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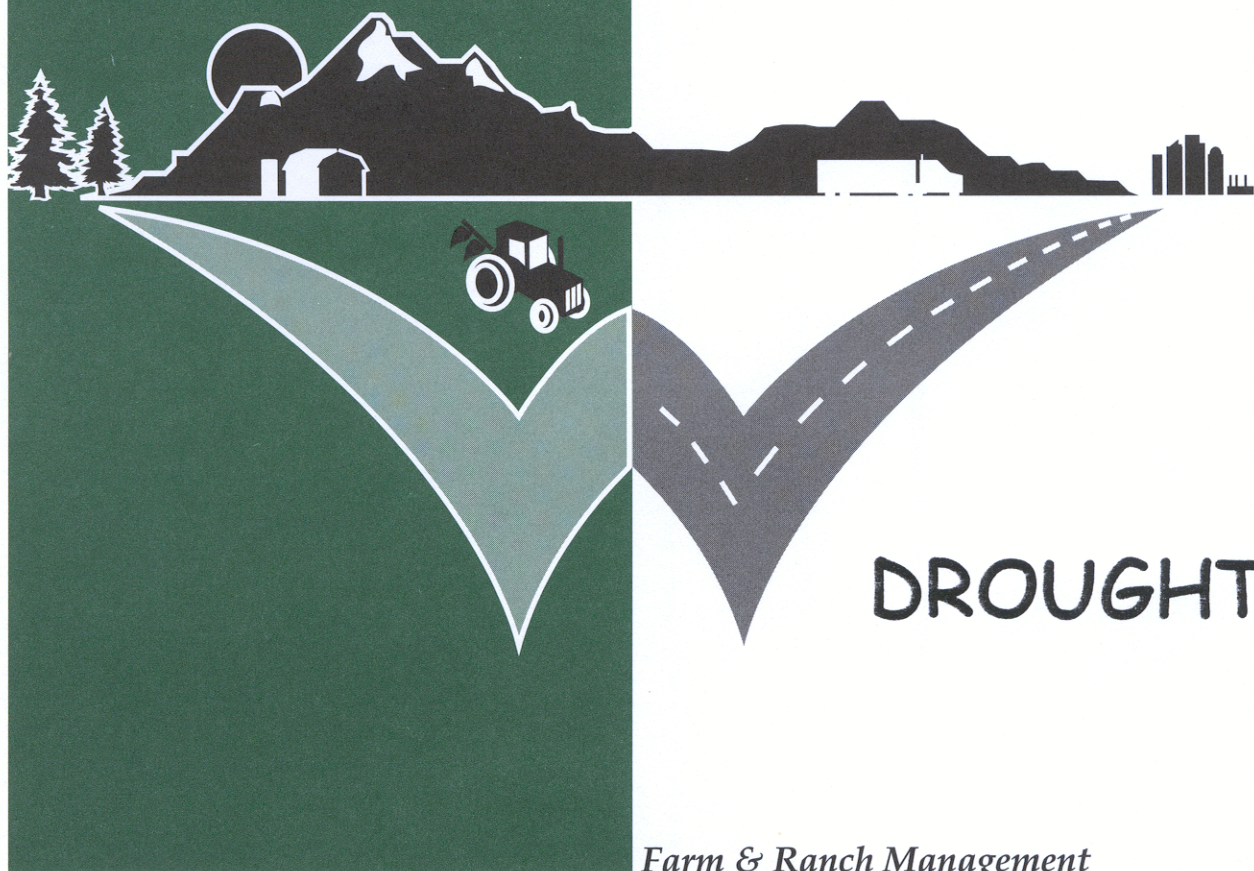
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DROUGHT AND CLIMATE CHANGE: IMPLICATIONS FOR THE WEST

By

Richard M. Adams and Dannele E. Peck¹

**Department of Agricultural and Resource Economics
Oregon State University
Corvallis, OR 97331**

The prolonged drought over large portions of the West generated a set of adverse and costly effects in 2002, ranging from record wildfires in Oregon, to large fish kills in California's Klamath River triggered by warm water temperatures. In some regions of the West, drought has persisted for nearly a decade, leading to severe stress on vegetation and water resources. The intensity and frequency of recent droughts has raised concerns that fundamental climate shifts may be occurring in the western U.S. and elsewhere, due perhaps to the generally rising temperatures observed globally over the past decade. This paper reviews the current understanding of possible links between drought and global climate change, the physical and economic consequences of drought, and the potential to mitigate the adverse consequences of such climatic events using long term climate forecasts and other meteorological information.

