Impacts, Adaptation, and Vulnerability: A Summary of the Report from IPCC Working Group 2 and Implications for the Western U.S.

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This summer the Intergovernmental Panel on Climate Change (IPCC) released its report on "Impacts, Adaptation and Vulnerability," a contribution to the IPCC Fourth Assessment Report. This report is based on the IPCC assessment of the physical basis for climate change, and assesses how climate interacts with human and ecological systems in terms of potential negative and positive consequences and the potential to respond or adapt.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) is an international panel of experts organized under the United Nations and the World Meteorological Organization. The role of the IPCC is to "assess on a comprehensive, objective, open and transparent basis" the scientific, technical, and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation. The goal of the IPCC is to articulate a scientific consensus on climate change based on peer-reviewed and published data and findings accepted by at least 90% of the research community. The IPCC conducts its work primarily through three Working Groups (WG), which include hundreds of scientists from over 100 countries. For example, the Working Group 1 (WG1) report, *Climate Change 2007: The Physical Science Basis*, included over 600 authors from 40 countries, and was reviewed by over 620 scientific experts. The shorter "Summary for Policymakers" of that report was ultimately adopted and accepted by 113 governments at a meeting in Geneva, Switzerland in February 2007. The other two working groups – WG2 on Impacts, Adaptation, and Vulnerability, and WG3 on Mitigation – had similar participation by a large number of scientists from around the world, including a number of Boulder scientists. Roger Pulwarty, a scientist at the NOAA Earth System Research Laboratory who has participated in the Western Water Assessment, is an author of the IPCC WG2 Technical Report on Climate Change and Water.

The IPCC has issued three previous assessment reports, in 1990, 1995, and 2001. Each report has found the state of the science is consistently moving forward, with increasingly firm conclusions that human activity is enhancing global climate change. The significance of the IPCC's work is underscored by the announcement this fall that the IPCC and former Vice President Al Gore will share the 2007 Nobel Peace prize for their efforts to disseminate knowledge about climate change, and to lay the foundations for the measures to counteract such change.

This article describes the findings of the WG2 on "Impacts, Adaptation and Vulnerability." This group assessed the scientific, technical, environmental, economic and social aspects of the vulnerability to climate change of, and the negative and positive consequences for, ecological systems, socio-economic sectors and human health. Building on the WG1 report, which focused on the physical basis for climate change, the WG2 report moves into the human and ecological realms, and a set of concepts that embody how society interacts with climate. WG2 concluded, *"A global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems"* (IPCC, 2007a). WG2 issued a Summary for Policymakers, a Technical Summary and separate technical report chapters assessing the impacts of climate change on key sectors including water, ecosystems, food, coasts, and health, and on various regions such as North America and Latin America.

***"A global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems,"* Working Group 2 Summary for Policymakers.**

Observed Impacts of Climate Change on the Natural and Human Environment

The WG1 report established that changes in many physical and biological systems are linked to anthropogenic (human-induced) warming (IPCC, 2007b). WG2 reviewed additional evi

Key Definitions

Impacts: the actual consequences (losses or gains) resulting from climate change, including climate variability and extremes.

Adaptation: a process by which individuals, communities and countries seek to cope with the consequences of climate change.

Vulnerability: the potential for negative outcomes or consequences, incorporating a human judgment of value. It is the extent to which climate change will damage or harm a system. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the system's sensitivity and adaptive capacity.

Adaptive Capacity: the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Sensitivity: the degree to which a system will respond to a change in climatic conditions.

