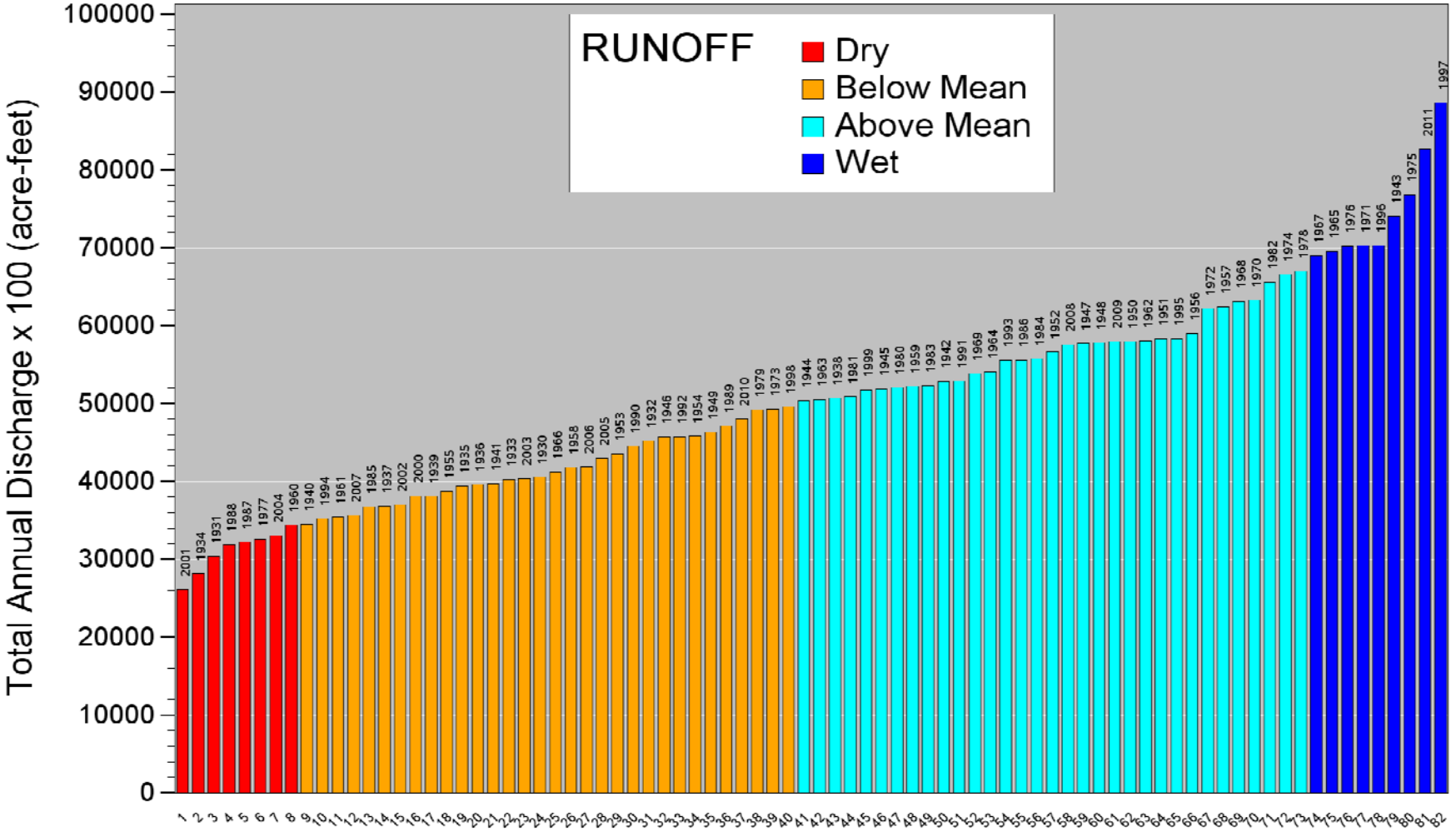
Historic Streamflow and Variability



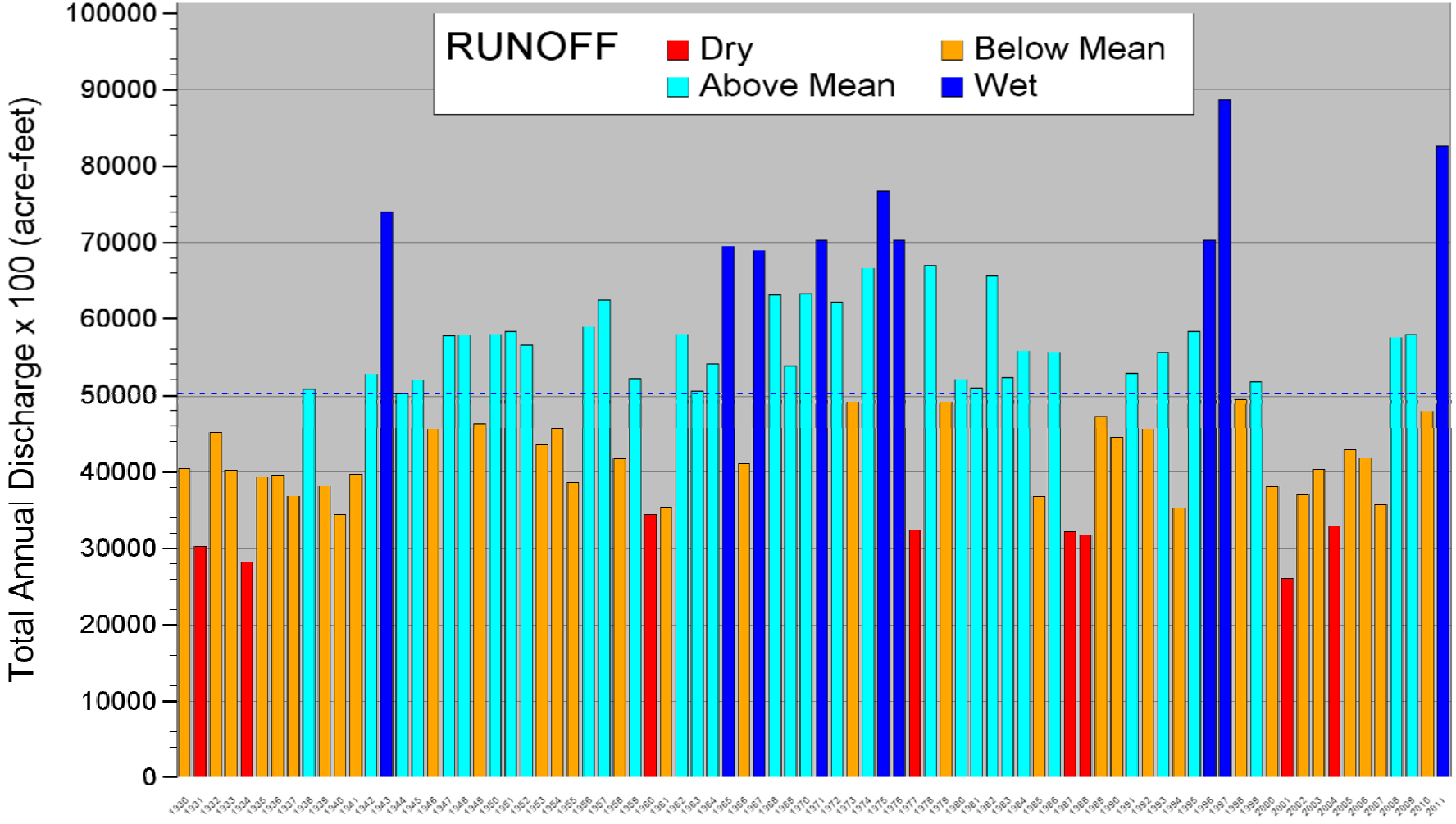
2015 Montana Water Supply Initiative

Yellowstone River Basin

Yellowstone River at Billings--Historic Annual Total Discharge 1930-2011



2015 Montana Water Supply Initiative

Yellowstone River Basin

Yellowstone River at Billings--Historic Annual Total Discharge 1930-2011