A range of potential effects of global climate change on water resources and agricultural management has been suggested. These include increased surface temperatures and evaporation rates, increased global precipitation, increased proportions of precipitation received as rain, not snow, earlier and shorter runoff seasons, increased water temperatures, and decreased water quality. Variability in precipitation patterns is also expected to increase, resulting in more frequent droughts in the U.S. and elsewhere (see Adams et al. 1999, for a review of the effects of climate change on agriculture and agricultural resources).

The economic consequences of drought are well documented. On average, annual costs in the United States due to drought are estimated at \$6 to 8 billion (Knutson, 2001). Flooding and hurricanes, though more publicized than drought, are responsible for only \$3.6 to 7.2 billion in annual damages combined (Knutson, 2001). Some of these economic costs arise from the direct physical impacts of drought, such as crop failure, municipal water shortage, wildfires, and fish and wildlife mortality. Indirect effects also occur. For example, water deficits reduce hydroelectric power generation, and increase electricity prices. The National Oceanographic and Atmospheric Administration (2002) and Claussen (2001) offer comprehensive discussions of the physical and socioeconomic impacts of drought in the United States.

Water resource managers, agricultural producers, and policy makers can reduce the negative effects of drought through a number of strategies. These include revising water storage and release programs for reservoirs; adopting drought tolerant crops and cropping practices; adjusting crop insurance programs, and supporting water transfer opportunities. The ability to anticipate and efficiently prepare for future drought conditions is currently limited by imprecise long-term weather forecasts and climate models. Improvements in some forms of climate forecasts, such as those associated with the El Nino-Southern Oscillation phenomenon (ENSO), offer potential for reducing the impacts of drought. However, economic costs associated with drought could be further reduced if drought forecast improvements increased the ability to detect drought farther in advance, enhanced forecast accuracy, and improved the geographical detail of forecasts to pinpoint drought location, intensity, and duration.

¹ Authors are professor and graduate student, respectively, in the Department of Agricultural and Resource Economics, Oregon State University, December, 2002.

Global climate change, drought and implications for the West

The ability of the earth's atmosphere to trap solar radiation, and increase global temperature (the so-called "greenhouse effect"), has been recognized for at least 150 years. More recently, global climate change, or "global warming," associated with human activities, such as the burning of fossil fuels, has been a topic of intense scientific and political debate.

Certain evidence is unequivocal; carbon dioxide concentrations (the most abundant greenhouse gas in the earth's atmosphere) have been increasing steadily for over a century. The decade of the 1990s was the warmest (on a global scale) in over a century. Specifically, CO₂ levels have increased 30%, since the late 1800s, and are higher now than they have been in the last 400,000 years (National Assessment Synthesis Team or NAST, 2000). Average annual temperature of the United States has risen almost 0.6° C (1.0° F) over the 20th century (NAST, 2000). The role that humans have played in recent global warming is still debated. The belief that global warming will continue, however, is becoming more widely accepted.

Several general circulation models (GCMs) have predicted U.S. average annual temperatures to rise 3 to 5° C (5 to 9° F) over the next 100 years (NAST, 2000). Atmospheric scientists anticipate numerous climatic effects to arise from these increasing temperatures. For example, precipitation, which has increased in the U.S. by 5 to 10% over the 20th century (IPCC, 2001a), is predicted to continue to increase in many regions, particularly those at higher latitudes (Frederick and Gleick, 1999; Gleick, 2000). Increases in precipitation, given warmer atmospheric conditions, will not necessarily mean more available water at the state or regional level; as noted earlier, global warming is expected to bring more frequent and intense drought to several regions (IPCC, 1998).

Water quantity, timing, and quality

Drought can result from water quantity shortages, inappropriate timing of water availability (precipitation), and impaired water quality. The computer-based GCMs predict that selected regions of the U.S. will experience decreased precipitation due to global warming. Areas in the immediate lee of the Rocky Mountains, for example, are expected to receive less precipitation during this century than the current average (NAST, 2000). Two GCMs, from the Canadian Climate Centre, and the Hadley Centre in the United Kingdom, have projected precipitation changes across the U.S. These include 25% precipitation increases in the Northeast, 10 to 30% increases in the Midwest, 20% increases in the Pacific Northwest, 10% precipitation decreases in the southern coast of Alaska, and up to 25% declines in the Oklahoma panhandle, north Texas, eastern Colorado and western Kansas (NAST, 2000).