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems	Water resources	Human health	Industry, settlements and society
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks [5.8.1, 4.4.5]	Effects on water resources relying on snow melt; effects on some water supply [3.4.1, 3.5.1]	Reduced human mortality from decreased cold exposure [8.4.1, T8.3]	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism [7.4.2, 14.4.8, 15.7.1]
Warm spells/ heatwaves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; wildfire danger increase [5.8.1, 5.4.5, 4.4.3, 4.4.4]	Increased water demand; water quality problems, e.g., algal blooms [3.4.2, 3.5.1, 3.4.4]	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated [8.4.2, T8.3, 8.4.1]	Reduction in quality of life for people in warm areas without appropriate housing; impacts on elderly, very young and poor [7.4.2, 8.2.1]
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils [5.4.2]	Adverse effects on quality of surface and groundwater; contamination of water supply; water stress may be relieved [3.4.4]	Increased risk of deaths, injuries, infectious, respiratory and skin diseases [8.2.2, 11.4.11]	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property [T7.4, 7.4.2]
Area affected by drought increases	Likely	Land degradation, lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire [5.8.1, 5.4, 4.4.4]	More widespread water stress [3.5.1]	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases [5.4.7, 8.2.3, 8.2.5]	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration [T7.4, 7.4, 7.1.3]
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs [5.4.5, 16.4.3]	Power outages cause disruption of public water supply [7.4.2]	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders [8.2.2, 8.4.2, 16.4.5]	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migrations, loss of property [7.4.1, 7.4.2, 7.1.3]
Increased incidence of extreme high sea level (excludes tsunamis)[c]	Likely[d]	Salinisation of irrigation water, estuaries and freshwater systems [3.4.2, 3.4.4, 10.4.2]	Decreased freshwater availability due to salt-water intrusion [3.4.2, 3.4.4]	Increased risk of deaths and injuries by drowning in floods; migration-related health effects [6.4.2, 8.2.2, 8.4.2]	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above [7.4.2]

Table 1a.
[a] See WGI AR4 Table 3.7 for further details regarding definitions.
[b] Warming of the most extreme days and nights each year.
[c] Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
[d] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period [WGI AR4 10.6]. The effect of changes in regional weather systems on sea-level extremes has not been assessed.

Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21st century. These do not take into account any changes or developments in adaptive capacity. Examples of all entries are to be found in chapters in the full WG2 Assessment (see sources in brackets). The first two columns of this table (shaded yellow) are taken directly from the WG I Fourth Assessment (AR4 Table SPM.2). The likelihood estimates in column 2 relate to the phenomena listed in column 1. The direction of trend and likelihood of phenomena are for SRES projections of climate change [IPCC, 2007b, Table TS.5 and abbreviated caption].

dence including ecological data sets and global synthesis of data, and they concluded that *observational evidence from all continents and most oceans indicates that natural systems are being affected by regional climate changes, particularly temperature increases* (IPCC, 2007a). Findings of WG2 include high confidence[1] that hydrologic systems around the world are being affected: they find increased runoff and earlier spring peak discharge in many glacier-and snow-fed rivers [14.21[2]] including a shift in the magnitude and timing of hydrologic events. For example, April 1 snow water equivalent (SWE) has declined 15-30% in the western mountains of North America, particularly at lower elevations and primarily due to warming, not changes in precipitation. They express very high confidence that recent warming is strongly affecting terrestrial biological systems, including "earlier timing of spring events, such as leaf-unfolding, bird migration, and egg-laying" [1.3] and "poleward shifts in ranges in plant and animal species" [1.3, 8.2, 14.2]. These impacts are summarized in Table 1a.

The WG2 concludes with high confidence that anthropogenic warming over the last three decades has had a discernible influence on many physical and biological systems [1.4]. This conclusion is based on two lines of evidence: 1) consistence between observed and modeled changes and 2) the spatial agreement between significant global warming and consistent impacts at the global scale. This global synthesis is illustrated in Figure 1a. From 80,000 data series in 577 studies, WG2 selected 29,000 data series in 75 studies that (i) ended in 1990 or later; (ii) spanned a period of at least 20 years; (iii) showed a significant change in either direction, as assessed in the individual studies. They found that more than 89% of the changes to physical systems (snow, ice, and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater) are significant with the direction of change expected as a response to observed warming from 1970-2004. Most of these data series (over 28,000) were from studies of terrestrial biological systems in Europe where temperatures have increased 0.2 – 2.0 °C during that time. In North America, many studies are in the Western U.S.