Areas receiving increased precipitation will not necessarily see net increases in available water. The higher evaporation rates that accompany rising temperatures are expected to result in less water available in many regions (Frederick and Gleick, 1999). For example, GCMs project global average evaporation to increase 3 to 15% with doubled CO₂ levels (Gleick, 2000). Simulation studies suggest that precipitation must increase by at least 10% to balance evaporative losses resulting from a 4° C temperature increase (Gleick, 2000). Projections of rising evaporation rates indicate they will outpace precipitation increases, on a seasonal basis, in many regions (IPCC, 1998; Gleick, 2000). The greatest deficits are expected to occur in the summer, leading to decreased soil moisture levels and more frequent and severe agricultural drought (IPCC, 1998; Gleick, 2000).

Shifts in the form and timing of precipitation and runoff, specifically in snow-fed basins, are also likely to cause more frequent summer droughts (Adams et al., 1988). More precisely, rising temperatures are expected to increase the proportion of winter precipitation received as rain, with a declining proportion arriving in the form of snow (IPCC, 2001b; Frederick and Gleick, 1999). Snow pack levels will form much later in the winter, accumulate in much smaller quantities, and melt earlier in the season (IPCC, 2001b).

These changes in snow pack and runoff are of particular concern to irrigated agriculture and to commercial and recreational fisheries. For example, if the runoff season occurs primarily in winter and early spring, rather than late spring and summer, water availability will decline during crucial spring and summer months, causing water shortages to occur earlier in the growing season. Shifts in runoff, precipitation, and evaporation patterns may also enhance interstate water allocation conflicts, as water managers struggle to meet obligations of compacts and court decrees, given more variable water availability and timing in headwater areas (Adams et al., 1988).

A shift in stream hydrographs to more winter flow may also disrupt the life cycle of anadromous species, like salmon, which depend on late spring flows to “flush” young salmon to the ocean. Unless reservoir systems are in place to capture and store winter runoff for late spring or summer use, reduction in summer flows is expected to lead to higher water temperatures. Summer temperatures now exceed the lethal levels for salmonids and other coldwater fish species in some streams; further warming could lead to more frequent fish kills, such as those observed this summer in the Klamath River of northern California.

Water quality impairment is predicted to increase under climate change (IPCC, 2001b; NAST, 2000; Gleick, 2000). Specifically, precipitation is expected to occur more frequently through high-intensity rainfall events, causing increased runoff and erosion. Sediments and pollutants, like fertilizer, will be transported into streams and groundwater systems, decreasing water quality (Gleick, 2000). Water quality will also be impaired in areas receiving less precipitation, as nutrients and contaminants become more concentrated (IPCC, 2001b).

Rising air and water temperatures will impact water quality by increasing primary production, organic matter decomposition, and nutrient cycling rates in lakes and streams, resulting in lower dissolved oxygen levels (IPCC, 2001b). Increased evaporation rates from open water-bodies threaten to increase the salinity of surface water. Lakes and wetlands associated with return flows from irrigated agriculture are of particular concern (IPCC, 2001b). Water quality impairment is thus a threat to agricultural water supplies, as well as to fish and wildlife.

Coastal areas are at additional risk of water quality impairment, due to saltwater intrusion (Nuttall, 1993; Frederick and Gleick, 1999). As global temperatures increase, seawater warms, causing ocean density to decrease and sea levels to rise (Solow, 1993). Sea levels are also rising in response to the melting of land ice, which includes glaciers, and the Greenland and Antarctica ice sheets (Solow, 1993). Global sea levels rose 10 to 20 cm during the 20th century (NAST, 2000). The Intergovernmental Panel on Climate Change projects a sea-level rise over the next century of 38 to 66 cm (Clausen, 2001).

Rising sea levels may also affect water availability indirectly by causing water tables to rise. Higher water tables cause surface runoff to increase at the expense of aquifer recharge. Groundwater quality and recharge are impaired by rising sea levels and saltwater intrusion. Radical changes to the freshwater hydrology of coastal areas, caused by saltwater intrusion, threaten many coastal regions' freshwater supplies.

El Nino-Southern Oscillation and seasonal to interannual climate variability

The possible long-term effects of global warming on drought and other extreme weather phenomenon are based on climate models that are associated with high levels of uncertainty, particularly at the regional or state level. A more immediate and predictable climate phenomenon is the increased frequency of ENSO events and increased intensity of ENSO-related droughts and flooding, which are expected to accompany global climate change (IPCC, 2001a; Gleick, 2000).

The El Nino-Southern Oscillation (ENSO) is a natural weather phenomenon resulting from interactions between the atmosphere and ocean in the tropical Pacific Ocean (Trenberth, 1996). Concurrent weakening and strengthening of ocean and air currents causes warm and cold ocean currents to mix, with one covering the other (warm water over cold during an El Nino; cold water over warm during a La Nina) (IPCC, 2001a).

Changes in the thermal profile of ocean currents alter wind, sea surface temperature, and precipitation patterns in the tropical Pacific, and drive climatic effects throughout much of the world (IPCC, 2001a).

El Nino and La Nina events are associated with both drought and flooding in many regions of the United States. For example, El Nino events cause drier winters in the northwestern U.S. and the Great Lakes region, but results in increased precipitation in southern California, where the ENSO “signal” is particularly strong (IPCC, 1998). The affect of global warming on the behavior of ENSO events is uncertain. However, more frequent ENSO events, as suggested by Timmermann et al. (in Gleick, 2000), would enhance the variability of precipitation and streamflow in many ENSO-sensitive regions of the western US (IPCC, 1998), leading to greater risk of droughts and floods (IPCC, 2001a).

The negative economic consequences of ENSO events have been measured in a number of studies (e.g. Adams et al., 1995; Chen et al., 2001). ENSO-based drought has historically generated billions of dollars in damage annually in the United States, as has ENSO-related flooding. Increased drought frequency and intensity under global warming scenarios threatens to increase these damages, unless adaptive measures are taken.

Coping with drought: the use of climate forecasts

The first step in preparing for potential increased frequency and intensity of drought or ENSO events is an improved understanding of potential regional precipitation and evaporation shifts under a changed climate. The reliability of seasonal or longer forecasts is likely to affect their adoption by farmers and other resource managers. Providing reliable year-to-year forecasts of precipitation is difficult; decadal forecasts as provided by GCMs are even more problematic. However, some types of forecasts, such as those associated with ENSO events, are becoming more reliable (NAST, 2000; Trenberth, 1996). Adaptation strategies to ENSO events, such as changing crop mixes, are currently being practiced in many parts of the western hemisphere.

Improved seasonal to interannual weather forecasting will be needed to efficiently manage resources under the more extreme interannual weather variability expected to accompany global warming. Improving the accuracy and lead-time of drought forecasts can reduce the risk for decision makers and decrease economic losses due to drought (see NOAA, 2002).

With more precise, timely and reliable forecasts, current drought management tools can be reassessed and revised in preparation for more frequent seasonal drought. For example, drought insurance programs may need revision in order to provide efficient and affordable coverage. Increased crop diversity on individual farms or in economic regions could reduce losses during extreme weather events (IPCC, 2001b). Reservoir capacity, timing of water releases, and safety will need to be reconsidered and updated. Voluntary water transfers, with or without climate change, will become an increasingly important tool to mitigate water distribution problems. Municipalities are currently considering the vulnerability of their fresh surface and groundwater supplies to drought, pollution and saltwater intrusion, and may need to consider new protection programs and supplemental water sources. Improved confidence in regional forecasts of climate change impacts is, however, of primary importance in helping regional managers understand risk levels, identify management priorities, and define realistic adaptations.

Summary

Global climate change is likely to increase the frequency and intensity of drought for many regions of the western United States. Although subject to substantial uncertainty, regional forecasts of long term climatic change from GCM's do offer a glimpse into possible future drought conditions. Predicted impacts vary by region, but include increased temperatures and evaporation rates; increased, but more variable precipitation;

higher proportions of winter precipitation arriving as rain, not snow; earlier and more severe summer drought, and decreased water quality.

Drought currently results in substantial economic losses in the United States annually. These losses occur across a range of sectors, from agriculture to energy to recreation, and have profound effects on local communities. Increases in drought imply increased costs to society, unless agricultural producers, water users and others are able to adapt to these changes in seasonal weather patterns (as forecast by some GCM analysts). Improved forecasts concerning future drought conditions, particularly at the regional scale, are thus necessary for managers and policy makers to identify efficient adaptive strategies, and reduce the economic costs of drought.

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