Impacts in the Intermountain West

Although the WG2 report did not focus specifically on regions at the scale of the interior Western U.S., this region has charac

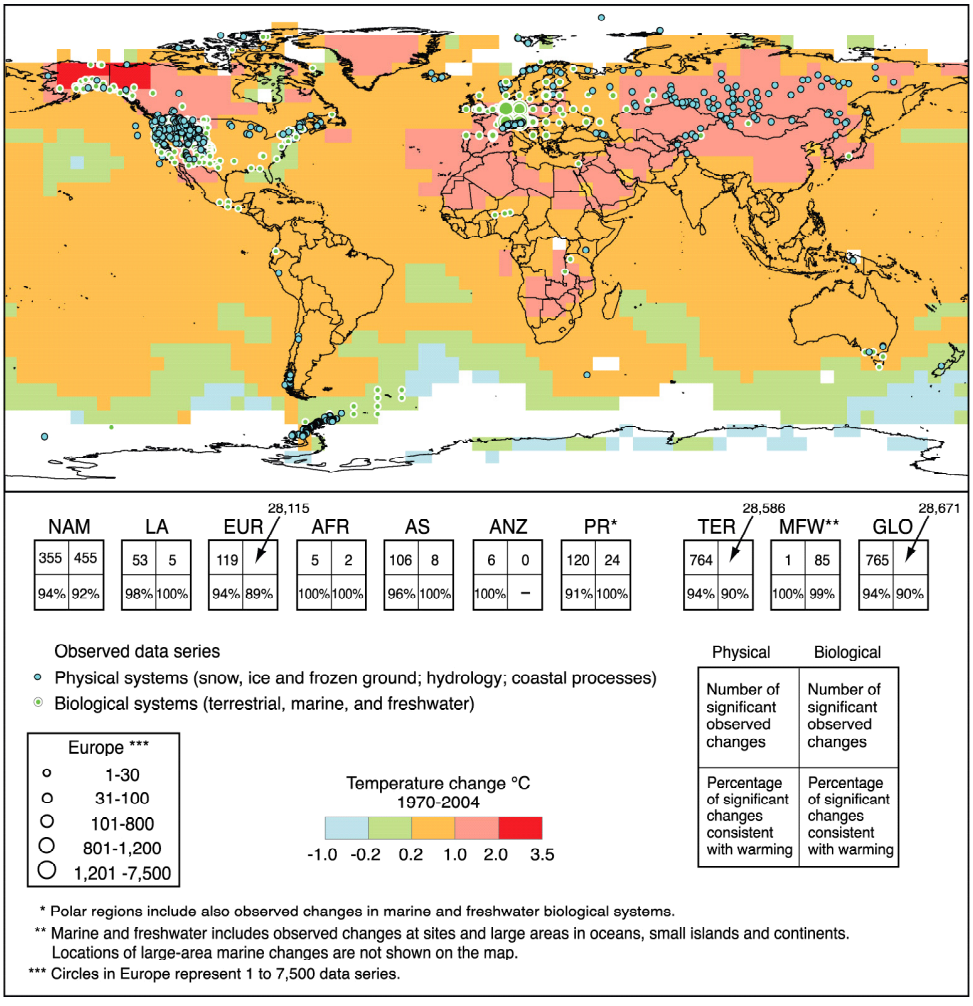
[1] The IPCC uses the following levels of confidence to express expert judgments on the correctness of the underlying science: *very high confidence* represents at least a 9 out of 10 chance of being correct; *high confidence* represents about an 8 out of 10 chance; *medium confidence* represents about a 5 out of 10 chance; *low confidence* represents about a 2 out of 10 chance; *very low confidence* represents less than a 1 out of 10 chance.
[2] These numbers refer to sections in the technical report chapters, for example chapter 14, section 2. http://www.ipcc-wg2.org/

teristics identified by the WG2 as the most vulnerable to climate change. In particular, its economies are closely linked with climate-sensitive resources, including water and ecosystems, which are already sensitive to weather events (e.g., drought, floods, and storms). In addition, rapid urbanization and population growth are occurring, and there is an ongoing shift from agricultural to urban water use. The affects of climate change will vary widely by location and scale (as with global impacts). There are several potential direct impacts and concerns resulting from increased temperatures (considered very likely)[3] and decreased precipitation (considered likely). In the Interior West these include:

- Decreased water supply reliability, in particular, supplies relying on snow melt
- Increased surface water evaporation and evapotranspiration rates
- Decreased hydropower production
- Reduced minimum flows for fish and estuaries
- Earlier peak flow timing
- Greater likelihood of extreme events: drought, flood

Direct impacts may cascade in a chain of impacts to create indirect, or second order and higher order effects. For example, increased wildfire may result in more areas at risk for post-fire erosion, then decreased water quality and enhanced flooding. Wildfire or increased temperatures may also create more opportunity for invasive and pest species, which in turn have higher order effects on plant and animal migration and landscape transformation. Other examples of potential indirect impacts and concerns include:

- Increased water and energy demands for warm season cooling
- Amplified urban heat islands
- Stress on ecosystems
- Enhanced insect-related disturbances



Symbol	Name
Continental Regions	
NAM	North America
LA	Latin America
ER	Europe
AFR	Africa
ANZ	Asia
PR	Australia and New Zealand
Global Scale	
TER	Terrestrial
MFW	Marine and Freshwater
GLO	Global

Figure 1a. Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2x2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row). The numbers of studies from the seven regional boxes (NAM, …, PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map [IPCC, 2007a, Figure TS.1 and abbreviated caption].

[3] The IPCC uses the following terms to indicate the assessed likelihood, using expert judgment, of an outcome or a result: *Virtually certain > 99%* probability of occurrence, *Extremely likely >95%, Very likely > 90%, Likely > 66%, More likely than not > 50%, Unlikely< 33%, Very unlikely < 10%, Extremely unlikely < 5%.*

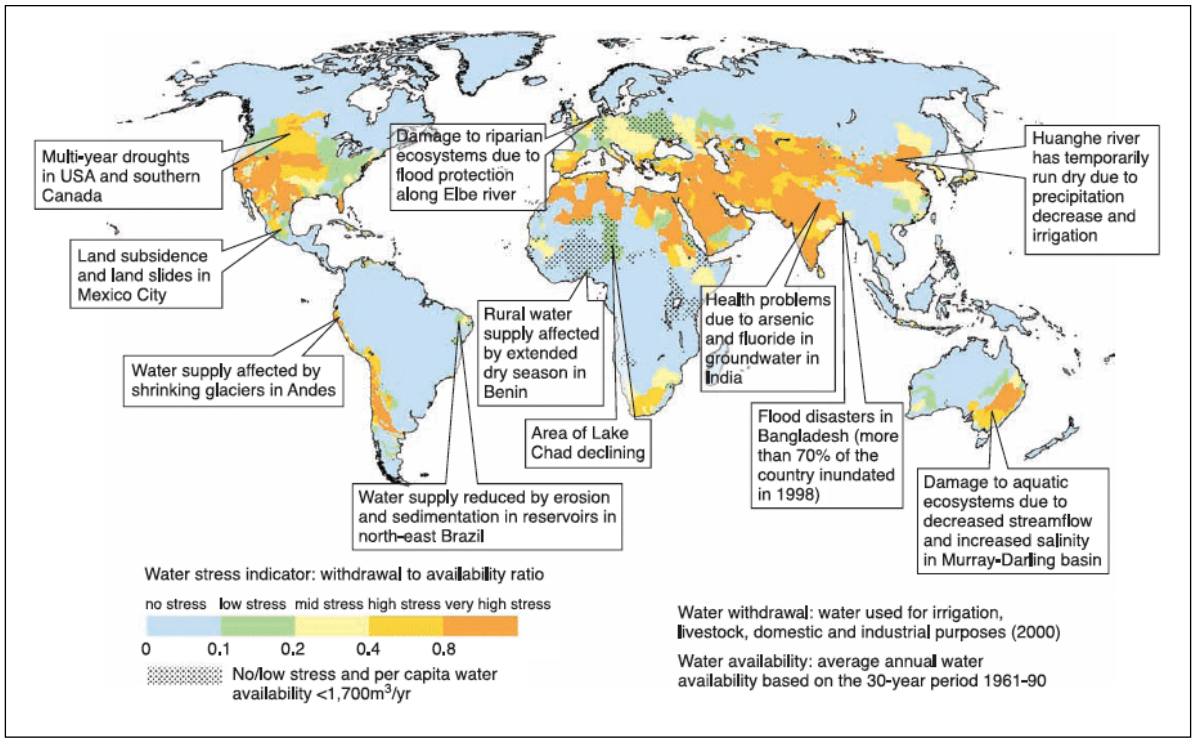


Figure 1b. Examples of current vulnerabilities of freshwater resources and their management that are likely to be exacerbated by climate change. In the background, a water stress map [IPCC, 2007a, Figure 3.2 and abbreviated caption].

Vulnerability

Vulnerability is the extent to which climate change will damage or harm a system, and the potential for negative outcomes or consequences. Vulnerability is a function of the physical climate impacts to which a system is exposed, and the system's sensitivity and adaptive capacity; it can be exacerbated by the presence of other stresses. Vulnerabilities exist inherently in the institutions and cultures of a system, and are exposed when events occur such as drought. WG2 has identified vulnerable areas worldwide with respect to water resources (Figure 1b).

The Western U.S. is vulnerable to climate change because its economies are closely linked with climate-sensitive resources, including water and ecosystems. Even without climate change, the region's water supply is undergoing stresses from population growth, urbanization, the shift in water use and ownership from agricultural to urban, and shifts in the economy among agricultural, mining and resource extraction, recreation, industries and services. Each of these factors is resulting in over-allocation of water resources, which will be more stressed with future changes in the hydrologic system related to climate. Other factors that affect how various sectors and subpopulations in the region are vulnerable to climate include poverty and inequal access to resources, affects of economic globalization and other economic trends influencing the region. Actual vulnerability to climate change in North America depends on the effectiveness and timing of adaptation and the distribution of coping capacity [14.2].

Adaptation

Adaptation is a process by which individuals, communities and countries seek to cope with the consequences of climate change. Societies adapt to climate as part of their culture, including laws, policies and practices, and even architecture. Differences in climate partly explain the differences in water law between the arid areas of southern Europe and the Western U.S. and wetter/less arid areas in northern Europe and the eastern U.S. Adaptation to climate change, however, has been an idea that many have been reluctant to discuss (Pielke et al., 2007). For some, it represents an admission that climate change is occurring. For others, including some advocates of greenhouse gas emissions reductions, it represented the idea that we could not react in time to minimize damages and we have given up trying. However, as Pielke and his co-authors describe, perspectives have changed. A common view now is that adaptation is needed because climate change is underway and the system is already committed to a certain level of warming based on past greenhouse gas emissions, even if mitigation actions drastically reduce future emissions.

The WG2 asserts that a portfolio of adaptation and mitigation measures can diminish the risks associated with climate change. Potential responses include: purely technical (e.g. infrastructure defenses against sea level rise) to behavioral (e.g. altered food and recreational choices) to managerial (e.g. altered farm practices) to policy (e.g. planning regulations). The WG2 technical summary also describes adaptation measures that are in place or

	Food, fibre and forestry	Water resources	Human health	Industry, settlement and society
Drying/ Drought	*Crops*: development of new drought-resistant varieties; intercropping; crop residue retention; weed management; irrigation and hydroponic farming; water harvesting *Livestock*: supplementary feeding; change in stocking rate; altered grazing and rotation of pasture *Social*: Improved extension services; debt relief; diversification of income	Leak reduction Water demand management through metering and pricing Soil moisture conservation e.g., through mulching Desalination of sea water Conservation of groundwater through artificial recharge Education for sustainable water use	Grain storage and provision of emergency feeding stations Provision of safe drinking water and sanitation Strengthening of public institutions and health systems Access to international food markets	Improve adaptation capacities, especially for livelihoods Incorporate climate change in development programmes Improved water supply systems and co-ordination between jurisdictions
Increased rainfall/ Flooding	*Crops*: Polders and improved drainage; development and promotion of alternative crops; adjustment of plantation and harvesting schedule; floating agricultural systems *Social*: Improved extension services	Enhanced implementation of protection measures including flood forecasting and warning, regulation through planning legislation and zoning; promotion of insurance; and relocation of vulnerable assets	Structural and non-structural measures. Early-warning systems; disaster preparedness planning; effective post-event emergency relief	Improved flood protection infrastructure "Flood-proof" buildings Change land use in high-risk areas Managed realignment and "Making Space for Water" Flood hazard mapping; flood warnings Empower community institutions
Warming/ Heatwaves	*Crops*: Development of new heat-resistant varieties; altered timing of cropping activities; pest control and surveillance of crops *Livestock*: Housing and shade provision; change to heat-tolerant breeds *Forestry*: Fire management through altered stand layout, landscape planning, dead timber salvaging, clearing undergrowth. Insect control through prescribed burning, non-chemical pest control *Social*: Diversification of income	Water demand management through metering and pricing Education for sustainable water use	International surveillance systems for disease emergence Strengthening of public institutions and health systems National and regional heat warning systems Measures to reduce urban heat island effects through creating green spaces Adjusting clothing and activity levels; increasing fluid intake	Assistance programmes for especially vulnerable groups Improve adaptive capacities Technological change
Wind speed/ Storminess	*Crops*: Development of wind-resistant crops (e.g., vanilla)	Coastal defence design and implementation to protect water supply against contamination	Early-warning systems; disaster preparedness planning; effective post-event emergency relief	Emergency preparedness, including early-warning systems More resilient infrastructure Financial risk management options for both developed and developing regions

Table 1b. Examples of current and potential options for adapting to climate change for vulnerable sectors. All entries have been referred to in chapters in the WG2 Fourth Assessment (AR4). Note that, with respect to ecosystems, generic rather than specific adaptation responses are required. Generic planning strategies would enhance the capacity to adapt naturally. Examples of such strategies are: enhanced wildlife corridors, including wide altitudinal gradients in protected areas [IPCC, 2007a, Table TS.6 and abbreviated caption].

being developed to cope with these changes.

Some adaptive responses are occurring, but more extensive adaptation is needed. The WG2 has identified a number of adaptive responses (Table 1b). In the Intermountain West these might include incorportion of the potential for climate change into policies. For example:

- Water management practices at multiple spatial and organizational scales
- Infrastructure planning, forest and water management plans, energy planning

Pathways for Adaptation and Response to Climate Change

A number of efforts are underway to elevate the adaptive capacity in the region. The National Integrated Drought Information System (NIDIS) seeks to enhance the nation's drought preparedness and provide comprehensive information on emerging and ongoing events resulting from chronic hydrologic shortages that are expected to increase in the west under climate change (NIDIS, 2007). Agencies are taking steps to build resilience to climate variations into their long-term planning. For example, the U.S. Bureau of Reclamation studied methods to incorporate climate change information into its Colorado River Basin planning studies (Brekke et al., 2007). The U.S. Forest Service has also recognized significant vulnerabilities to the forest and grassland resources it manages, and is seeking to develop and demonstrate adaptation strategies, including new natural resource management and use strategies and options to help reduce the negative effects of climate variability and change. Next year they will issue their Global Change Research Strategy for 2009-2019, which will reflect these adaptation goals. In Colorado, the state Climate Action Plan was recently unveiled by Governor Bill Ritter, that will assess the climate-induced changes in streamflows and the effects on the yield of individual water rights and the pattern of calls on Colorado's rivers, and assist water users to prepare for and adapt to large-scale droughts that are a likely effect of increased temperatures (Ritter, 2007).These efforts and others underway

have the potential to assist policymakers, planners, managers and individuals in the Intermountain West to anticipate changes and prepare for them.

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On the Web

- WWA has created a new webpages designed to provide background, context, and links associated with the IPCC process: http://wwa.colorado.edu/resources/water_and_climate.
- IPCC Working Group 1 Fourth Assessment Report: http://www.ipcc.ch/ipccreports/.ar4-wg1.htm.
- IPCC Working Group 2 Fourth Assessment Report: http://www.ipcc.ch/ipccreports/ar4-wg2.htm.
- NIDIS: http://www.drought.gov